INTELLIGENCE TRACTOR AUTOMATED GROUND LEVELING AND IMPLEMENT SYSTEM BASED ON HYBRID CONTROL

MR. SOMDAVEE BHOSINAK

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE DEGREE OF MASTER OF ENGINEERING
PROGRAM IN MECHATRONICS ENGINEERING (INTERNATIONAL PROGRAM)
FACULTY OF TECHNICAL EDUCATION
RAJAMANGALA UNIVERSITY OF TECHNOLOGY THANYABURI
ACADEMIC YEAR 2022

INTELLIGENCE TRACTOR AUTOMATED GROUND LEVELING AND IMPLEMENT SYSTEM BASED ON HYBRID CONTROL

MR. SOMDAVEE BHOSINAK

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE DEGREE OF MASTER OF ENGINEERING
PROGRAM IN MECHATRONICS ENGINEERING (INTERNATIONAL
PROGRAM)
FACULTY OF TECHNICAL EDUCATION
RAJAMANGALA UNIVERSITY OF TECHNOLOGY THANYABURI
ACADEMIC YEAR 2022

Thesis Title	Intelligence Tractor Automated Ground Leveling and Implement System Based on Hybrid Control
Name-Surname	Mr. Somdavee Bhosinak
Program	Mechatronics Engineering
Thesis Advisor	Associate Professor Dechrit Maneetham, D.Eng., Ph.D.
Academic Year	2022

THESIS COMMITTEE

………………………………………… Chairman
(Associate Professor Evi Triandini, Ph.D.)

Worawat
………………………………………… Committee
(Professor Worawat Sa-ngiamvibool, Ph.D.)

………………………………………… Committee
(Associate Professor Petrus Sutyasadi, D.Eng.)

Ren-Jean Liou
………………………………………… Committee
(Associate Professor Ren Jean Liou, Ph.D.)

D. Maneetham
………………………………………… Advisor
(Associate Professor Dechrit Maneetham, D.Eng., Ph.D.)

Approved by the Faculty of Technical Education, Rajamangala University of Technology Thanyaburi in Partial Fulfillment of the Requirements for the Master's Degree

……………………Dean of Faculty of Technical Education
(Assistant Professor Arnon Niyomphol, M.S.Tech.Ed.)
Date 19 Month April Year 2023

หัวข้อวิทยานิพนธ์	รถแทรกเตอร์อัจฉริยะเคลื่อนที่อัตโนมัติภาคพื้นดินด้วยระบบควบคุมแบบไฮบริด
ชื่อ – นามสกุล	นายสมทวี โพธิ์ศรีนาค
สาขาวิชา	วิศวกรรมเมคคาทรอนิกส์
อาจารย์ที่ปรึกษา	รองศาสตราจารย์ เดชฤทธิ์ มณีธรรม, วศ.ด., ปร.ด.
ปีการศึกษา	2565

บทคัดย่อ

ในปัจจุบันปัญหาสำคัญอย่างหนึ่งในการผลิตภาคเกษตรกรรมของประเทศไทยคือการขาดแคลนแรงงานคน และในขณะที่อัตราประชากรเกิดใหม่ที่เข้ามาแทนที่จึงทำให้แรงงานภาคเกษตรลดลงส่งผลกระทบโดยตรงต่อผลผลิตทางการเกษตรทำให้เกิดปัญหาต้นทุนแรงงานที่สูงขึ้น การแก้ปัญหาดังกล่าวสามารถนำเทคโนโลยีในปัจจุบันนำมาประยุกต์ใช้ในรูปแบบการเกษตรสมัยใหม่โดยมีวัตถุประสงค์เพื่อให้สามารถลดต้นทุนการผลิตและเพิ่มผลผลิตทางการเกษตรได้ ดังนั้นการวิจัยระบบควบคุมการบังคับเลี้ยวสำหรับรถแทรกเตอร์การเกษตรสมัยใหม่เพื่อนำมาประยุกต์ใช้งานแบบไร้คนขับจึงเป็นวิธีการอย่างหนึ่งที่สามารถแก้ปัญหาดังกล่าวโดยสามารถช่วยลดต้นทุนแรงงานคน สามารถสั่งงานให้ทำงานได้อย่างอิสระทั้งกลางวันและกลางคืนตามโปรแกรมคำสั่งในชุดควบคุมส่วนกลาง ดังนั้นงานวิจัยนี้จึงมีบทบาทในการแก้ปัญหาการเกษตรของประเทศไทย โดยในเนื้อหาของวิทยานิพนธ์ฉบับนี้มีวัตถุประสงค์หลัก 3 ข้อดังนี้ 1) เพื่อออกแบบรถแทรกเตอร์การเกษตรไร้คนขับอัจฉริยะสำหรับการเกษตรสมัยใหม่เพื่อลดปัญหาแรงงานในการควบคุมรถแทรกเตอร์ 2) เพื่อพัฒนาอุปกรณ์บังคับเลี้ยวอัตโนมัติสำหรับรถแทรกเตอร์การเกษตรอัจฉริยะสมัยใหม่ที่ควบคุมการหมุนพวงมาลัยได้อัตโนมัติ 3) เพื่อประยุกต์ใช้เซ็นเซอร์เข็มทิศสำหรับนำมาประยุกต์ใช้เป็นระบบนำทางสำหรับรถแทรกเตอร์การเกษตรไร้คนขับอัจฉริยะ

ระเบียบวิธีวิจัยนี้เป็นการออกแบบระบบนำทางอัตโนมัติด้วยเซนเซอร์เข็มทิศสำหรับรถแทรกเตอร์การเกษตรสมัยใหม่ โดยใช้วิธีควบคุมการบังคับเลี้ยวโดยอัตโนมัติตามเส้นทางตรงที่กำหนดไว้ โดยใช้หลักการบังคับเลี้ยวแบบ PID (Proportional-Integral-Derivative) ร่วมกับ Fuzzy Logic ร่วมกับเซ็นเซอร์เข็มทิศและอุปกรณ์อื่นๆ ระบบบังคับเลี้ยวของรถแทรกเตอร์ได้ออกแบบการวัดมุมบังคับเลี้ยวโดยติดตั้งตัวเข้ารหัสชนิด Incremental Encoder บนชุดเฟืองบังคับเลี้ยว โดยตัวเข้ารหัส

ชนิดนี้มีข้อดีคือหาซื้อได้ง่ายและราคาถูกในประเทศไทย การออกแบบพวงมาลัยรถแทรกเตอร์ขับเคลื่อนอัตโนมัติโดยใช้เข็มทิศนำทาง ทำงานอัตโนมัติร่วมกับ พวงมาลัย ล้อหน้า และชุดควบคุมหลักซึ่งออกแบบระบบโดยใช้มอเตอร์กระแสตรงเพื่อใช้เป็นอุปกรหลักบังคับเลี้ยวควบคุมด้วยไฟฟ้ากระแสตรง

งานวิจัยนี้บรรลุวัตถุประสงค์หลัก 3 ข้อทั้งหมดโดยการออกแบบและพัฒนาอุปกรณ์บังคับเลี้ยวอัตโนมัติสำหรับการควบคุมบังคับเลี้ยวรถแทรกเตอร์การเกษตรอัจฉริยะแบบใหม่โดยอาศัยเซ็นเซอร์เข็มทิศ โดยการออกแบบและพัฒนาอุปกรณ์บังคับเลี้ยวอัตโนมัติสำหรับการควบคุมบังคับเลี้ยวรถแทรกเตอร์การเกษตรอัจฉริยะประยุต์ใช้งานด้วยระบบควบคุมการบังคับเลี้ยวแบบไฮบริด PID-Fuzzy Logic เพื่อควบคุมการเคลื่อนที่ของรถแทรกเตอร์การเกษตรอัจฉริยะเข้าสู่งเป้าหมายปลายทางที่กำหนดไว้ ผลการทดลองแสดงให้เห็นว่าอัลกอริทึมที่ควบคุมการเคลื่อนของรถแทรกเตอร์การเกษตรอัจฉริยะบนสภาพเส้นทางที่กำหนดไว้ได้อย่างมีประสิทธิภาพ เนื่องจากการตอบสนองที่รวดเร็ว ความเสถียรสูง ด้วยระบบควบคุม PID-Fuzzy Logic แบบไฮบริดจึงเป็นตัวเลือกที่เหมาะสมที่นำมาใช้งานควบคุมการเคลื่อนที่รถแทรกเตอร์การเกษตรอัจฉริยะตามทฤษฎีการเคลื่อนที่ของ Ackerman อัลกอริทึมสามารถประยุกต์ใช้ต่อไปในสภาพแวดล้อมการทำงานการเกษตรที่ซับซ้อนมากยิ่งขึ้น

คำสำคัญ : รถแทรกเตอร์ไร้คนขับ, การเกษตรสมัยใหม่, ระบบควบคุมพวงมาลัย, การติดตามเส้นทาง, การควบคุมรถแทรกเตอร์แบบไฮบริด

Thesis Title	Intelligence Tractor Automated Ground Leveling and Implement System Based on Hybrid Control
Name-Surename	Mr. Somdavee Bhosinak
Program	Mechatronics Engineering
Thesis Advisor	Associate Professor Dechrit Maneetham, D.Eng, Ph.D
Academic Years	2022

ABSTRACT

At present, one of the major problems in agriculture in Thailand is a shortage of agricultural workers since traditional agriculture is primarily labor intensive. The problem is acccelerated by higher labor costs while the birthrate has decreased. This leads to the decrease of replacement in agricultural workers and has direct impact on agricultural products. To solve the problems, modern agriculture can be applied with the objectives of making it possible to reduce production costs and increase agricultural production. Research on the steering control system for new modern tractor can be applied to drive the agricultural tractor without a driver. As a result, it can reduce labor costs because it can be self-driving and can work independently during the day and night according to the programmed instruction. Therefore, this research of modern technology has played an important role in solving the agricultural problems in Thailand. The three main objectives of this research are to: 1) design a new intelligent unmanned agricultural tractor for modern agriculture to reduce the reliance on labor to operate the tractor , 2) develop automatic steering equipment that can control steering wheel rotation automatically for new intelligent agricultural tractor, and 3) apply compass sensor for a new intelligent unmanned agricultural tractor guidance system.

The methodology of this research is designing an automated navigation system for the modern agricultural tractor as the control method for steering automatically follows a predetermined straight route by using PID (Proportional-Integral-Derivative) control steering principles combined with Fuzzy Logic. The compass sensor and other devices were also applied for driving modern tractor. In this research, the steering system of the tractor was Bring a sensor to measure the steering angle by installing it on the steering column to detect signal from steering. The advantage of the encoder is that it can easily be acquired in Thailand and it is affordable. The compass naviation was used to design autonomous driving tractor steering wheel. The modules consist of mechanical component and Main Micro Controller for controlling the tractor steering motor.

This research has fulfilled all of the proposed objectives by designing and developing an automatic steering equipment for new intelligent agricultural tractor steering control based on compass sensor and wheel rotation. This research also proposed PID Fuzzy hybrid controller to the tractor steering to get the target. The results showed the effectively controlled the path on pavement and fast tracking accuracy, the controller is the ideal for point-based application of Ackerman robots. The proposed algorithm has potential applications in the complex and harsh agricultural working environment for agricultural machinery.

Keywords: unmanned autonomous tractor, modern agriculture, steering control system, path tracking, tractor hybrid control

Acknowledgments

I would like to express my sincere gratitude to Associate Professor Dr. Dechrit Maneetham for his helpful guidance, suggestion and encouragement throughout this study.

I would like to thank my thesis committee members, who are Dr. Worawat Sa-ngiamvibool, Dr. Petrus Sutyasadi, and Dr. Evi Triandini for their suggestions to improve my thesis.

Finally, I wish to thank my wife, family and friends for all given supports and encouragement to overcome all obstacles in order to accomplish my M.Eng.

Somdavee Bhosinak

Table of Contents

Table of Contents (Continued)

Table of Contents (Continued)

Page

List of tables

List of Figures

Page

List of Figures (Continued)

List of Figures (Continued)

List of Figures (Continued)

CHAPTER 1
INTRODUCTION

At present, one of the major problems in agriculture in Thailand is a shortage of agricultural workers. Since traditional agriculture is primarily human labor, the problem is caused by higher labor costs while the rate of emerging populations that replaces agricultural workers has decreased causing direct impact on agricultural products. The solving problems by modern agriculture the objective is to make it possible to reduce production costs and increase agricultural production. Especially, agriculture on medium and large areas is suitable to use technology to replace human labor in order to compete with the products in the market[1].

The smart tractor research concept is to solve the labor problem in the agricultural sector by designing a modern tractor by functional such as driverless tractor[2], equipped with compass sensor to increase driving efficiency according to the programmed path. Currently, compass sensor are inexpensive and easy to buy, so these sensors are suitable for applying such technology to be able to actually use to achieve agricultural effectiveness, reduce time, reduce the labor of tractor operators, thus lowering the operating costs by using low investment in unmanned tractor control equipment and can also be easily maintained.

Research on the steering control system for new modern tractor [3] can be applied to drive the agricultural tractor without a driver, so it can reduce human labor costs because it can drive and work independently both day and night. According to the programmed instruction, therefore, modern technology has played a role in solving the agricultural problems of Thailand.

1.1 Background

Labor is a factor of production and human capital that is essential to development at all levels. The sub-level of the economy is labor in the manufacturing sector. Both agricultural and service industries and at the national macro-level that is if the labor in various manufacturing sectors of the country with knowledge and ability Have high skills and potential will result in higher production efficiency and productivity which will affect economic development in the whole country. The problem of low-level Thai workers has started to lack in recent years to be caused by many factors. This is partly due to the continued slowdown in the Thai population[4].

When classified by age it was found that the number of childhood and labor population tended to decline while the elderly population tends to increase from the prediction data of older adults with different health conditions type in Thailand in the next 10 years (2020–2030) create a multi-status model defined by four statuses of elderly patients (age ≥ 60 years) according to four different grades. Activities of Daily Living (ADL): Social Groups; homegroup; Bedridden patients and among the dead. The volume of newcomers is estimated by the trend forecasting method with exponential growth. The transition probabilities from one state to another were obtained from literature reviews and models by 2030, the number of social groups, homes, and bedridden patients is 15,593,054, 321,511, and 152,749.Correspondingly, the model prediction error was 1.75% with a 20% probability, and the number of bedridden patients varies between 150,249 and 155,596. In total, the number of bedridden elderly will reach 153,000 in the next decade, and policymakers may consider using these findings as information for the future [5].

Due to agricultural workers has been moved to the industrial sector and the existing agricultural workers began to enter the aging society more including lack of welfare and labor protection have unstable income these are hard work and hard work. Causing the new generation to lack the motivation to enter the agricultural sector as a result, there is a shortage of labor in the agricultural sector. The situation of changing the population structure of Thailand and the agricultural sector has affected the number of agricultural workers which is the main production factor of the agricultural sector which has tended to decline continuously, together with the start to become an aging society in Thailand agricultural sector. Therefore, it affects the efficiency of the production of important economic crops such as rice and rubber. Rice plays an important role in Thai society from food to export. Rice planting accounts for more than half of the nation's arable land and employing more than half of the labor force. Moreover, rice is one of the staple foods and is also an important part of Thai exports [6].

1.2 Purpose of the Study

Based on the problems encountered and the needs of farmers, both medium and large landowners need to reduce their labor costs. The solution is to design and build a self-driving tractor without a driver and installed a compass sensor to be a navigation device for modern agriculture.

In order to work continuously become reduce the time of operation and reduce the operating costs of farmers to be lower which the purpose of this research is aimed at developing an automatically steered tractor when it is successfully carried out Farmers will get a new prototype of an autonomous tractor with a low-cost.

The control and drive systems are less complex and can be easily maintained and can also reduce the cost of hiring workers these factors obviously play a very important role and control the cost of investing in agriculture.

1.3 Research Questions and Hypothesis

1. Due to the shortage of agricultural labor and the agricultural sector in Thailand, there is still a lag in the development of machinery and equipment to replace agricultural labor. In Thailand, research or invention of modern equipment to replace labor is essential to increase productivity and reduce costs in agriculture. Smart farming tools that can play a role in making decisions, work with precision and accuracy, will replace fewer current workers.
2. Generally, farming in Thailand with medium-sized arable land and large, such as growing rice, beans, sugar cane, cassava, must be prepared for planting by plowing the soil. Originally, in the past, cattle were employed and now have agricultural tractors using engines to drive while relying on drivers. But due to labor shortage and higher labor costs in Thailand.

3. As the labor problem in Thailand, this research aims to design a new unmanned tractor to be able to direct the plowing of agricultural plots and to be able to control the direction of driving along a pre-programmed route. The work of this new unmanned tractor can work automatically. It also can be controlled by the steering wheel of the tractor by itself in the direction and the programmed path also controlled speed appropriately. The new driverless tractor's main control technology uses a compass sensor which is inexpensive, easy-to-buy, which can reduce future maintenance costs

1.4 Objectives

1. Design a new intelligent unmanned agricultural tractor for modern agriculture to reduce the labor of tractor operators.

2. Development of automatic steering equipment for new intelligent agricultural tractor control steering wheel rotation automatically.

3. Applied compass sensor for a new intelligent unmanned agricultural tractor guidance system.

1.5 Scope of the Study

1. Development of new intelligent agricultural tractor with unmanned automation system focusing on the automatic steering system that can control the position and direction of linear motion.
2. Development of a new intelligent agricultural tractor can be accessible via the availability of open-source software such as C++, C#, and hardware by using an Arduino board with sensors and peripheral devices.
3. Design control system for the speed pedal and gear shifting of the new intelligent agricultural tractor body.
4. Design and Installed sensors or equipment of safety system to prevent accidents during operation test.
5. Video captured with a camera is used as preliminary research for rice field sidewalk detection and is not used to make tractor movement decisions.

1.6 Theoretical Perspective

This research introduces the overall structural design of new unmanned tractor has been composed of hardware and software design parts. The hardware design includes mechanical design and circuit design. Software design includes control system execution process programming and path tracking control using the Fuzzy combined with PID to control the new unmanned tractor steering. Main new unmanned tractor control functions:

1. Unmanned tractor driving with constant speed.
2. Remote control and Manual driving mode for testing.
3. Planed for tracking path test.
4. Input is a compass sensor for tracking navigation.
5. Hybridge control theory with PID and Fuzzy Logic applied for autonomous tractor steering control.

1.7 Delimitations and Limitations of Study

This research aims to design-build a prototype unmanned, automated, compass sensor-guided tractor for modern agriculture and design algorithms for controlling linear motion positions and test for the actual working capability of the tractor it consists of tractors, mechanical controls, and a control unit for direction as following items :

1. The hardware design includes mechanical design and circuit design.
2. Software design includes control system execution process programming and path tracking control algorithms.
3. Using the Fuzzy PID control algorithm to control the tractor steering.
4. Using the manual control the speed and breaking system during the traveling process.
5. The automatic control system based on compass sensor and electronically controlled steering developed on new designed tractor to realize high-precision steering control.

6. Reduce control overshoot and improve the navigation precision of tractor tracking in the path area.

1.8 Significance of the Study

Design new technology for tractors to be able using in real-time requires detailed information from Sensors and tractor control units that can be used together efficiently. It is also necessary to control the steering that is appropriate the path of the unmanned tractor, in order not to malfunction, or lose control.

Through the electronically controlled steering system, the steering of the tractor is realized, which effectively alleviates the problem of lack of agricultural labor and effectively improves the accuracy of agricultural operations.

CHAPTER 2

LITERATURE REVIEW

In outdoor agriculture, tractors are the predominant agricultural machine used for field preparation before to planting. Tractors vary in size according to their capability for use. Currently, many countries have developed technology to increase agricultural productivity by 40 to 45% compared to the total investment in agricultural machinery, which revealed that the investment in tractors is the primary role of investment. There are tractors with novel technologies that can boost both production and operational efficiency. On the other hand, not only do the features of the tractor include the impact of the tractor on the environment, but most farmers from many nations across the world also require a tractor with a price that is affordable and substantial for marketing purposes[7].

2.1 Review of Tractor Components

Most state-of-the-art tractors operate with various equipment through a lever, such as power transmission take-off (PTO) with fluid power hydraulic system. Tractors take a lot of effort and focus on reducing fuel consumption because they are the fuel used to produce mechanical energy. Innovations and improvements in tractor engines, powertrains, and auxiliary systems have continued since the invention of the tractor a century ago and have brought great benefits.

2.2 Tractor Engine

In the new preliminary, the firm introduces a model with a new patch that conforms to European Euro II or Level II [8] standards. Light relates to allowable reductions in air pollution levels, such as NOx, HC, and CO, and laws. New engine innovation A kind of engine with a standard rail system is more efficient than the previous engine type due to reduced combustion heat loss than previous technology engines with an indirect injection combustion chamber, in contrast to typical models with a pressured fuel injection pump—General high inline engine with individual fuel injection lines

[9, 10]. Figure 2.1 depicts the input/output of the ECU. This technology entered the market in early 2002. An increasingly higher-pressure injector-pump system composed of engine components:

1. The diesel tractor storage
2. Diesel filter
3. Diesel supply
4. Diesel High-pressure pump
5. Pressure regulator
6. Common rail
7. Diesel injector with high pressure
8. Tractor ECU

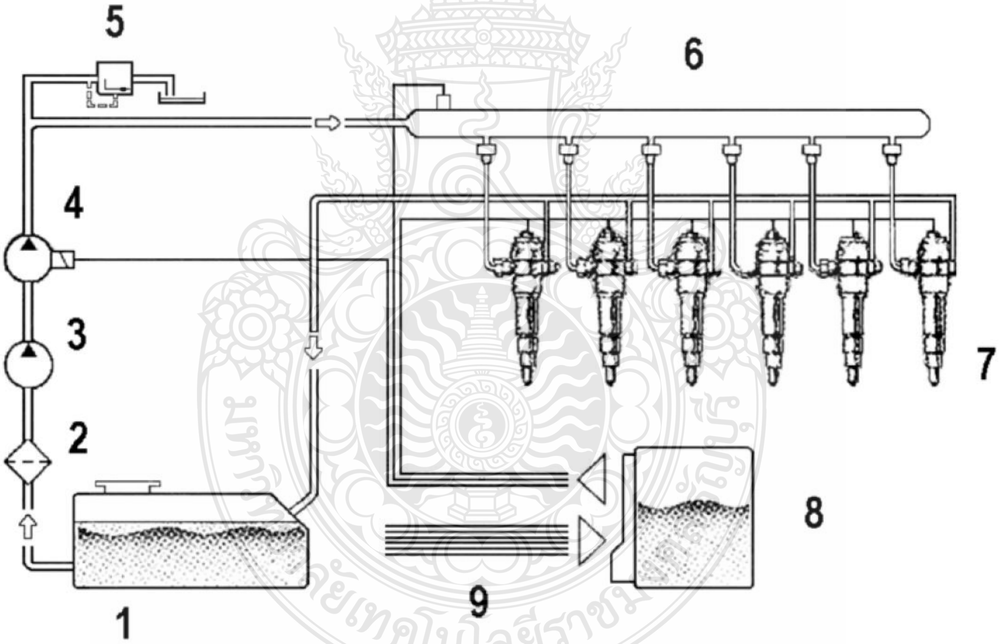


Figure 2.1 Common-rail and Injector- pump fueling systems

2.3 Tractor Transmission

A tractor arrived in the middle of the 1880s. The maximum speed surpasses the requirement by approximately 30 kilometers per hour; speeds over 40 kilometers per hour are a criterion for a high-performance tractor. Early in the 21st century, a 50-kilometer-per-hour (km/h) improvement in tractor top speed was discovered, and it appears that this may be the future of tractor performance. The tractor's speed became one of the justifications for designing a speed of more than 60 kilometers per hour[11]. Increasing velocity is intended for the diverse terrain that is anticipated. During the 20th century, the performance of tractors with a speed range of 5 to 15 kilometers per hour would exceed 60 kilometers per hour[11].

In addition to increasing the number of gears, the speed of the gearbox must be really balanced. It is necessary to enable speed change under full load conditions, as the transmission can no longer meet all standards. It is also necessary to manufacture stepless gearboxes in tractor supplies operating at specified engine power limits to prevent gearbox overload before changing the tractor transmission and causing substantial transmission loss. Continuously Variable Transmission (CVT) energy splitting is a mix of suitable mechanical and hydrostatic transmission hydraulic performance and gear benefits that eliminates the disadvantage[12].

This transmission allows the use of power. It is transferred from the engine to the planetary gearbox through the center. Planetary gearboxes provide various torque speeds via stationary gears. The stationary part consists of a gearbox system for developing a modern tractor model that increases the piston tilt angle up to 15o to be a better performance and faster than the previous system. The planetary gearbox, as follows the gearbox system, can drive with a hydraulic system used for the changed oil motor system. Revolution of the motor, driven by the connecting rod, for a combination of the mechanical parts of the tractor power source to the rest of the torque drive. When the transmission is working and at increased speed. The mechanism of power transmission is becoming more and more run until the mechanism is complete at its maximum value. With the speed of this technique, it is possible to get the most suitable speed of the tractor and its pulling power in some operations. Conditions without the need for replacement. The continuously variable transmission (CVT) system is composed of parts, as shown in Figure 2.2[13].

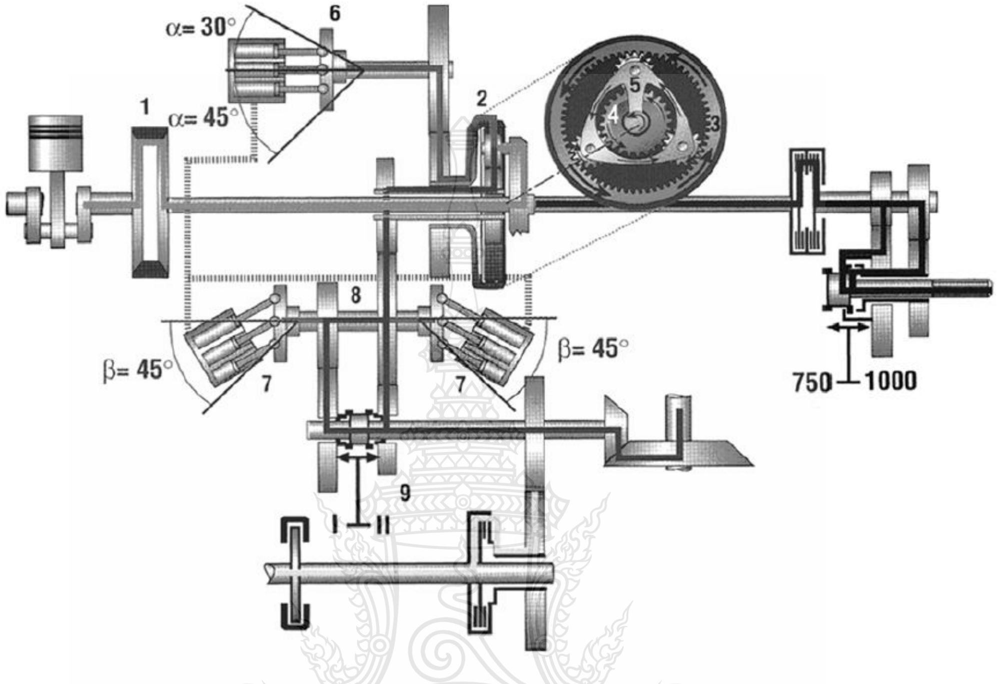


Figure 2.2 The Continuously Variable Transmission (CVT) system

2.4 Tractor Hydraulics System

In the past, hydraulic control and the three-point traction control were carried out by hydraulic mechanisms, mainly used on low-cost tractors. Therefore, this system measures the tensile force and position of the three-point bow and tow bar. The specified control is transmitted to the control valve via leverage within the system. In the past 20 years, Bosch has manufactured the popular Electronic-Hydraulic hitch control (EHR) system for tractors. Currently[14]. The application of electronics in control devices, sensors, and commanding components has opened new possibilities for tractor hydraulic hitch control. The tractor equipped with an electronic-hydraulic hitch control system consists of parts and system:

1. Battery,
2. Tractor ECU,
3.Central Unit Box,
4. Movement detector,
5. Lift cylinder,
6. Detector
7. Speed measurement,
8. Radio Detection and Ranging,
9. Hydraulic pump transmitter,
10. Control valve,
11. Fluid pressure source as shown in Figure2.3 [16].

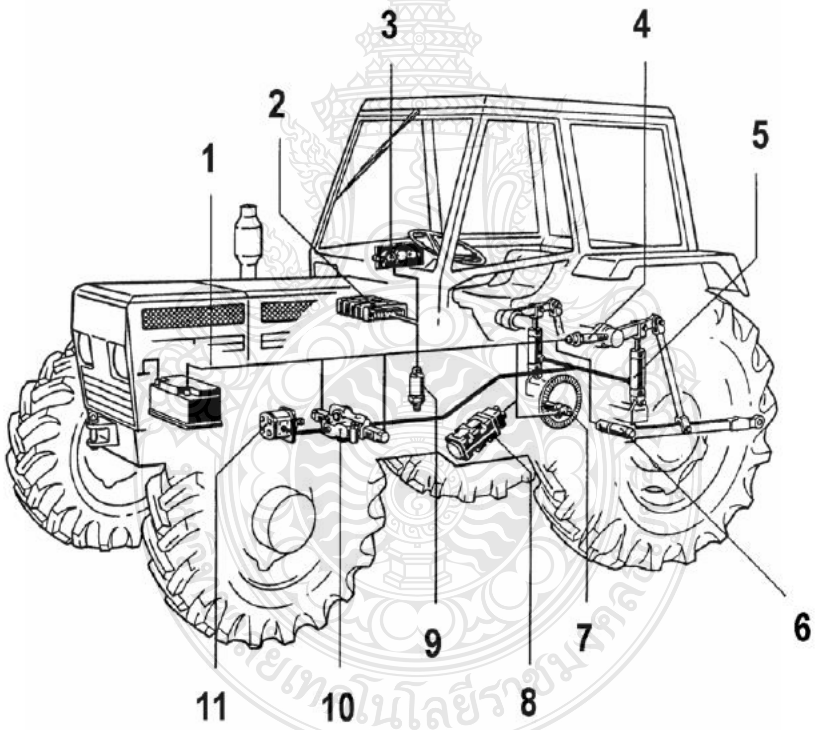


Figure 2.3 The Electronic-hydraulic Hitch Control System

2.5 Implementation of Electronics and Computers on Tractors

Following people's activities in the present governing law in a highly leader country is impossible, not including primary use and computer systems in general, especially in the machine. Increasing applications used for devices or tools for agriculture for productivity in farms, such as machine tools, require new scientific experts and an applied mechanical and electronics discipline with a high knowledge of intelligent machine tools. These combine theories from considerable knowledge and technology to become the new agricultural technology. The technology for farming, including the theory of control to be applied parts to the gearbox, also includes parts systems related to tractors of the same type of mixer truck. There must be all kinds of essential elements[15].

2.6 Steering Systems

The new crewless tractors can work in outdoor environments and withstand the sun, and most of the rain, so the equipment installation should be durable. And uneven path surfaces in farmland require a strong drive motor as well. The car power supply battery lasts for several hours. The architecture of an automated vehicle is composed of three main things as below:

1. Tractor stability and vehicle control include essential actuation controls, brakes, throttle, clutch, steering, and navigation elements related to tracking and vehicle response.

2. The response of Vehicles while driving must be aware of their position to function. In addition, be aware of the surrounding area to ensure workplace safety. How to make the driverless tractor the ability to control its course accurately may require sophisticated technology, causing user safety concerns; however, today's technology can be safely used by installing an anti-collision device that detects obstacles on its own to stop the car at a safe distance the sensor installed at the front of the tractor.

3. Autonomous vehicle control includes route planning and driving by incorporating other systems. Research has shown that developing in-vehicle technology will be applied to tractors, meaning future farmers may no longer have to learn to drive

tractors. The development of automatic steering tractors capable of unmanned steering along a programmed route of crewless tractors is a form of autonomous technology. It is considered that there is no driver because it works without humans in the tractor itself. It is like the other unmanned ground vehicles, which have been programmed to determine the position of moving freely. It can automatically decide the steering orientation.

The turning radius of the tractor is differently designed from tractor steering systems. There are three-wheel drives with one front wheel, front-wheel drive, all-wheel drive, and rear-wheel drive. The small turning radius makes the car more efficient in tight turns. However, the performance of a tricycle is at a disadvantage compared to a four-wheeler. Most tractors are in the middle of the driver's seat. It can drive easily, visibility is good, steering uses less torque, making use of power in the steering system stable. Choosing the advantages and disadvantages of a tractor for use on a difficult road. A traditional tractor with devices to control the tractor direction is perceived to become a steering-driven, hydraulic-controlled system. This system controls the mechanical part for the movement of the piston rod in the turning system to drive wheels for tractor control direction by using a fluid system. The electrical control system installed in the tractor to control tractor driving with electrical control is a combined operation of the electrical and fluid control systems shown in Figure 2.4 [16].

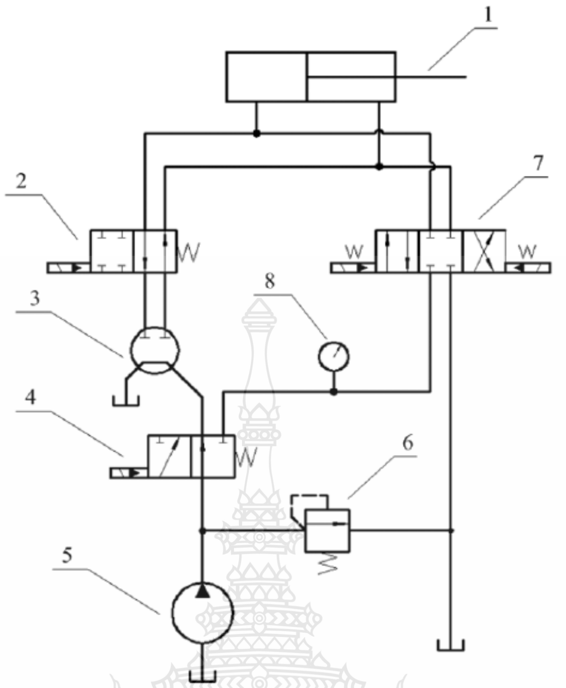


Figure 2.4 Structure of the Hydraulic Circuit in the Modified Steering System

1. Piston
2. 2 direction 4 port fluid control
3. Fluid transmission
4. 2 direction 3 port fluid control
5. Fluid pressurized source
6. Controlled valve
7. Varied steering valve
8. Gauge

The wheel angle is fed back to the control system using the encoder. Encoders are the Measuring of the speed or position of a rotating device. Typically, a sensor attached directly to the shaft measures rotational speed. The sensor frequency is used for calculations. Tractor Wheel Speed Encoder and the steering angle encoder are passed through the tractor's forward kinematic equations to achieve real-time position and direction. The most popular type of rotary encoder for the new tractor steering wheel is the incremental or absolute optical encoder and steering encoder system as shown in Figure 2.5[17].

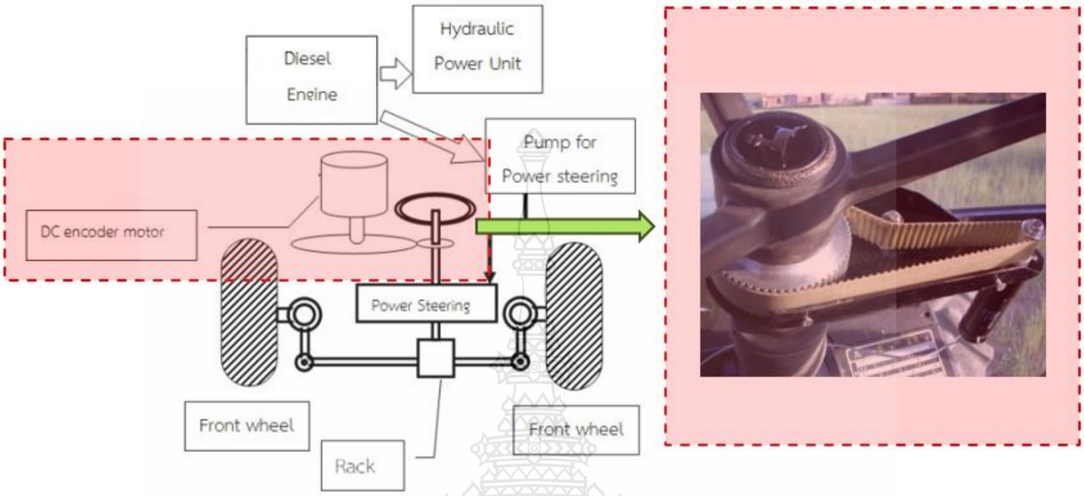


Figure 2.5 Steering Encoder System

The major advantage of using remote-controlled vehicles is a comfortable working environment and safety. Since nowadays, remote communication devices via wireless systems are cheap. But a major challenge in using remote-controlled vehicles is communication delays. Therefore, the design must also take into account the efficiency of the communication system for remote control. Using compass sensor navigation technologies to farm without a driver. Following Figure 2.6 Control Block diagram of the New Unmanned Tractor the Main important component including.

1. Compass Sensor
2. Arduino Uno
3. Encoder
4. DC Motor drive

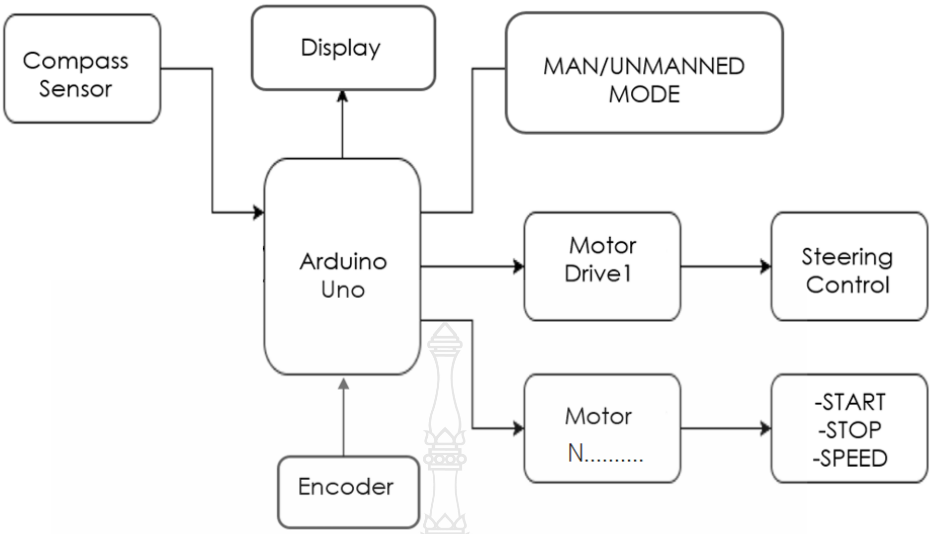


Figure 2.6 Control Block Diagram of the New Unmanned Tractor

2.7 Compass Sensor

The movement control has many sensors applied for intelligent agricultural tractor. Most widely for this application is the compass sensor, the intelligent agricultural tractor has acquired the position and data with digital compass.

Currently, the vast majority of research applications for automatic steering for tractors use tracking methods. Modern farming tractors are developed on the basis of smart agricultural tractors with compass sensors technology.

Following Figure 2.7 the compass sensor The IC is small and easy to install on the device and is widely used this surface mount integrated magnetic sensor can be used in many applications [18]. For example, an electric compass, a navigation device, this tiny surface-mounted chip has a built-in magnetic sensor with signal condition for high-precision applications such as car, ship, drones, robots etc. The compass sensor technology uses high-resolution and advanced magnetic resistance from Honeywell's patent in addition to a 16-bit ASIC, custom-designed ADC (analog-to-digital converter). It also has the advantage of low noise, high precision and low power consumption. Offset termination QMC5883L provides compass orientation accuracy from 1° to 2°. An I²C

(Inter-Integrated Circuit) serial bus allows the easy connection. Internal Schematic Diagram as shown in Figure 2.8.[19]

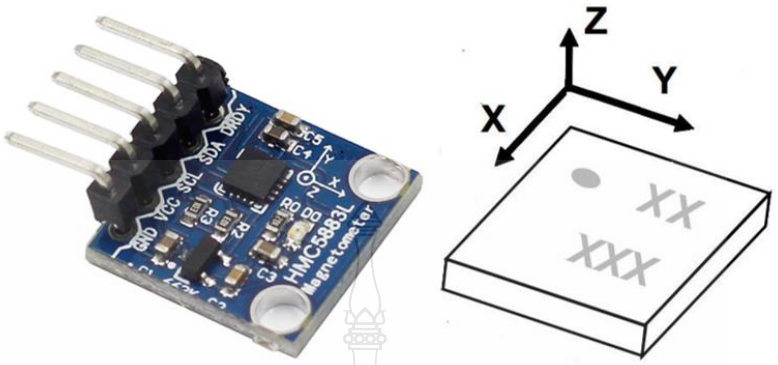


Figure 2.7 The QMC5883L multi-chip three-axis magnetic sensor

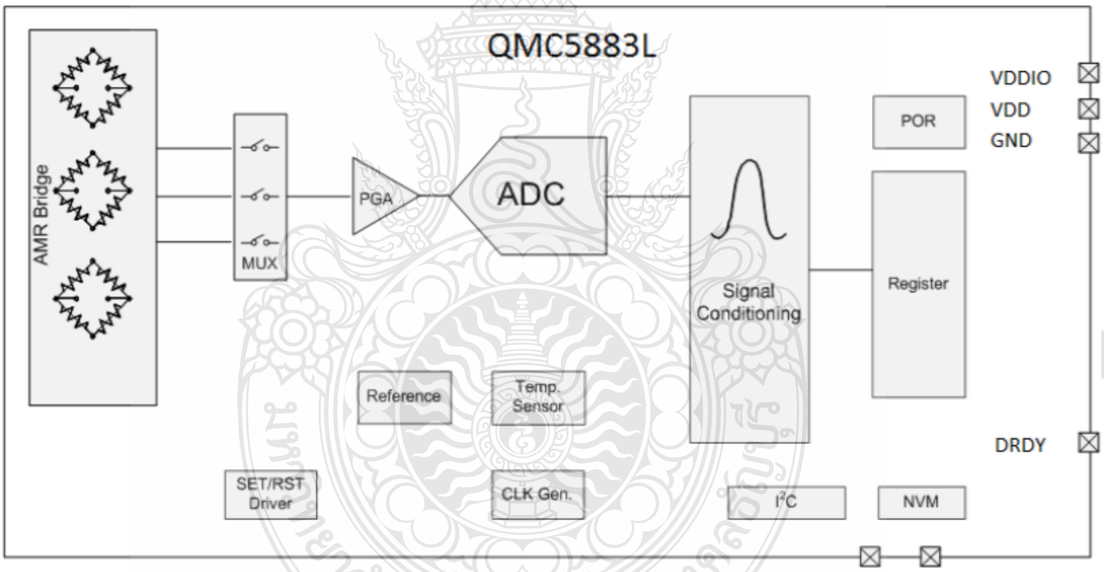


Figure 2.8 Internal Schematic Diagram.

2.8 Arduino Uno

Arduino is an open-source programmable board using C++ Language developer software as Arduino® Integrated Development Environment (IDE). It is very a powerful and multifunction microcontroller board widely use a lot of interest in both hobbies and professionals project. Arduino called Integrated Development Environment (IDE) which is programmable for various applications. The program is called sketch in the Arduino and the file. The Arduino board microcontroller can read the input power on the finger sensor on the button or twitter message and change to motor output, turn on the LED [20]. Arduino boards are widely roles in many disciplines today.

Intelligent homes application with an Arduino Microcontroller can control activities inside and outside the home by creating various control systems work with sensors installed in the house, such as motion detection, door opening and closing , control lamp, control garage door control air flow control sprinkler etc.

Radio Detection and Ranging (RADAR) application is the use of magnetic waves.Detected object detection system that can find the range, height, direction, or speed of an object. Radars can be of different sizes and have different performance characteristics, for example, they are used for airport air traffic detection. Vehicle object detection and early warning systems, etc.[21]

Programming with other devices for replacement is easy. Easy to reset Arduino is used in many industries. Arduino boards are low cost and flexible alternatives to common industrial devices in remote type applications. Control and monitor the operation of traditional small industrial systems as well as working with wireless technology.

Traffic Signal Control: It can be used to control traffic lights applied in various functions for controlling system with programing for scheduling traffic signal lights, etc. Intersection time will automatically adjust to accommodate. The smooth movement of the vehicle avoids the waiting time at intersection.[22]

Arduino Medical Applications For example, an Arduino-based heartbeat meter to count and beat the number of heartbeats in the module has a heartbeat sensor attached to it. To capture heartbeats, Arduino is also used for designing many medical devices. About medical research such as open source use of thermometers, body scales, etc. Arduino in use in the lab helps for basic circuit design and can be developed to a high level and learning Arduino is a useful basis in the future because it is a device. Arduino microcontroller with continuous technology development and affordable costs, easy to buy via the internet.

Physical hardware Arduino UNO as shown in Figure 2.9. digital input/output is 14 channel, for 6 channel provided for PWM, 6 analog channel. Arduino board use transmission via serial port to other devices [23].

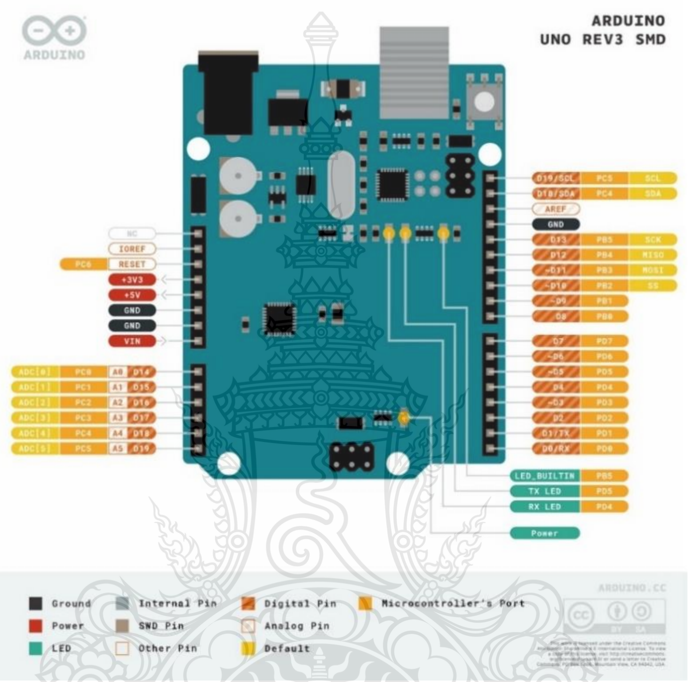


Figure 2.9 Arduino UNO

2.9 Encoder Sensor for Steering Control

The most popular sensor-based measurement of mechanical motion today is the encoder, which is a motion sensor based on angular rotation and generates a digital signal in response to movement also decode electrical signals that can easily be applied to the user's location, speed, and direction measurement tasks[24]. of motion control systems. Encoder usage differs according to the type of encoder. The linear response to the path motion while the rotary encoder responds to the rotational motion. Encoders can generally be categorized according to their counting methods. The incremental encoder generates signal pulses which can be used to determine position and speed. And absolute encoders can create unique bit configurations to directly track their position. In the automotive industry is using actuators and sensors for driving vehicles traditional functions connected by linking arm with reduce the load from mechanical loss form friction also support vehicle moving smooth this method replaced electronic technology in the past the system of ECU unit for controlling devices steering module. A DC motor steering mechanism with a digital encoder based on feedback control is used to actuate the steering forced with the steering wheel to use. Based on that capability, the steering wheel control design application is implemented as shown Figure 2.10.

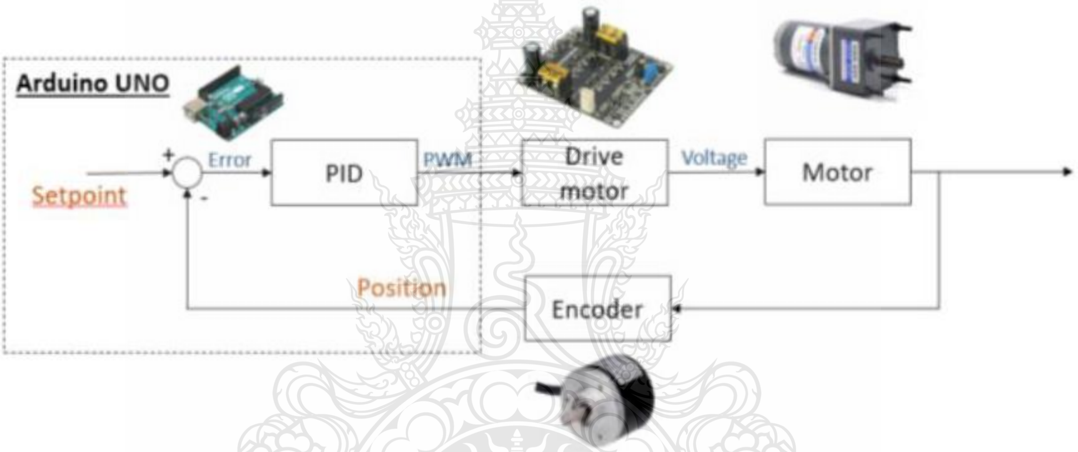


Figure 2.10 Close loop control position motor with PID

The encoder components consist of transparent discs with alternating opaque stripes. These strips are provided in the corners on the disc to get Pulses in one rotation of the tractor wheel the aperture sensor is used to detect clear and opaque bands as shown in Figure 2.11.

Figure 2.11 Motor with encoder on steering system

The sensor operation has an emitter and a signal detector with a black stripe of the disk coming in between the emitter and the detector. The phototransistor will turn off and because the collector signal to increase and when the transparent bar appears the transistor will open and the collector signal will decrease can be described as the clear and opaque detection between the sensor's emitter and detector allows it to be detected and converted into an electrical signal. as shown in Figure 2.12 components of optical encoder 1. Trans. disc, 2. Optical sensor, 3. Bearings, 4. Rod, 5. Seal, 6. Wiring[25].

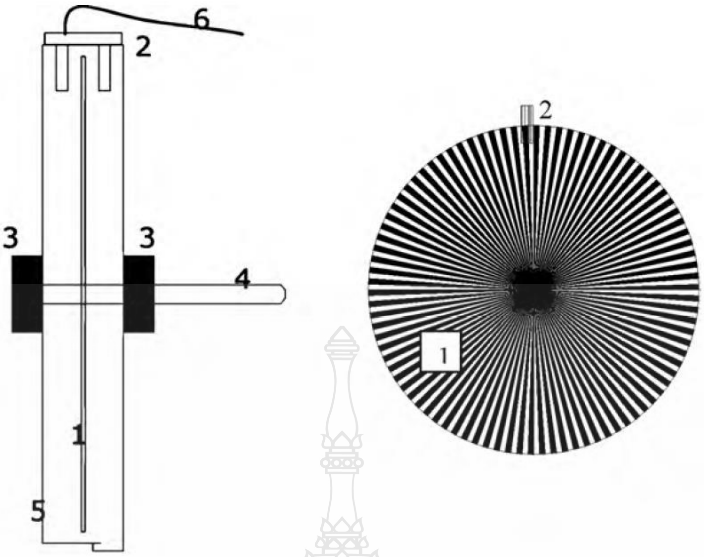


Figure 2.12 Components of Optical Encoder

2.10 DC Motor Drive

DC motor applications are widely used in industrial applications are widely used for speed and position control according to load type. It is also easy to control, providing efficient and accurate performance. The function of the motor speed controller is to receive feedback to control with a closed system that represents a comparison of the required speed and current to drive the motor at the desired speed for speed and position control according to load type. It is also easy to control, providing efficient and accurate performance. The function of the motor speed controller is to receive feedback to control with a closed system that represents a comparison of the required speed and current to drive the motor at the desired speed.

The Pulse width modulation (PWM) means supplying for controlling the speed of a DC motor is to control the driving voltage. When the voltage is high, the speed is high by the duty cycle equation of the PWM pulse is written as equation 2.1.

$$D.C = \frac{t_{on}}{t_{on} + t_{off}} \times 100\% \tag{2.1}$$

t_{on} = switch on duty cycle time of pulse and t_{off} = Switch off duty cycle time of pulse.

Arduino microcontroller, MOSFET motor driver, DC motor, 100k potentiometer and real-time computer monitor to test in MATLAB/Simulink. Figure 2.13.

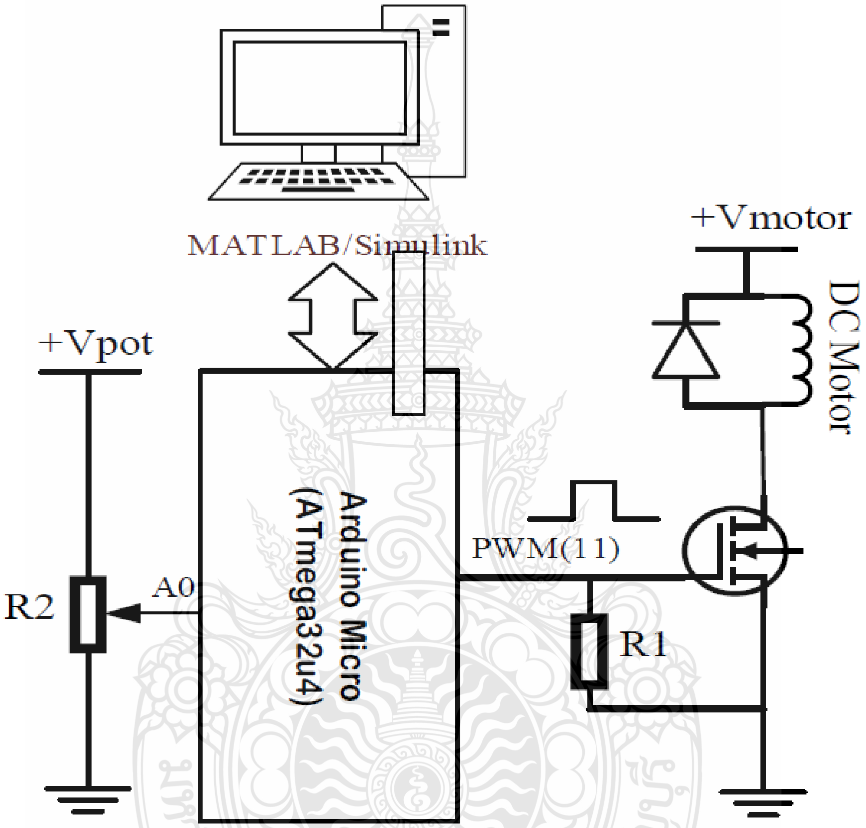


Figure 2.13 Circuit diagram of the proposed real time simulator

Figure 2.14 is shown the result duty cycle signal. The Arduino generates these signals and sends them to the motor driver which controls a wide range of motor speed, all control signals, speed, duty cycle, and analog digitization. The value are changeable from MATLAB/Simulink [20].

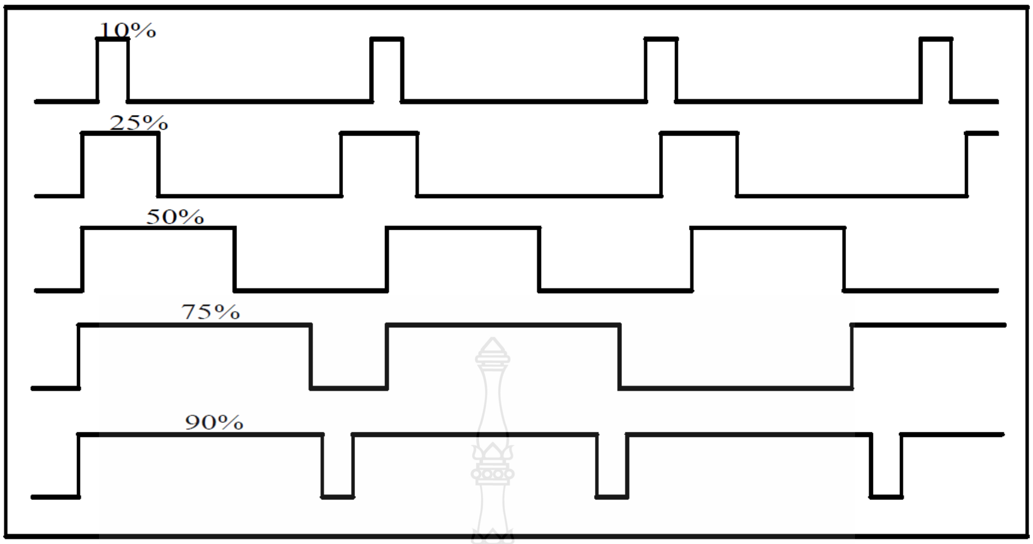


Figure 2.14 PWM waveform at different duty cycles

The IRFZ44 MOSFET is used for motor control Receiving a signal from the microcontroller to control the motor current makes the speed of the motor variable Using MOSFETs This type is widely popular for general industrial applications, this device can supply power up to approximately 50 watts. Analog-to-digital conversion depends on the system voltage equations related to values with voltage as equation 2.2:

$$\frac{\text{ADC resolution } \left(2^{10}-1=1023\right)}{\text{System Voltage}}=\frac{\text{ADC reading}}{\text{Measured Analog Voltage}} \tag{2.2}$$

Analog to digital conversions are dependent on the system voltage.

$$\frac{1023}{5}=\frac{\text{ADC Reading}}{\text{Analog Voltage Measured}}$$

The pulse output at PWM pin no.11by calculated digital ADC value can be various following value as shown in Table 2.1.

Table 2.1 Measured Analog Voltage.

ADC Value	PWM Value	Voltage
1023	255	5V
900	223	4.39V
700	174	3.42V
500	124	2.44V
0	0	0V

2.11 Control Theory Review

Because it has advantages of permanent magnetic pole DC motors are better than other conventional motors, such as better speed and torque better dynamic response high efficiency no stimulation current and low price easy to buy the permanent magnet DC (PMDC) motor has been started for using in various applications such as dryer fan, car toy, car fan and notebook computer also easily controlled speed. The widely use methods of control listed as below[26–34]. The equivalent circuit of PMDC motor as shown in Figure 2.15.

1. The classic PID controller.
2. Fuzzy Logic

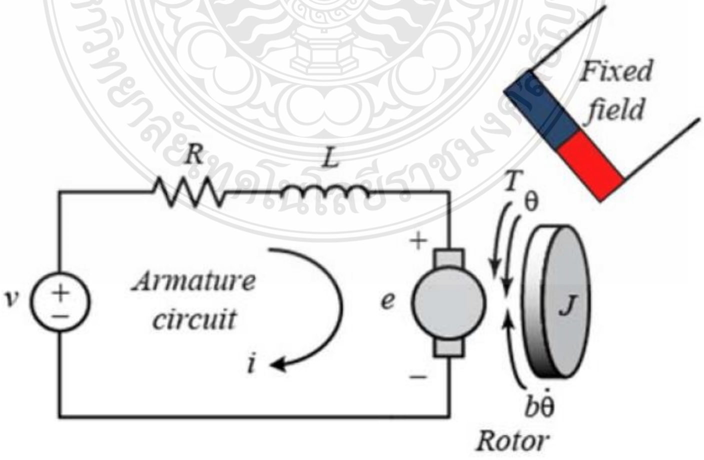


Figure 2.15 Schematic representation of the PMDC motor

2.12 PID Controller Review

PID (Proportional–Integral–Derivative) PID means closed feedback control. This causes a continuous change of output. Reduced reference errors used to control by using a control loop feedback mechanism. For precise, rapid process control and process optimization, PID control causes a continuous to reduce real-time error by the control loop feedback mechanism for more precise process control, eliminating error and improving the process where proportional gain is used for reducing the vibration nature of the on-off control.

PID control is slightly increased to reduce errors and ensure process accuracy and stability. By employing integral and derivative operations to improve control deviation errors also tuning for rapid process movement, this control method requirements must be optimized process control to get the goal of target by using PID controller.

PID control is commonly used in industrial processes such as the control of various production processes, temperature, and flow, and pressure, in general, complex applications such as industrial heat treatment processes. Including in the manufacturing industry by using various industrial robots, such as heavy lifting robots robot delivery parts to assemble the workpiece in the factory and can also be used in the automobile industry. That require safety in automatic speed control, stopping system, stability assist system, etc. as shown in Figure 2.16.

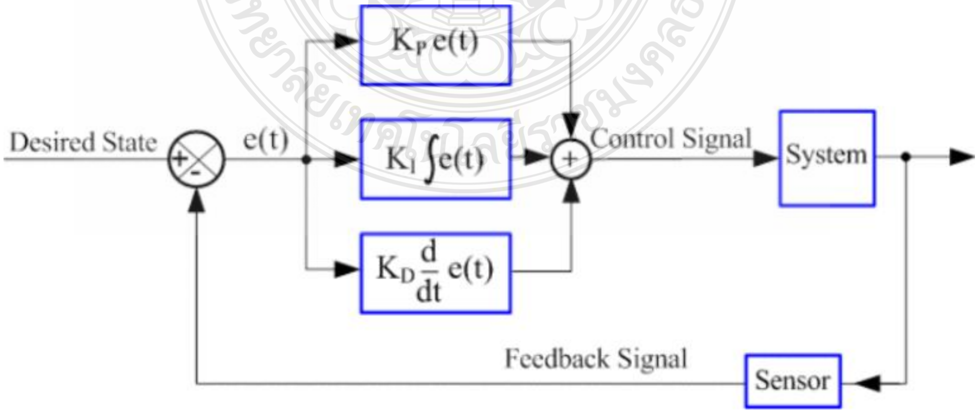


Figure 2.16 PID controller diagram

PID controllers system for controlling PMDC motor are simple design[35]. As shown in Figure 2.17 Output signal (U) , Gain (Kp), Integral (Ki), Derivative (Kd) the error signal (e (t)).[36]

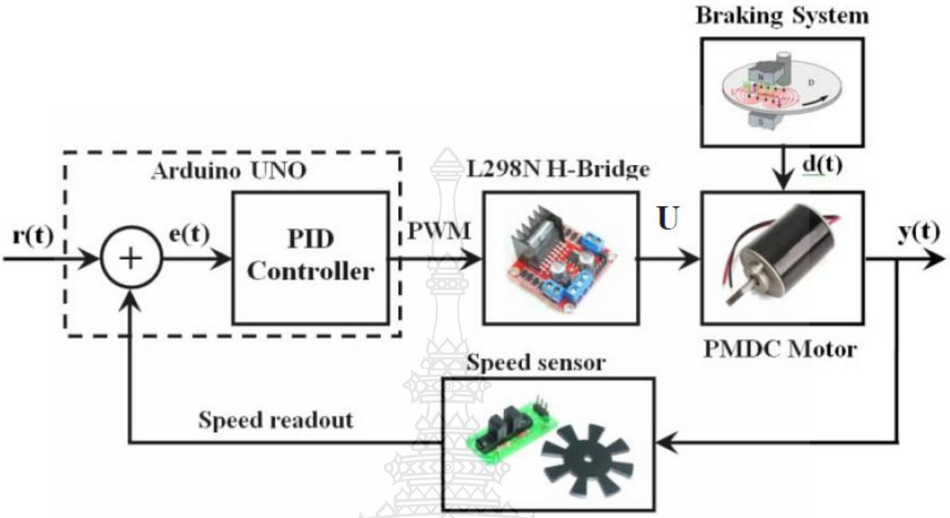


Figure 2.17 Closed-loop motor speed control scheme based on PID controller

2.13 Fuzzy Logic Review

Fuzzy logic refers to things that cannot be clearly stated or ambiguous. The fuzzy logic design provides flexibility in data-driven decision-making. This makes it possible to consider the inaccuracies and uncertainties of various situations. Using arithmetic, sometimes Boolean Truth values 1 represent absolute truth and 0 for false but in a fuzzy system there is no logic for that kind of truth, absolute, in fuzzy logic varying according to the weight or predetermined. Below are the fuzzy logic architechture:

RULE BASE: It is a set of IF-THEN rules and conditions developed by the designers of fuzzy logic systems to control language-based decision-making systems. Recent developments in fuzzy theory offer several effective methods for designing and customizing fuzzy controls.

FUZZIFICATION: is to use fuzzy logic to read input values such as numbers with very high resolution into fuzzy sets. The incoming input is the exact input measured by the sensor and passed to the control system for processing such as weight, distance, and angle.

INFERENCE ENGINE: Used to determine the level of comparative pairs of fuzzy inputs to arithmetic the current according to each defined rule and decide which rules will be applied according to the events. After that, the input field the default rules are merged to sum up the control values to the output.

DEFUZZIFICATION: An implementation to convert the fuzzy set obtained from the inference engine into a detailed value by calculating the rule based on it to make the judgments with decision weights pre-designed by specialists to minimize errors. Fuzzy logic architecture system is shown in Figure 2.18.

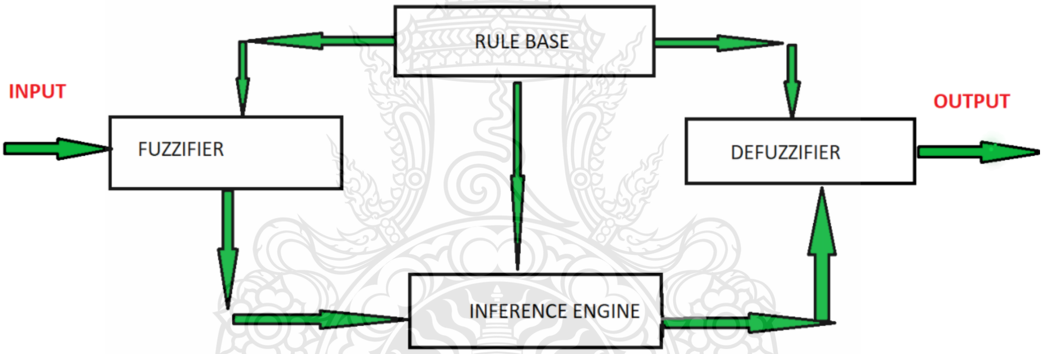
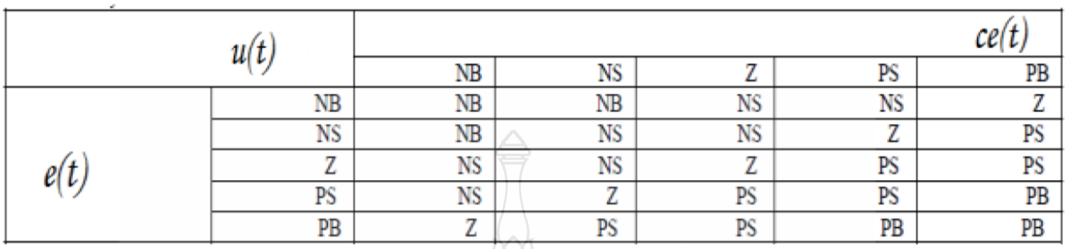


Figure 2. 18 Fuzzy logic architecture system

The member functions of fuzzy sets are a generalization of the indicator functions for classical set in fuzzy logic, it represents a level of truth as a complement to the valuation. Although there are differences in concepts. Because the vague truth represents membership in a given set. The Fuzzy rule is created by the experience of an expert or knowledge base. First, set the error e(t) and Changing the angular velocity ce(t) error to a fuzzy logic controller's input variable. The function u(t) is defined as the output variable of a fuzzy logic controller. Program variables are defined as groups (NB, NS, Z, PS, PB). No. NB means large negative, NS means small negative, Z means zero, PS means small positive, and PB, largely positive. The designed fuzzy rule, summarized in

Table 2.2 is that the type of fuzzy inference mechanism is Madani [37–40]. Following as Fig 2.19, Fig 2.20 and Fig 2.21.

Table 2.2 Fuzzy Rules.



$u(t)$		$ce(t)$				
		NB	NS	Z	PS	PB
$e(t)$	NB	NB	NB	NS	NS	Z
	NS	NB	NS	NS	Z	PS
	Z	NS	NS	Z	PS	PS
	PS	NS	Z	PS	PS	PB
	PB	Z	PS	PS	PB	PB

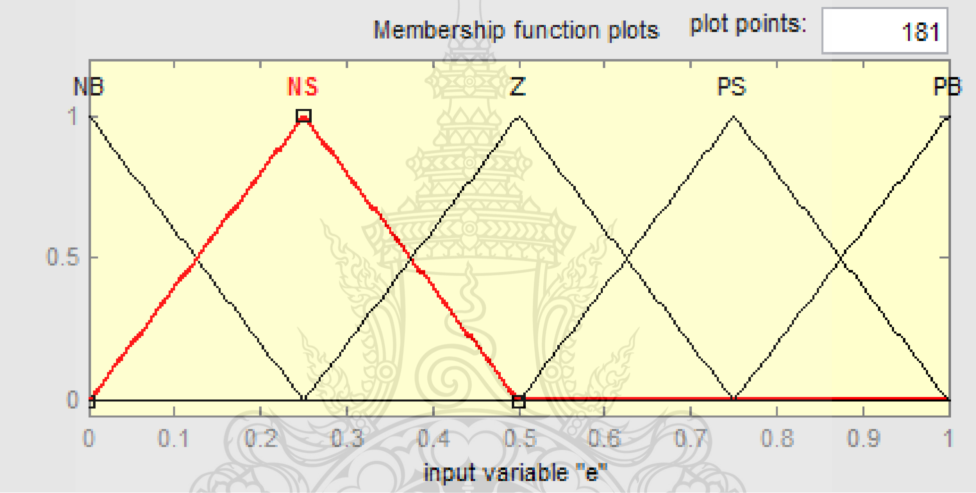


Figure 2.19 Membership functions for e normalized input

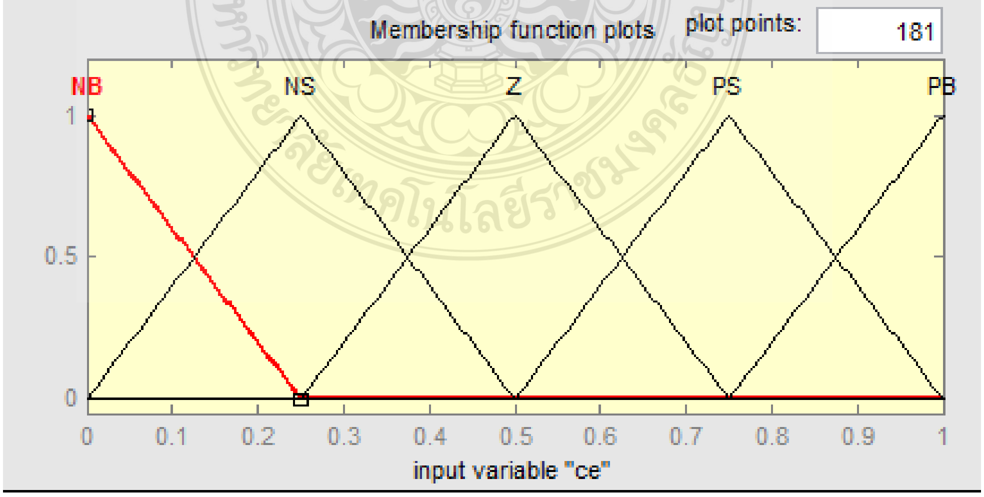


Figure 2.20 Membership functions for ce normalized input

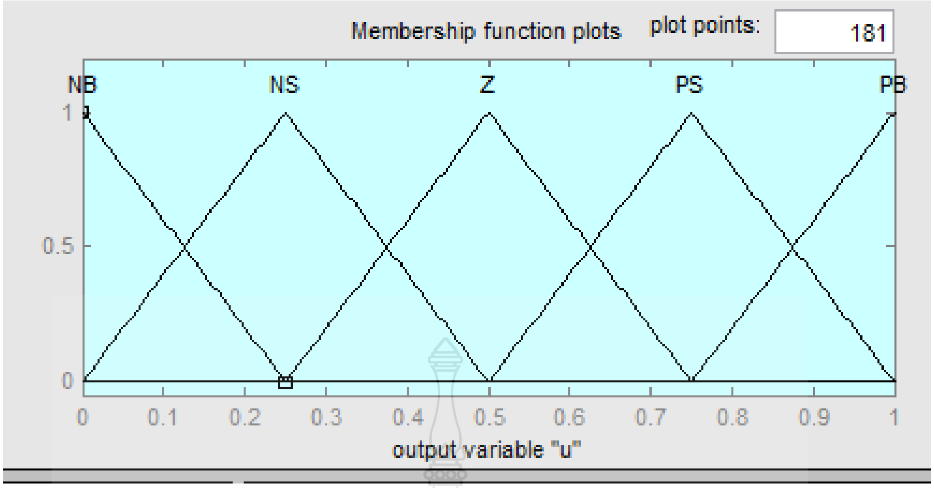


Figure 2.21 Membership functions for u normalized output

A max-min type reciprocal is used and the end result is for a system processing can be written as equation 2.3.

$$\mu_B(u(t)) = \max[\mu_{A_1}j(e(t)), \mu_{A_2}j(ce(t)), \mu_B j(u(t))] \tag{2.3}$$

Where;

$\mu_{A_1}j(e(t))$ = the membership function of e(t)

$\mu_{A_1}j(ce(t))$ = the membership function of ce(t)

$\mu_B j(u(t))$ = the membership function of u(t)

j is the measure of every member function of the fuzzy set m, the number of rules, and inference results. The fuzzy output u(t) processing by the center of gravity of the fuzzy force of gravity can be written as equation 2.4 :

$$u(t) = \frac{\sum_{i=1}^{m} \mu_B(u_i(t)).u_i}{\sum_{i=1}^{m} \mu_B(u_i(t))} \tag{2.4}$$

Table 2.3 Literature Review Summary

Article	Summary
1. Tractor Components	The typical tractor components are agricultural diesel engines, and the steering system uses a hydraulic system to help reduce the effort by turning the steering wheel manually but in modern times, the electric motor has been used to drive instead, allowing it to be controlled without human use which is consistent with this research.
2. Compass Sensor	Currently, most of the research work on automatic steering for tractors is based on the tracking method. Modern farming tractors are developed based on smart farming tractors with compass sensor technology.
3. Arduino Uno	Programming with other devices for replacement is easy and Arduino boards are low cost and flexible alternatives to common intelligent devices in remote type applications. Control and monitor the operation of traditional small systems as well as working with wireless technology.
4. Encoder Sensor	The most popular sensor-based measurement of mechanical motion today is the encoder, which is a motion sensor based on angular rotation and generates a digital signal in response to movement also decode electrical signals that can easily be applied to the user's location, speed, and direction measurement tasks
5. DC Motor	DC motor applications are widely used in industrial applications are widely used for speed and position control according to load type. It is also easy to control, providing efficient and accurate performance

6. PID Control	PID (Proportional–Integral–Derivative) PID means closed feedback control. This causes a continuous change of output. Reduced reference errors used to control by using a control loop feedback mechanism. For precise, rapid process control and process optimization, PID control causes a continuous to reduce real-time error by the control loop feedback mechanism for more precise process control, eliminating error and improving the process where proportional gain is used for reducing the vibration nature of the on-off control.
7. Fuzzy Logic Control	Fuzzy logic refers to things that cannot be clearly stated or ambiguous. The fuzzy logic design provides flexibility in data-driven decision-making. This makes it possible to consider the inaccuracies and uncertainties of various situations. Using arithmetic, sometimes Boolean Truth values 1 represent absolute truth and 0 for false but in a fuzzy system there is no logic for that kind of truth, absolute, in fuzzy logic varying according to the weight or predetermined.

Literature review to be used as a preliminary study for intelligent tractor research on automatic steering control. It was found that this could be done in several ways. In particular, this research was different because it created a new tractor and found the equipment available in the market easily and cheaply used to develop a control program using modern control theory to design a specific control for this research only. In the future, this research can be used as a model for further development in the agricultural sector of Thailand.

CHAPTER 3

RESEARCH METHODOLOGY

Designing an automated navigation system for the modern agricultural tractor is the control method for steering automatically following a predetermined straight route by using PID (Proportional-Integral-Derivative) control steering principles and combined with Fuzzy Logic were used in this research also the compass sensor and other devices brought to be applied for driving modern tractors.

3.1 Preliminary Design of The Steering System

- Hardware Design

Self-driving tractor steering design using a compass to navigate. The components are tractor's steering controlled the front wheel and the controller box MCU. The control steering uses a DC motor to control the steering wheel is electrically controlled as shown in Figure 3.1.

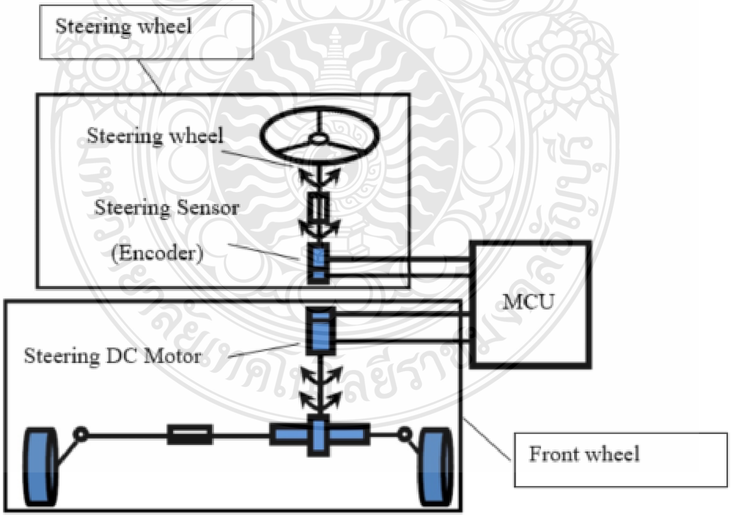


Figure 3.1 The steering control system

The steering have been fixed by setting to re-alignment steering driving gear matching to the motor gear and installed an rotary encoder 400 pulse/rev directly to shaft of motor gear. Gear design for tractor steering drive the concept of the design is about 4 inches in diameter, suitable for the available space to drive the steering wheel easily shown in Figure 3.2.

Figure 3.2 Steering motor gear and encoder

Geared motors installed with chain couple to the steering driving gear are selected according to the size that can be installed easily and can be easily purchased from general geared motor stores to test whether it can drive the steering wheel easily enough for use, the size is 90 Watt 24 Volt 3.75 Amp, torque 3.75 N.M 2000RPM Gear Box Ratio 1:20 Speed 209 rad/s Installed wheel marked position and degree angle ruler for measuring wheel angle at steering center check point as marked position shown in Figure 3.3.

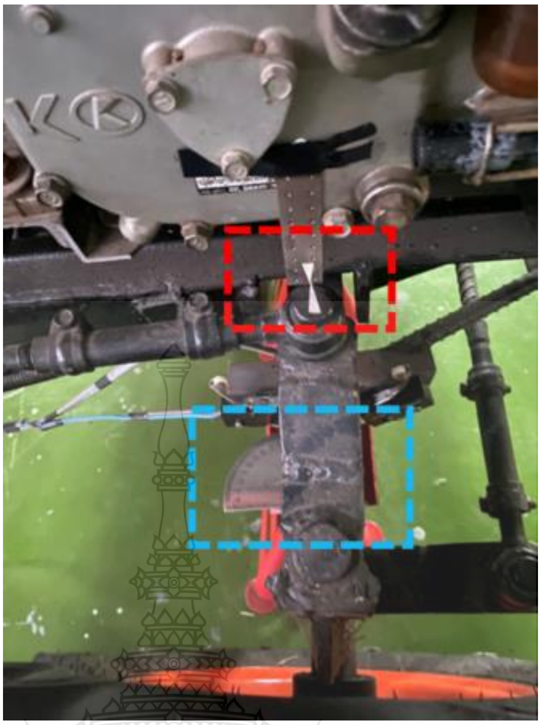


Figure 3. 3 Masked position and degree angle ruler

- **Control System Design**

New tractor mounting design with electronic control box for steering control using MCU control unit, control DC motor for driving tractor with PWM signal motor control by 24 VDC drive module, PWM supplying voltage for the DC motor and PMDC drive controlled by Arduino Module 2, a PID and Fuzzy Logic controller that works as a hydride theory controller for controlling PWM motors up to 24 VDC. The input sensor using compass sensor Adoption of Compass sensor model HMC5883L for magnetic field detection applications together with the automatic steering control system such as compass and field concentration measurement. The advantages of the sensor are low cost, easy to find magnets, suitable for agricultural research.Using an encoder to detect steering angles By connecting the MCU series signal to the encoder output pin A, B with right angle detection signal through the Arduino micro controller with400 P/R to be able measuring rotation speed in Rad/s unit calculated by Arduino. The microcontroller Arduino UNO operating with clock speed 16MHz can be used for reading input signal from encoder with an interrupt signal from connected to digital pin 11 limit angle switch to reset when start at initial mode. Monitoring data Arduino connected via I2C bus with analog Pin A4 and A5 also using for compass sensor in the same time. The PID and Fuzzy Logic by Arduino module are calculated by receiving error signal from sensor for reading the position and send signal output 24VDC motor as shown in Figure 3.4 hardware physical diagram.

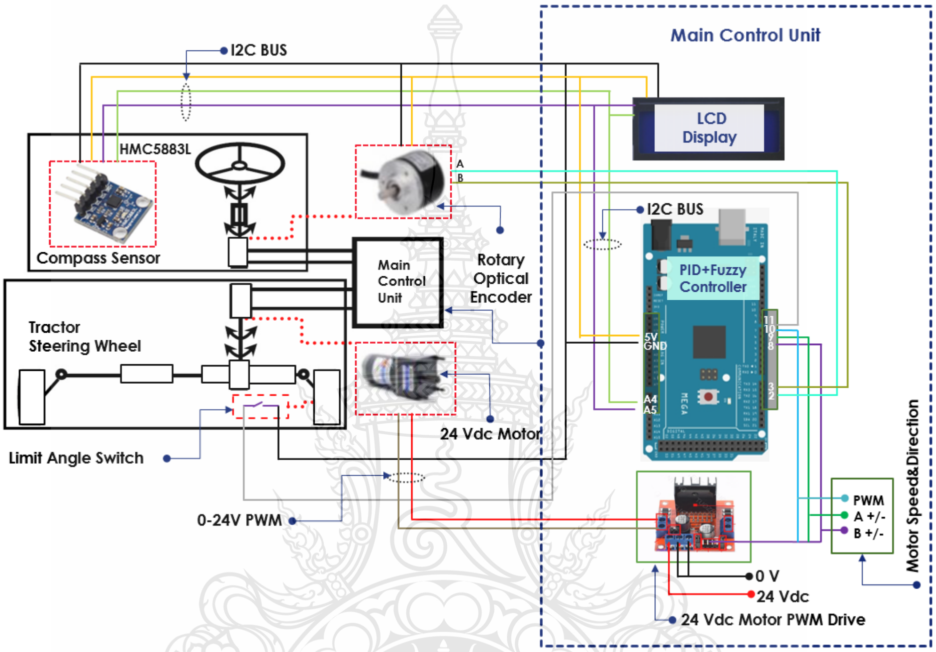


Figure 3.4 Hardware Physical Diagram

The navigation system controlled steering wheel. The position is represented in terms of Easting and Northing provided by the compass sensor. Local position of the tractor as given by the compass reading. The compass measures the angle of the tractor’s axis with respect to the geographic North Pole. Steering system is composed of the Arduino Uno micro controller that converts the inputs from compass sensor into PWM signal by using the Hybridge theory control by using fuzzy and PID control algorithm the steering linear actuators as shown following Fig 3.5.

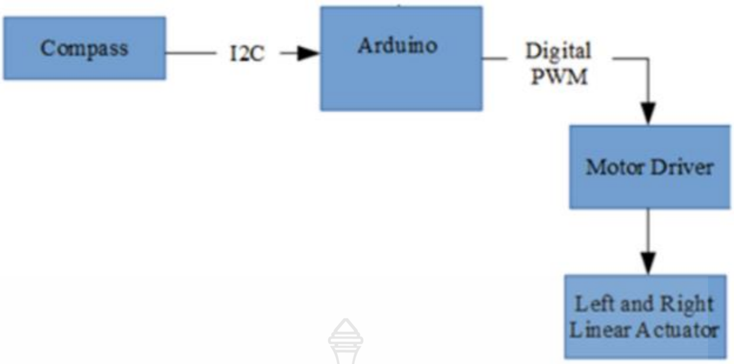


Figure 3.5 Steering wheel control system

Following the path tracking process in Figure 3.6 the initial mode starts that the tractor steering will be controlled by using a PID for resetting the steering wheel turning it into the target position detected by a limit switch sense the point of limit position then the position sensor by the encoder counting signal to controller until control the steering wheel at the center position to be ready for controlling in navigation mode by using compass sensor senses the tractor direction.

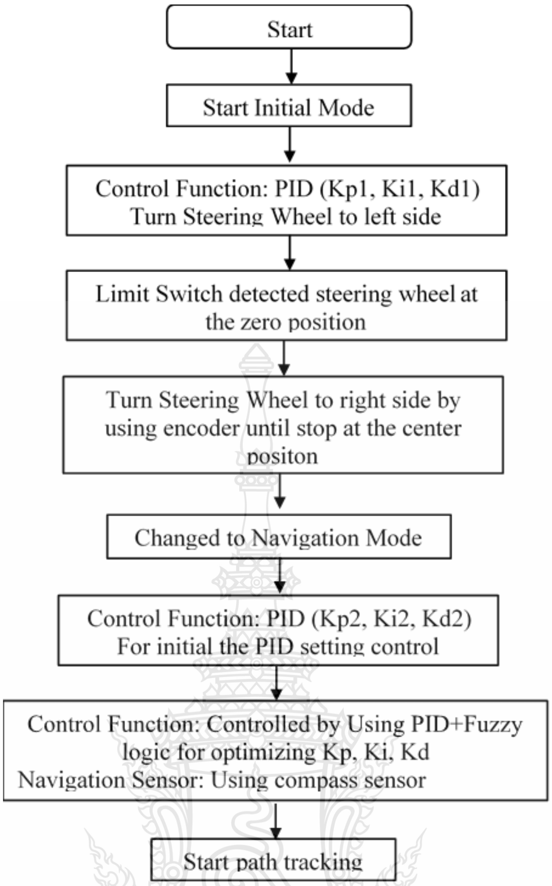


Figure 3.6 Path tracking process

The center of the area is defined to the centroid point also designated as the target point for tractor navigation. The steering angle α = Tan-1. (Cx / Cy) is calculated from the centroid point can be written as equation 3.1. The angle value is sent to MCU to control DC motor driving to the tractor steering for navigation respecting to the target position. The control steering avoids damage to the steering wheel controls that the steering angle is limited between −45° and +45° as shown Figure 3.7.

$$\alpha = \tan^{-1}\frac{c_x}{c_y} \tag{3.1}$$

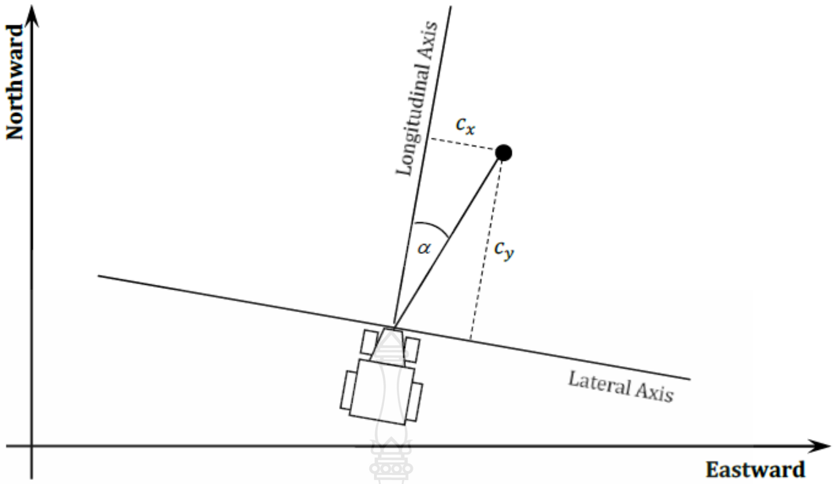
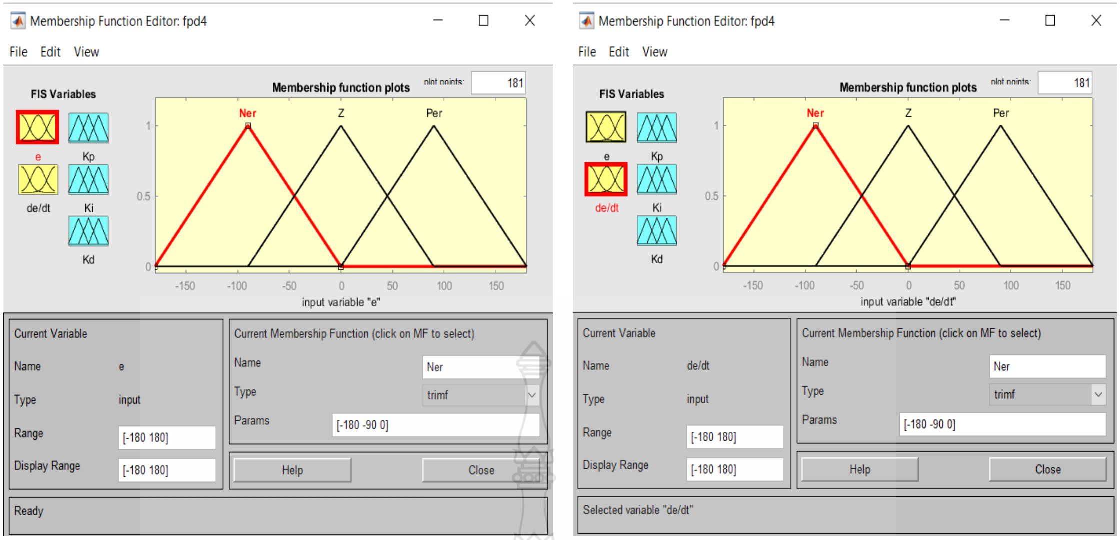


Figure 3.7 Calculation of the steering angle

- **Software Development**

Designing fuzzy rules is an important part of fuzzy rules. The controller follows a set of fuzzy and fuzzy rules and provides comprehensive analysis and control in order to achieve the expected goals for the controller objects through adjusting the control function [28]. The fuzzy logic rule can be defined for Kp, Ki, and Kd by technical knowledge and engineering practices of the steering characteristics as summarized in the Figure 3.8 error (e) and (ec) Input membership function, Figure 3.9 Output Kp, Ki, Kd membership function and Figure 3.10 Fuzzy Logic Rules and Surface of Kp, Ki, Kd. The fuzzy logic membership function variables of the differential error. The linguistic variables are defined as Ner, Z, Per where Ner means negative direction of error, Z means zero, Per means positive direction of error.



Current Variable
Name e
Type input
Range [-180 180]
Display Range [-180 180]

Current Membership Function (click on MF to select)
Name Ner
Type trimf
Params [-180 -90 0]

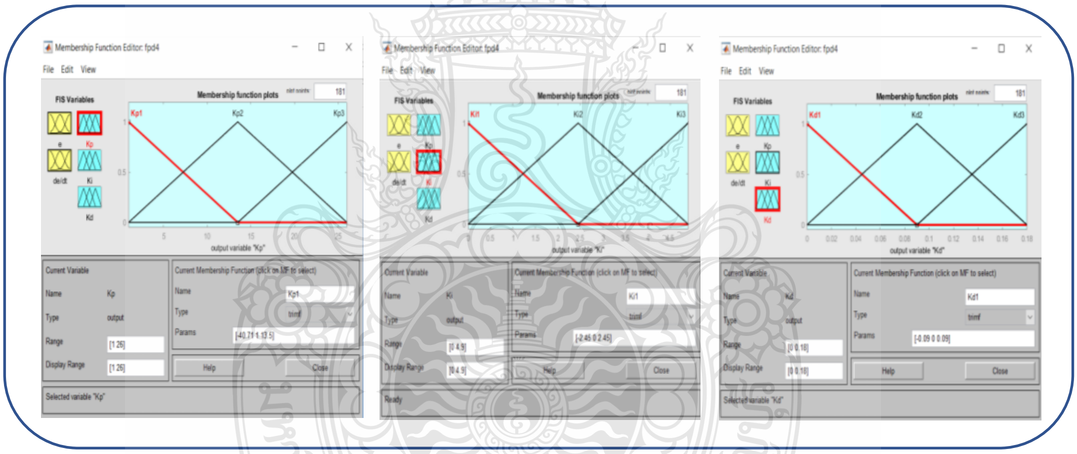
Ready

Current Variable
Name de/dt
Type input
Range [-180 180]
Display Range [-180 180]

Current Membership Function (click on MF to select)
Name Ner
Type trimf
Params [-180 -90 0]

Selected variable "de/dt"

Figure 3.8 Error (e) and (ec) Input membership function



Current Variable
Name Kp
Type output
Range [1 26]
Display Range [1 26]

Current Membership Function (click on MF to select)
Name Kp1
Type trimf
Params [-40.71 1 13.5]

Selected variable "Kp"

Current Variable
Name Ki
Type output
Range [0 4.9]
Display Range [0 4.9]

Current Membership Function (click on MF to select)
Name Ki1
Type trimf
Params [-2.45 0 2.45]

Ready

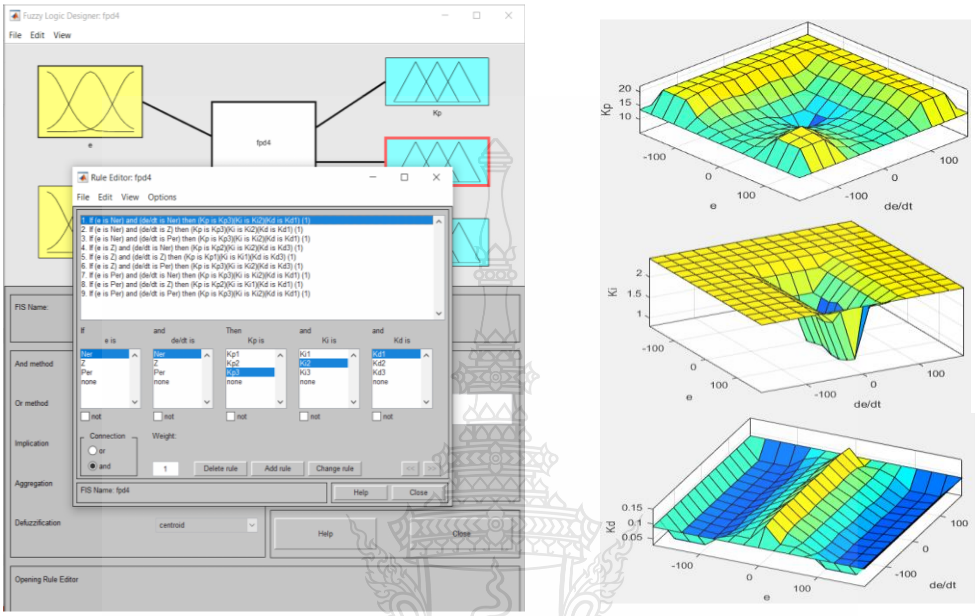
Current Variable
Name Kd
Type output
Range [0 0.18]
Display Range [0 0.18]

Current Membership Function (click on MF to select)
Name Kd1
Type trimf
Params [-0.09 0 0.09]

Selected variable "Kd"

Figure 3.9 Output Kp, Ki, Kd membership function

The Fuzzy rules of Kp, Ki, Kd surface as shown in Figure 3.9 explained all boundary of tuning operation in the graph by shading color from blue, green, yellow means levelling color of less, medium, high value from minimum to maximum scale for each of Kp, Ki, Kd. Following the graph Kp,Ki shows the boundary control value when the feedback error getting to reach zero value the Kp, Ki tuning decrease to eliminate overshoot response calculation process to improve the steady error response by increasing the Kd value automatically.



1. If (e is Ner) and (de/dt is Ner) then (Kp is Kp3)(Ki is Ki2)(Kd is Kd1) (1)
2. If (e is Ner) and (de/dt is Z) then (Kp is Kp3)(Ki is Ki2)(Kd is Kd1) (1)
3. If (e is Ner) and (de/dt is Per) then (Kp is Kp3)(Ki is Ki2)(Kd is Kd1) (1)
4. If (e is Z) and (de/dt is Ner) then (Kp is Kp2)(Ki is Ki2)(Kd is Kd3) (1)
5. If (e is Z) and (de/dt is Z) then (Kp is Kp1)(Ki is Ki1)(Kd is Kd3) (1)
6. If (e is Z) and (de/dt is Per) then (Kp is Kp3)(Ki is Ki2)(Kd is Kd3) (1)
7. If (e is Per) and (de/dt is Ner) then (Kp is Kp3)(Ki is Ki2)(Kd is Kd1) (1)
8. If (e is Per) and (de/dt is Z) then (Kp is Kp2)(Ki is Ki1)(Kd is Kd1) (1)
9. If (e is Per) and (de/dt is Per) then (Kp is Kp3)(Ki is Ki2)(Kd is Kd1) (1)

Figure 3.10 Fuzzy Logic Rules and Surface of Kp, Ki, Kd

The Fuzzy rules of Kp, Ki, Kd surface as shown in Figure 3.10 explained all boundary of tuning operation in the graph by shading color from blue, green, yellow means levelling color of less, medium, high value from minimum to maximum scale for each of Kp, Ki, Kd. Following the graph Kp,Ki shows the boundary control value when the feedback error getting to reach zero value the Kp, Ki tuning decrease to eliminate overshoot response calculation process to improve the steady error response by increasing the Kd value automatically. Development of a new intelligent agricultural tractor can be accessible via the availability of open-source software such as C++ and hardware by using an Arduino board with sensors and peripheral devices.

3.2 Mathematical Model

- System Modelling

General advantages of Permanent magnet DC motors (PMDC) it can be applied for controlling speed and position of rotation and running operation only armature circuit wiring and can be self-inductance using permanent magnet no exciting current required from outside source. PMDC motor starting wide range of useful such as tools, car devices, air conditioners fan and notebook computers etc. Thus the PMDC can be used to be applied for tractor steering control as well. The schematic PMDC motor parameter as shown in Figure 3.11.

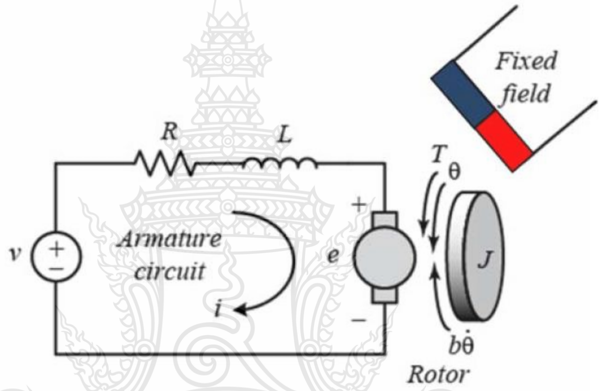


Figure 3.11 Schematic representation of the PMDC motor

The PMDC motor supply as V connecting to the PMDC motor for driving the angular speed by $\dot{\theta}$ the output and motor shap friction and assumed model parameter for simulating in Matlab Simulink as following variable below:

(J) Moment of inertia of the rotor.

(b) Motor viscous friction coefficient.

(Ke) Electromotive force coefficient.

(Kt) Motor torque coefficient.

(R) Armature resistance.

(L) Armature inductance.

Use transfer function of PMDC to input for the steering for MATLAB Simulink test given by the transfer function parameter Figure 3.7 Angle steering control transfer function can be written as equation 3.2.

$$\frac{\dot{\theta}(s)}{V(s)} = \frac{K_t}{(L\,s+R)(J\,s+b)+K_e K_t} \tag{3.2}$$

Given PMDC motor parameter for transfer function as below:

(J) Moment of inertia of the rotor.	J=0.049e-4 (kg.m2)
(b) Motor viscous friction coefficient.	b=0.0 (N.m/(Rad/s))
(Ke) Electromotive force coefficient.	Ke=5.6e-3 (V.s/Rad)
(Kt) Motor torque coefficient.	Kt=5.3e-2 (N.m/A)
(R) Armature resistance.	R=2.7 (Ohm)
(L) Armature inductance.	L=1.4e-3 (H)

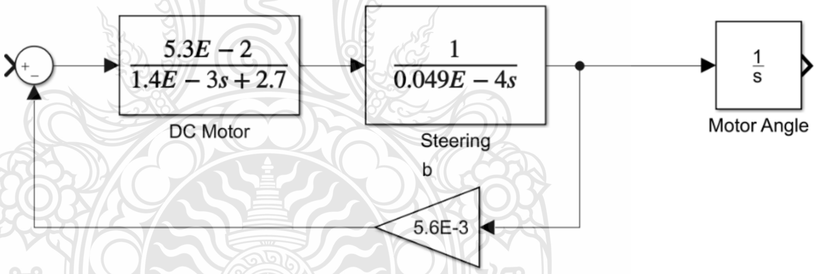


Figure 3.12 Angle steering control transfer function

The Fuzzy Logic rules designed and applied for Kp, Ki, Kd parameter of PID control can be a model to input by using the Simulink environment of MATLAB, to compare PID controller by using Kp, Ki, Kd tuned by hand method and the PID controller these are according Figure 3.13 Hybrid controller Fuzzy PID and PID Comparison.

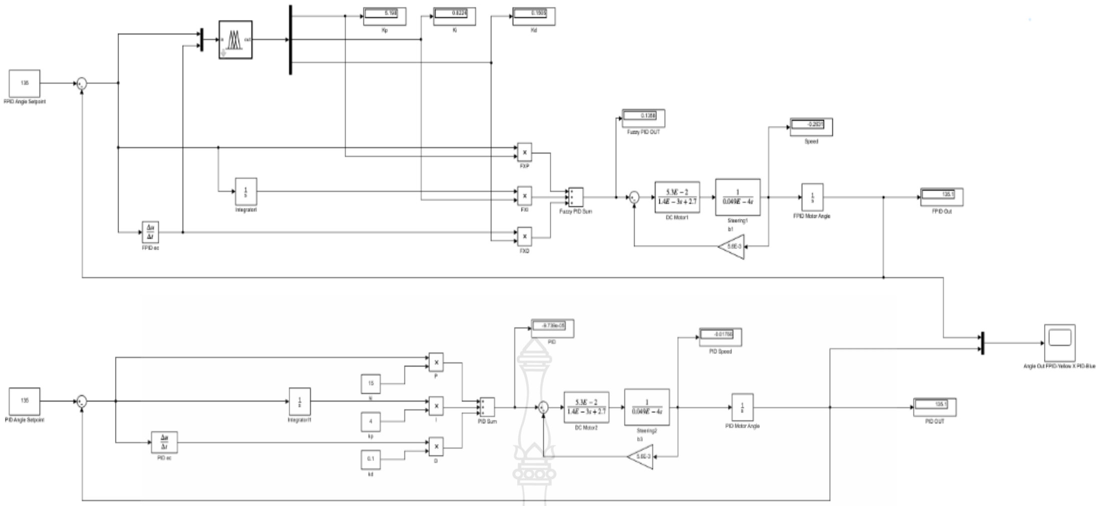
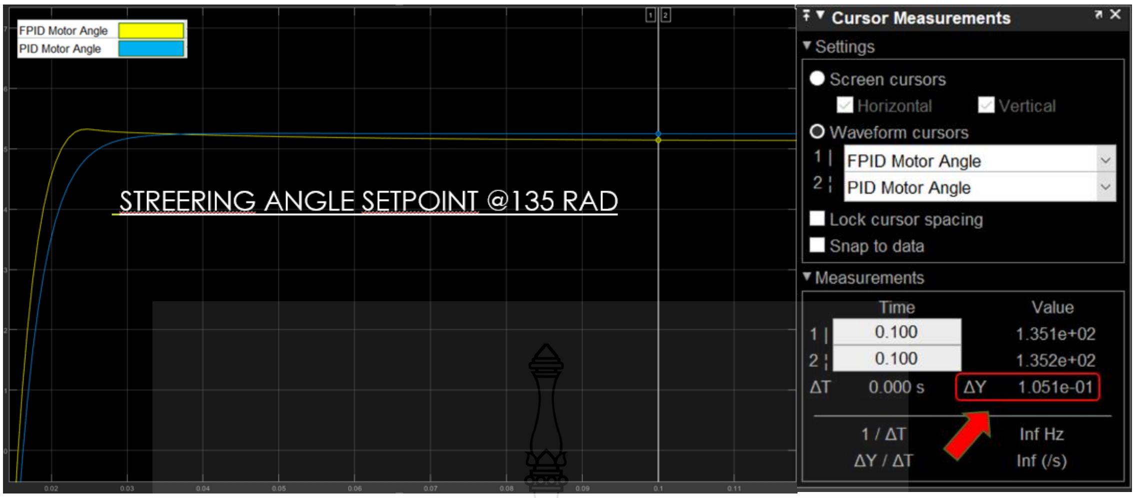


Figure 3.13 Hybrid controller Fuzzy PID and PID Comparison

Based on the results of the comparative experiment in Matlab, Simulink the results were compared the PID to Fuzzy PID controllers used control unit of DC motor drive to tuning PID parameters and finally, the sum of both the controller signals. Three will be processed as the resultant signal. In the Fuzzy Logic Matlab dialog box, all defined member functions and designed rules are initialized and customized PID parameters. Parameter values are further modified using fuzzy control rules. The result of simulation in MATLAB Simulink by setting the steering angle setting point at 135 RAD the comparison response shown in Figure 3.14.



● Screen cursors
☑ Horizontal ☑ Vertical
○ Waveform cursors
1 FPID Motor Angle
2 PID Motor Angle
☐ Lock cursor spacing
☐ Snap to data

	Time	Value
1	0.100	1.351e+02
2	0.100	1.352e+02
ΔT	0.000 s	ΔY 1.051e-01
1 / ΔT		Inf Hz
ΔY / ΔT		Inf (/s)

Figure 3.14 Hybrid controller Fuzzy PID and PID response

By tuning parameters Hybridge controller to improve a responsiveness of the PID controller to find out to be satisfied system response by using manual tuning method for Kp, Ki, Kd the satisfactory to be available to control the system of the steering wheel then take the Kp, Ki, Kd values from the PID controller to improve by divided control value range of Kp, Ki, Kd to be self-adaptive PID controller for improvement rising time, setting time and steady error. The purpose is to improve PID controller become more responsible time and more stability by using Hybridge controller Fuzzy Logic PID controller. As following the result in Figure 3.14 to compare hybrid controller with PID controller shows in yellow line compared with PID controller response which shows in blue line has been improved that in better for rising time, setting time and steady error.

Because the Fuzzy controller can process the result values for response-based improvements in real-time by using Fuzzy rules that recognize the response errors at any time to send the appropriate Kp, Ki, Kd values to improve the PID system in real-time.

3.3 PID Control Design

Control theory of the navigation system for the tractor can be automated by developing a simple kinetic tractor model with high-speed or very accurate navigation. Some effects such as inertia, sliding, and spring must be taken into account in tractor models. Dynamic tractor models may be used for such purposes also has been used for autonomous improvement by using a compass sensor for tractor navigation.

PID control is widely used in traditional PID systems, setting parameters of the control process in accordance of Proportional gain, Integral error time, and Derivative feedback error time also adjusting Proportional, Integral and Derivative, the actual results getting to the target when the PID-based controller is designed parameters of PID control are accurate.

Actually, using PID for nonlinear control might be not controllable to the target, so Fuzzy Logic was designed to modify the control parameters. PID according to the change of the input variable during the dynamic process.

A Proportional-Integral-Derivative or called feedback close loop control applied for process control to increase high quality of control system. A continuously modulated and close loop back is required. The PID controller runs real-time processing the error value of required set point and the process error measured feeding back to input and applied proportional interpolation, integrals, and conditional derivatives.

In practice, the PID controller is applied automatically responds to the control transfer function. Given a situation in everyday driving a car's running on speed setting mode, in which ascent will slow down the engine when car engine run over the speed setting. The PID processing returns output control to car engine when need to up speed the engine adding more power output. The PID controller is one of theory control to be used for automatic steering also for braking system in general car nowadays and applied in various industrial process.

Typically, the PID controls are adjusted using tuning method of manual tuning or Ziegler Nichols are usually used by following as a rule. As shown in the Table 3.2 Hand tuning rule and Table 3.1 Ziegler-Nichols rules [27].

Table 3.1 Hand tuning rules.

Operation	**Rise Time**	**Overshoot**	**Stability**
K_P ↑	Faster	Increases	Decreases
T_D ↑	Slower	Decreases	Increases
$1/T_I$ ↑	Faster	Increases	Decreases

Manually tuning step by step:

1. Set zero Kd and the Ki by setting as TD=0 and 1/TI =0.
2. Set Kp to be reached almost unstable.
3. Tuning TD to overshoot damping.
4. Set 1/TI.
5. Do steps from 3 to reach most possible.

Given a process with the PID parameters control as following: Kp= 2.9, KI= 0, Kd= 0 for The oscillation period wave form simulation as shown in Figure 3.15.

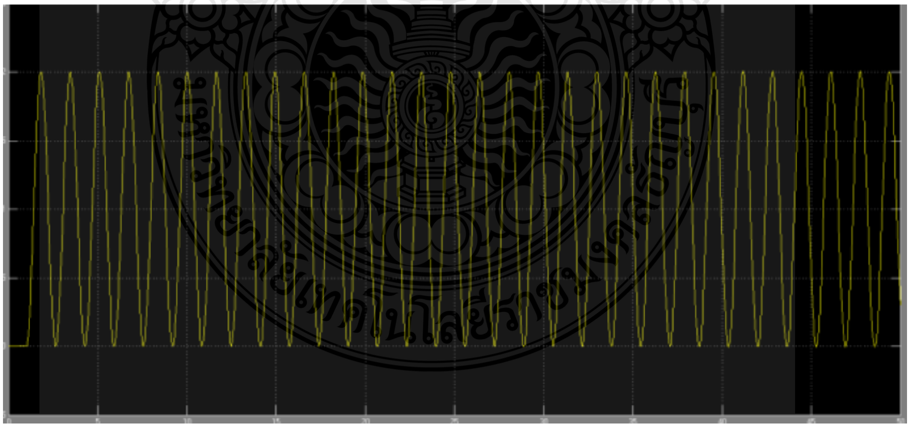


Figure 3.15. The oscillation period wave form

By using Hand Tuning method to decrease the overshoot response the parameter find out are as following : Kp= 1.9 , KI= 1.5 , Kd= 0.7 as shown in Figure 3.16 Hand tuning response below.

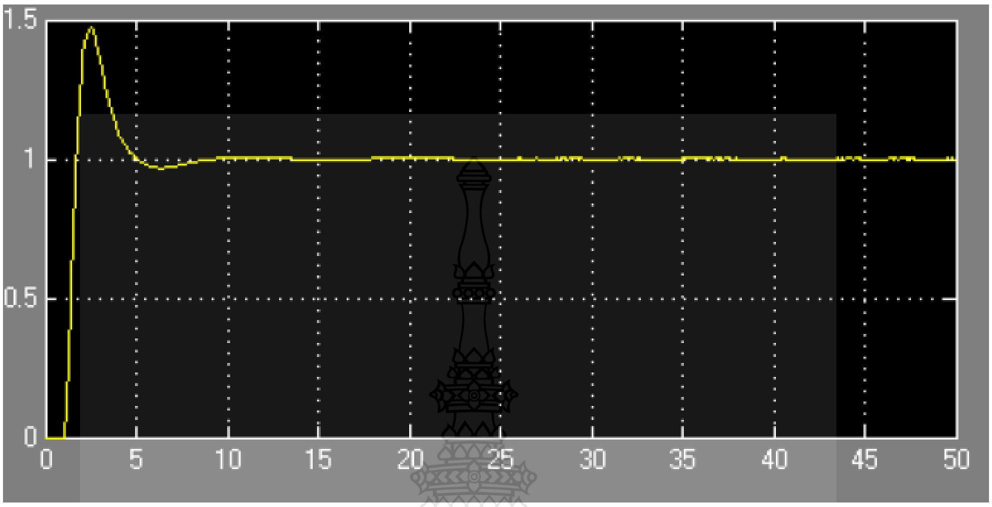


Figure 3.16 Hand tuning response

The Ziegler-Nichols tuning method:

1. Tuning up Kp until system reach up the sine wave to collect the data parameter as Ku as define to be an ultimate gain.

2. Find out parameter Tu as shown in Figure 3.3 The oscillation period wave form.

3. Follow Tuning by using Ziegler-Nichols method as the table Table 3.2 .

Table 3.2 Ziegler-Nichols rules.

Controller	K_P	T_I	T_D
P	$0.5K_u$		
PI	$0.45K_u$	$T_u/1.2$	
PID	$0.6K_u$	$T_u/2$	$T_u/8$

The Result of calculation are 1.67. The value of the parameters Kp, KI and Kd depending on Ziegler Nichols tuning method: Kp= 1.74, KI= 2.0963, Kd= 0.363225 result graphic shown in Figure 3.17.

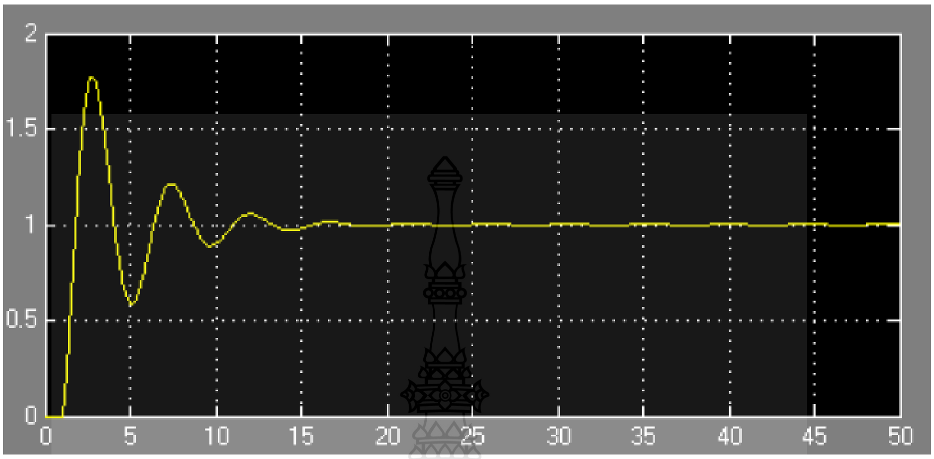


Figure 3.17 Ziegler Nichols tuning response

3.4 Hybrid Control Design

Fuzzy logic is a form of multivalued logic. In which the true value of a variable, for example, can be a real number between 0 and 1, both of which can be combined with various proportional computations by the given weighting. Used to deal with the concept of partial truth where the true value may be between total truth and total false. In contrast, in Boolean logic, a variable's truth can only be an integer 0 or 1.

Fuzzy logic refers data from observing how to make a decision on ambiguous and non-numeric data. A model of fuzzy set is a mathematical way of expressing ambiguity and ambiguous information. These models are capable of perceiving, displaying, manipulating, interpreting and applying ambiguity and uncertain that nowadays, fuzzy logic is exploited to solve the problem of granular and human decision-making by setting fuzzy rules like human decision-making.

Fuzzy Logic Control and PID control combined become hybrid theory control. The fuzzy-PID combined together to realize autonomous control system to be adjustment for tuning parameters PID parameter Kp,Ki,Kd by duty of proportion the Kp to accelerate rise time of the process to improve system. The duty of integral Ki to increase response process control and the duty of the differential coefficient Kd to prevent system noise and correct steady error.

Implementing the hybrid control theory is a combination of a fuzzy controller and a PID controller, showing the controller block of fuzzy-PID control to input between target and feedback errors for close-looping. An error ec error rated of a control loop for finding a volume of error was taken to fuzzy controller's variables the operation control of the DC motor so that it can be controlled. The tractor goes on a predetermined route. The control stage is for steering control. The aim of the research, the Hybrid Fuzzy PID control system is implemented for tractor steering. The PID control system parameters are tuned realtime to hybrid controller to change controls whether the PID parameter tuning is performed in the same time PID control time shown in Figure 3.18.

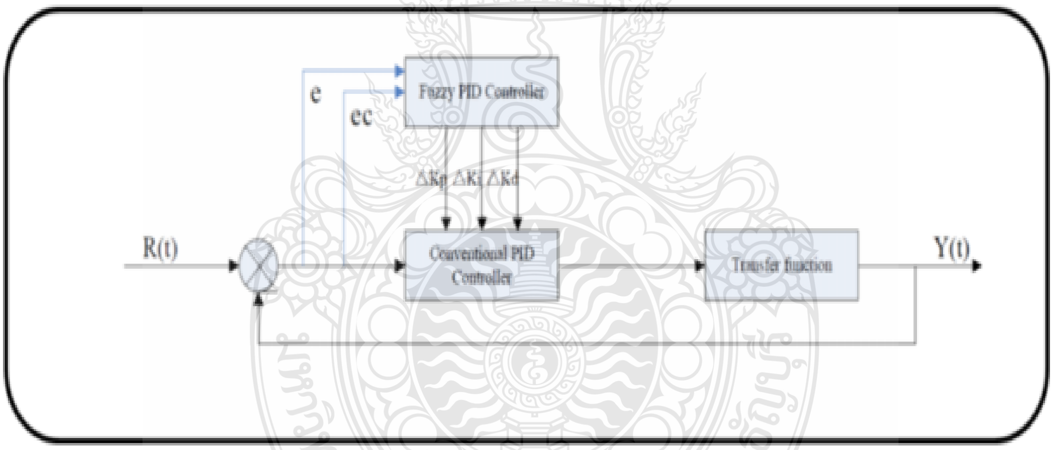


Figure 3.18 Hybrid controller Fuzzy PID Control System Block Diagram

Research Methodology was developed from Chapter 2 literature review to provide a practical and feasible approach for intelligent tractor steering with hybrid control using control theory PID and Fuzzy Logic to find the tuning value from manual adjustment before getting a control parameter design framework for PID and Fuzzy

Logic. This research can be a model for those interested in reviewing the advantages of development to be compatible with other machines.

CHAPTER 4
SIMULATION AND EXPERIMENT RESULTS

4.1 Tractor Structure and Specifications

The tractor's structure is depicted in Figure 4.1 including the engine, chassis, control system, and electronic equipment. The diesel engine (Kubota model RT 100) is 7.4 kW. The primary chassis comprises a gearbox, steering, drive, and braking system. DC motors, drivers, encoders, microcontrollers, and batteries are all examples of electronic equipment. The specifications of the tractor are presented in Table 4.1.

Table 4.1 Tractor Control Parameters

Function	Actuator	Voltage	RPM
Transmission	ZYTD80S-9F1-022-190404 DC MOTOR	24	2000
Brake	ZYTD80S-9F1-022-190404 DC MOTOR	24	2000
Steering	ZYTD80S-9F1-022-190404 DC MOTOR	24	2000

4.2 Chassis Design

The transmission is essential to the chassis, drive, steering, and braking systems (Figure 4.1). The chassis was constructed and modified to convert the tractor from a two-wheel hand tractor to a four-wheel tractor. It was equipped with a steering system to be ridden and controlled from the tractor's top. Additionally, improvements were made to allow for electrical control of the tractor using a series of actuators and microcontrollers. The chassis is critical in keeping the engine safe [41].

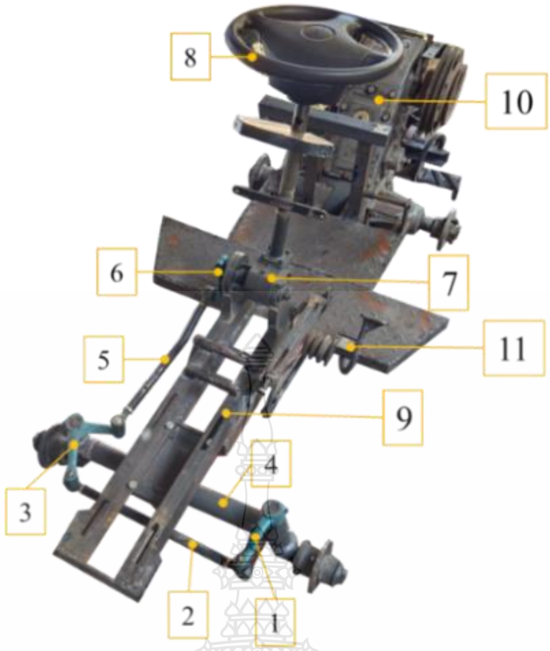


Figure 4.1 Chassis Components. (1) Knuckle arm; (2) Tie Rod; (3) Drag Link; (4) Front Axle; (5) Longitudinal Tie; (6) Pitman Arm; (7) Steering Gear; (8) Steering Wheel; (9) Main Chassis; (10) Wheel Gear Block; (11) Brake.

4.3 Transmission System

The transmission system ties the gearbox and rear axle together. This engine has only one forward gear and one neutral gear. The tractor's rear was modified by adding an actuator, gear, and chain to enable shifting from neutral to drive gear and vice versa. (See Figure 4.2). The gear ratio is identical, even though the actuator (DC motor) must be operated in the low-efficiency zone with high current and torque for an extended period [42].

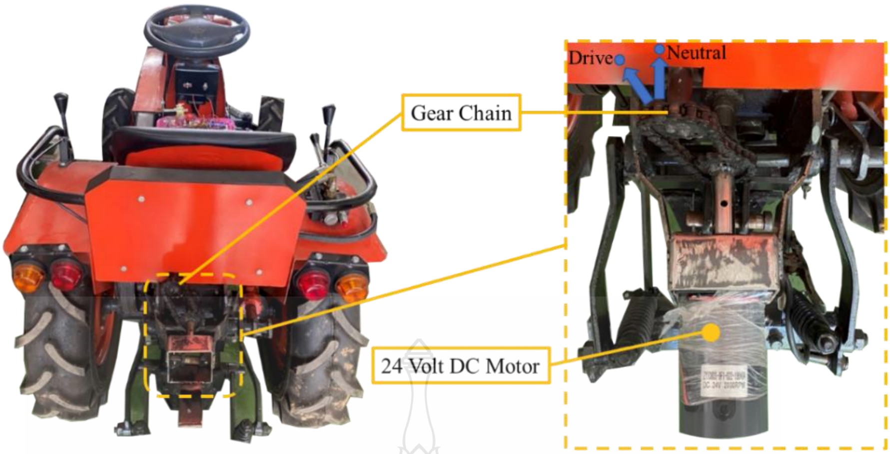


Figure 4.2 Transmission System

4.4 Drive System

The two-wheel tractor drive system was changed by connecting the base chassis, wheel gear block, and Kubota RT100 engine (Figure 4.3). A belt connects the wheel gear block to the engine. This study assumes the tractor speed is constantly based on the predetermined belt tension level. Testing costs are reduced by reusing outdated wheel gear blocks, which results in cheaper product prices and increased global competitiveness [43].

(a) (b)

Figure 4.3 Drive System. (a) Two-Wheel Tractor Gear Block Modification; (b) Kubota RT100 Engine

4.5 Steering System

As shown in Figure 4.4, by rotating the steering wheel, the gearbox converts the steering wheel’s rotational motion to a straight-line movement, allowing the tractor's front wheel to be moved obliquely right or left[44]. The fundamental design was modified with the addition of an automatic steering system. A combination of large and small gears allows the steering wheel to be moved automatically. At the same time, a switch is fitted on the drag link and knuckle arm to limit the angle of wheel movement (Figure 4.5).

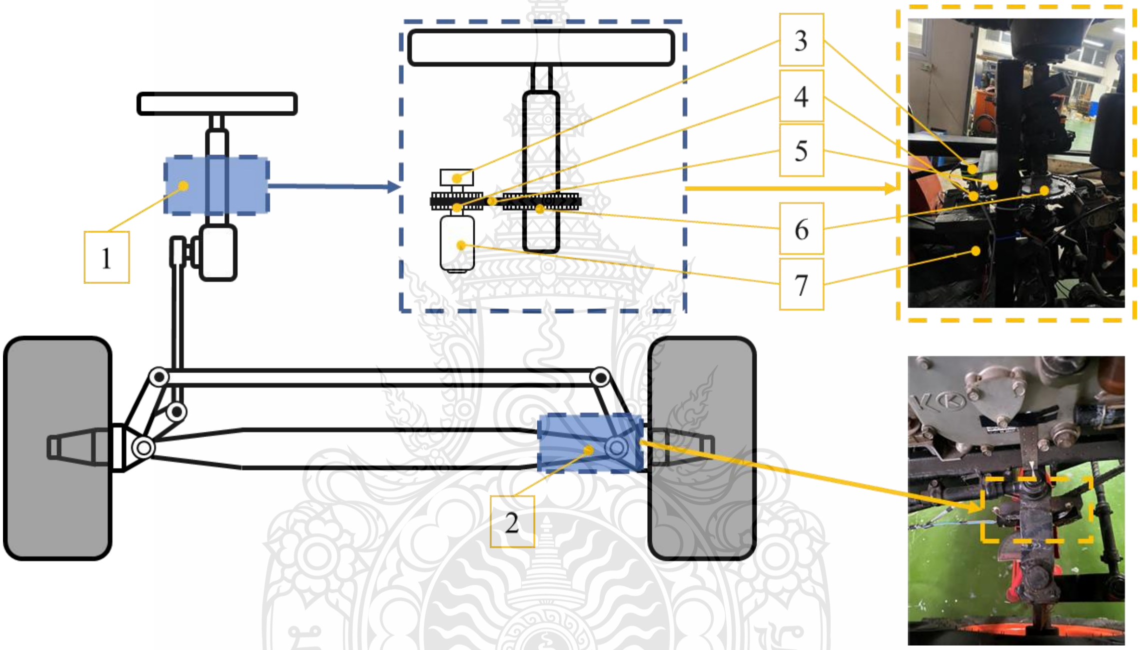


Figure 4.4 Steering System. (1) Actuator of the automatic steering system; (2) Front Wheel Limit Angle Switch; (3) Optical Rotary Encoder; (4) Actuator Gear; (5) Gear Chain; (6) Steering Axle Gear; (7) Actuator (DC Motor)

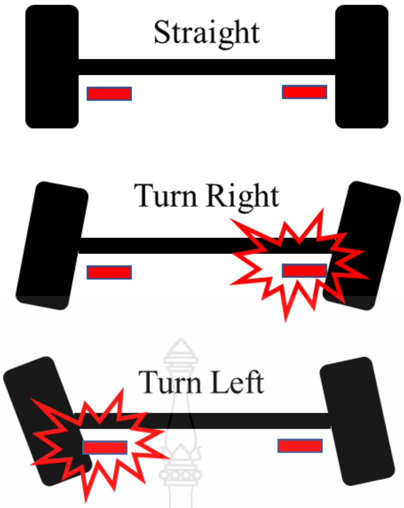


Figure 4.5 Limit Angle Switch Concept

4.6 Brake System

Although foot pedals actuate the manual braking system, changes have been made to allow the pedals to be controlled automatically, as shown in Figure 4.6. The top of the pedal is fitted with an actuator secured in place by the metal frame. The actuator is then connected via a shaft to the brake pedal pad. This design has both manual and automatic brakes for added safety. This system uses a rotary to linear motion concept[45].

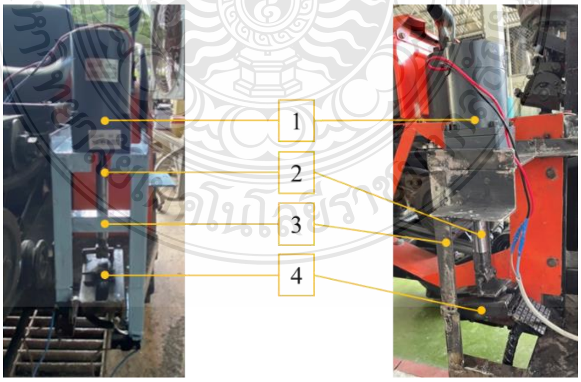


Figure 4.6 Brake System. (1) Actuator of the brake system; (2) Brake Shaft; (3) ActuatorHolder; (4) Brake Pedal Pad.

4.7 Control System

Compass sensor installed to the steering wheel at steel bar to feedback signal responding by heading direction steering control. By the installation of the compass sensor on the tractor body, it was found that the response to the movement to send a direction signal to the MCU to process the steering control to achieve the setpoint target, there is still a delay As a result, the control of the movement of the tractor does not follow the predetermined path.

The problem-solving compass sensor must be moved to an appropriate location. To be able to respond to the direction of movement according to the degrees acting towards the north. quickly in order to process commands to control the tractor's steering wheel can work quickly and respond to the movement very well where the proper position is installed on the steel bar shown in Figure 4.7

Figure 4. 7 Compass Sensor Installed on Right Steering Steel Bar

Figure 4.8 shown the electronic structure utilized to validate the mechanical and electronic functionality. The main control unit (MCU) is an Arduino Mega connected to several actuators in the form of a DC motor and sensors (rotary encoder and switch). The tractor is operated via a Radio Frequency (RF) Remote Control equipped with a TX-2B transmitter and an RX-2B receiver. This tractor is also embedded with a GPS tracker to record the tractor's movement. Table 4.2 summarizes the situation and the results of preliminary tests conducted before field testing. As a result of the table, it is possible to conclude that the complete system can operate by the specified parameters.

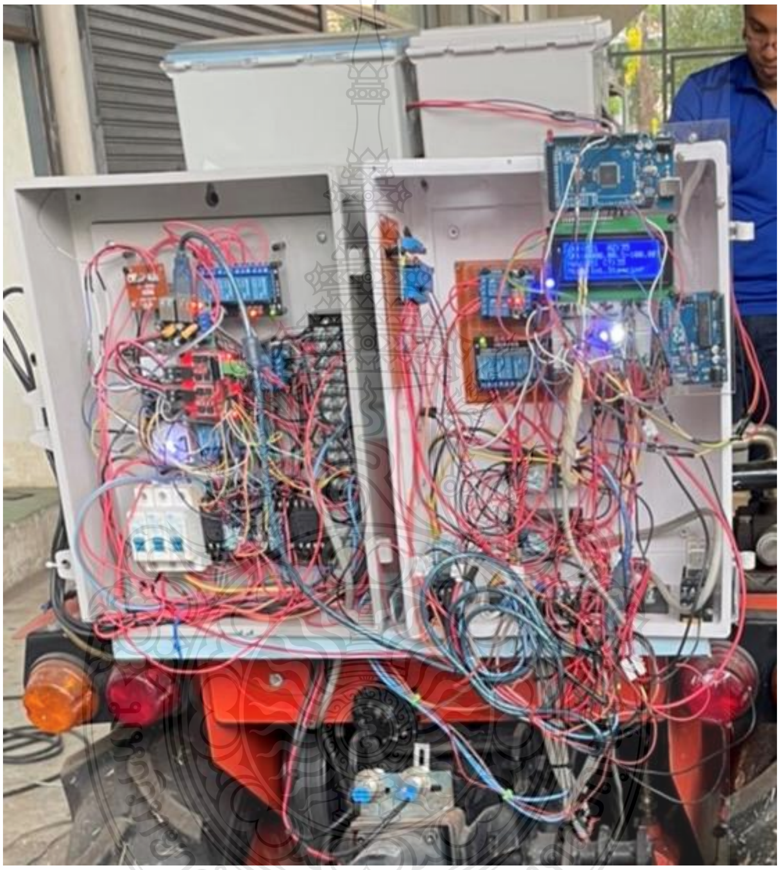


Figure 4. 8 Remote Control and GSP Tracker Component

Table 4.2 Testing Scenarios

Testing Scenario	**Target**	**Result**
RF Remote	The signal can be received	Success
Transmission	Switching from Drive and Neutral transmission (vice versa)	Success
Brake	Pressing and Loosen the Brake Pedal Pad	Success
Steering	Go Straight, Turn Right, and Turn Left	Success
	Encoder data reading	Success
	Limit angle switch (left and right)	Success

Steering control system component consists of the following control devices **:**

- Compass sensor
- Rotary optic encoder
- 24 VDC Motor
- 24 VDC Mortor PWM Drive
- LCD display
- MCU Arduino Mega 2560

The main device for controlling the steering wheel of an intelligent automatic tractor has a compass sensor that reports the movement direction of the tractor and sends the data to the MCU Arduino Mega 2560 for real-time processing with the Fuzzy Logic calculation process to find the control value. Real-time suitable Kp, Ki, Kd for PID control system to command the rotation of the 24 VDC motor by supplying 0-100% control voltage with a 0-5 Volt VDC signal through the 24 VDC Motor PWM Drive, which acts as an Actuator to control the automatic steering and various real-time operating parameters is programmed on the LCD Display.

Steering Control Hybrid Pid Fuzzy Logic for the automatic tractor with a hybrid control system using control theories has been adapted to working well together with Fuzzy Logic and PID control. The advantage of Fuzzy Logic is that it can analyze error data while PID control is operating in real-time. Normally, the important setting of the PID control system is using the proportional gain coefficient of the PID system with the parameter Kp Ki. The Kd is a customizable part of the control system only one form of a situation.

Fuzzy Logic workflow can be designed and tested in Matlab Simulink Software as well. which is widely used The process begins to design the quantity and type of Input. The error data from the PID control system is used to find the rate of change of the error to be 2 inputs error and differential error for quantitative consideration. The Fuzzy Logic computation starts from the quantitative separation of the 2 inputs as designed to be considered. Then, the value of such quantity was compared with the designed rule base. Then go into the process. Defuzzification calculates 3 output parameters, consisting of Kp, Ki, Kd, to be put back into the real-time PID control system. It can be seen that the PID system uses fuzzy logic for real-time tuning according to the real-time control situation shown in Figure 4.9

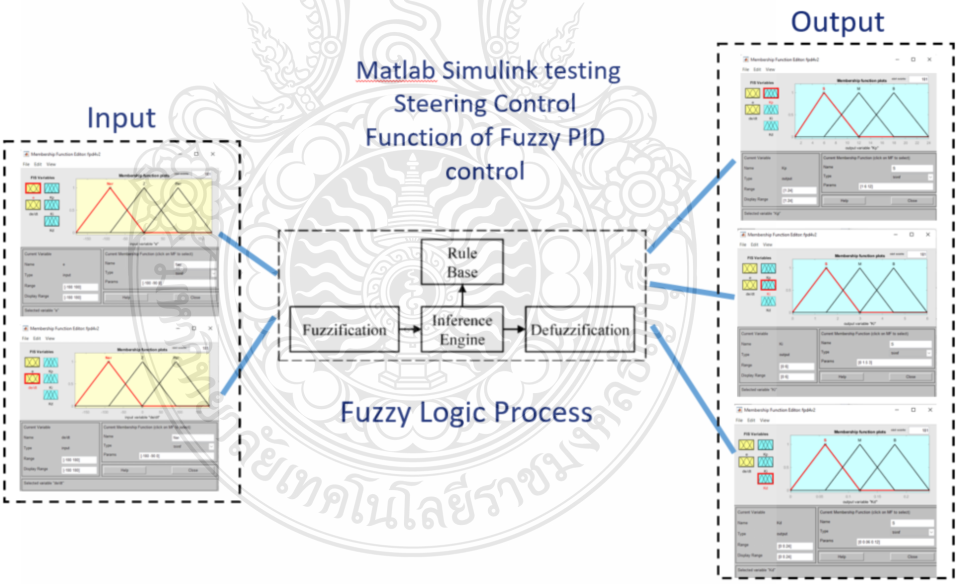


Figure 4.9 Fuzzy Logic Process Input and Output

Fuzzy Logic is therefore used to help optimize Kp Ki Kd as the control state changes. By analyzing the output error and rate of change of the error value, it will be used for mathematical processing in real time to send the appropriate PID control value according to the situation that has been programmed shown in Figure 4.10

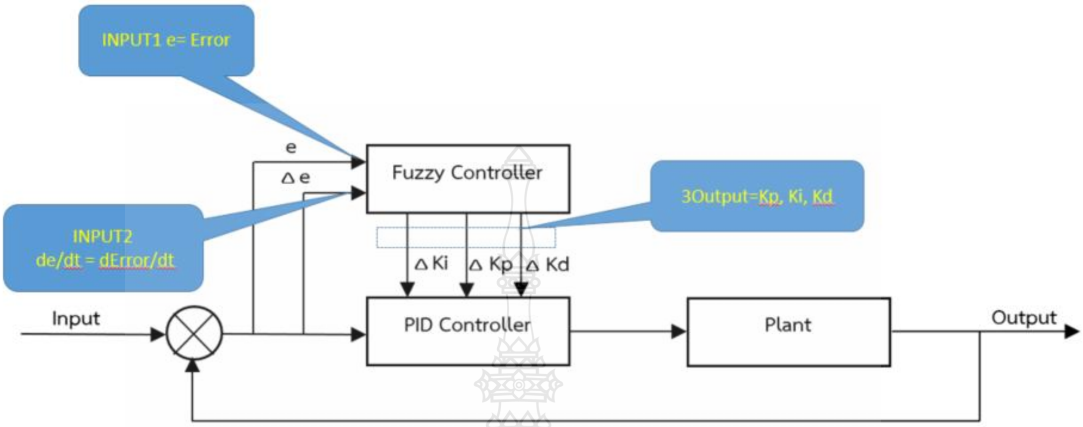


Figure 4.10 Steering Control Hybrid Fuzzy Logic PID

Hybrid Fuzzy PID control is a wise choice to control the steering of the tractor automatically by using the Compass Sensor as a navigation device. Because in the real situation Navigating tractors with GPS on rainy cloudy days makes it impossible to receive coordinates from satellites continuously, making it impossible to control the tractor moving properly.

In the situation that the tractor's movement on the runway has obstacles such as sloping areas, bumps, bumps, slippery, the Hybrid Fuzzy PID control system will automatically adjust the response of the steering wheel to suit such conditions.

4.8 Field Test

The Field Test is tested by manual control, the purpose is to ensure that the tractor's drive can actually be controlled according to the specified route. This test will use GPS to track the test results, location, time, and tractor speed calculation as designed.

The test route is for safety, so choose the route on level ground. Smooth tractor control To see the steering response from the installed DC Motor. Steering rate, turning circle, and battery power from all test data It will be used to write a program on MCU Arduino Mega to be able to work well according to the specified path.

Data recording is important, bringing the data to show how the tractor can be controlled to travel as planned in the preliminary test area by running around the loop shows that basic control in the form of straight lines and turns can be achieved by using Remote Control with RF signals. Recording values received from satellites of the GPS system by using a GPS sensor interfaced with an Arduino controller to receive GPS data will be displayed for consideration in preliminary testing in the field. Figure 4.11 GPS Recording Module shows the GPS Recording Path Testing by using software interface to GPS sensor and Figure 4.12 GPS Recording Module.

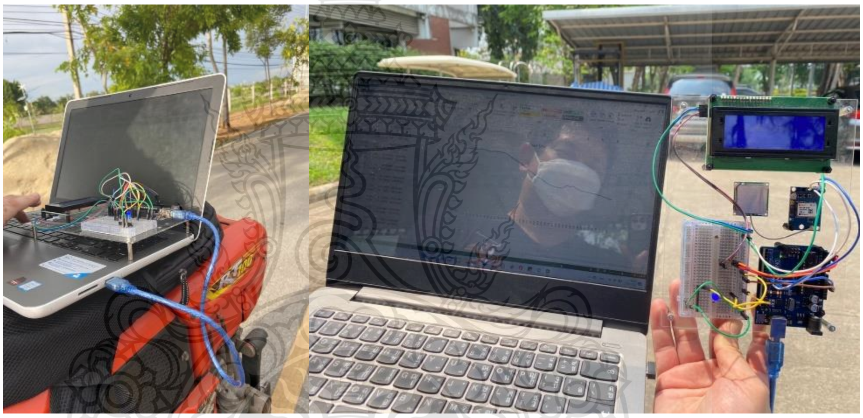


Figure 4.11 GPS Recording Path Testing

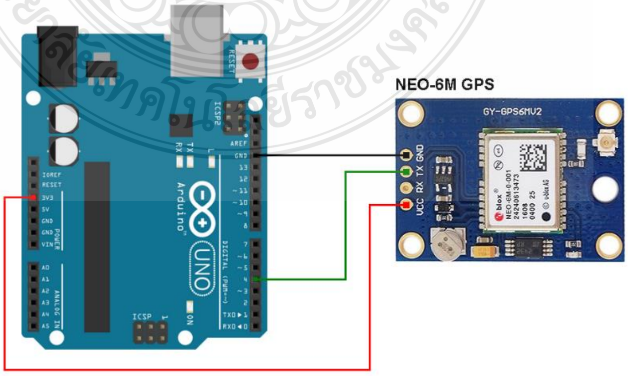
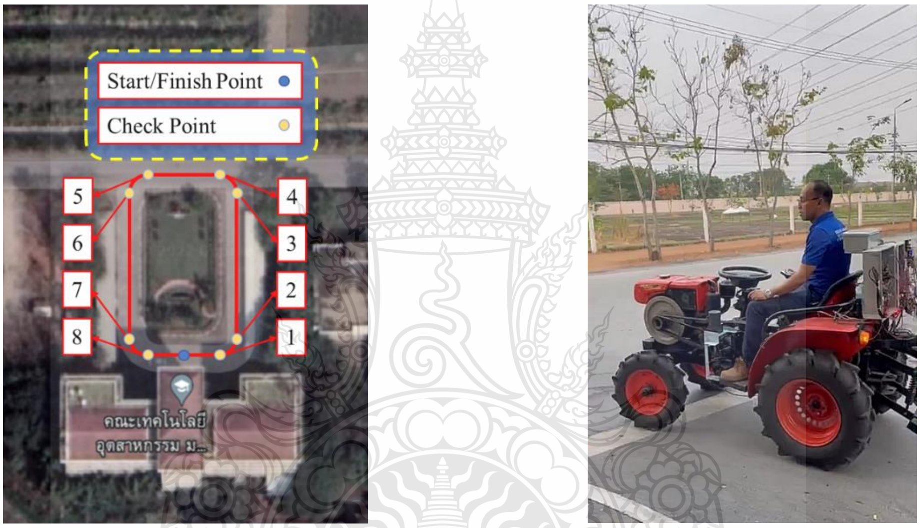


Figure 4.12 GPS Recording Module

This test was conducted in the vehicle park of the test area. The field test scenario entails using an RF remote to guide the tractor along a specified course. Figure 4.13(a) shown the path and checkpoints used to create the testing path. While Figure 4.13(b) depicts the field conditions during the test, it also shows the location of humans on the tractor in case the tractor becomes uncontrollable. The tractor controlled by a remote successfully gained nine points during this field test, as given in Table 4.3.



(a) (b)

Figure 4.13 Field Testing. (a) Scenario Path (b) Remote Tractor Test

Table 4. 3 Field Testing Scenarios

Path Testing Scenario	Latitude Target	Longitude Target	Result
Start Point	14.134200	100.6097498	Success
First Check Point	14.134200	100.6098358	Success
Second Check Point	14.134231	100.6098758	Success
Third Check Point	14.134574	100.610410	Success
Fourth Check Point	14.134605	100.610364	Success
Fifth Check Point	14.134605	100.610235	Success
Sixth Check Point	14.134605	100.610181	Success
Seventh Check Point	14.134231	100.610186	Success
Eight Check Point	14.134200	100.610234	Success

4.9 Hybrid Fuzzy PID for Inteligent Tractor

This research presents intelligent tractor focus on automouse steering using hybrid controller. The hybrid Fuzzy- PID controller characterizes the manual steering motion of the tractor. Although the fuzzy logic calculating the parameters tuning for PID controller. The Fuzzy logic mechanisms are rule-based, thus fuzzy rule-based optimization. The simulation tests have shown the operation tracking the target feedback and output control to reduce overshoot of output. The control system operation applied to a rear-wheel drive tractor. The tests have shown how the intelligent tractor steering works in autonomous driving mode systems.

Hybrid Fuzzy PID applied to tractors Mobile steering can be complicated involves combining many control communicaltion protocol [7, 31, 46]. The key of the tractor steering control is to be an autonomous driving tractor steering to tracking on the direction route to reach a planed destination [47] by using an automouse steering. It is necessary to have a controller which is an important role for controlling the tractor to move to right destination. Steering control reliability become main control for intelligent tractor because multiple target parameters are set to automatically drive the tractor and follow a set path. [47, 48]. In recent years, many research for intelligent tractor have become to the automouse tractor and commonly used the method of hybrid control is PID and Fuzzy Logic because controlled by PID the result satisfied stability but some drawbacks are not on accurate well which is solving the problem to combine the fuzzy logic with the PID controller real-time tuning by incorporating hybrid control system.

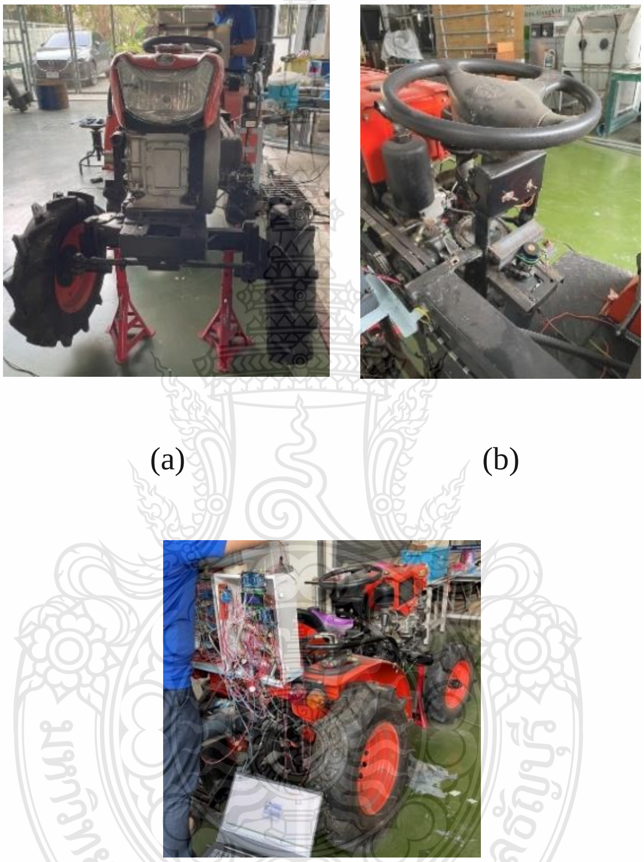
Over the past few decades, many studies on autonomous vehicles have used fuzzy logic control [49]. One well-known fuzzy ability is the handling of zero-to-one invalid data in heuristic rules according to a theory based on fuzzy logic with nonlinear control functions[50]. The best of the researcher's knowledge, there hasn't been any study that focuses on the tractor shown in Figure 4.9 explicitly. This tractor was created by altering a two-wheeled hand tractor and giving it four wheels. In this research Applying the Fuzzy-PID control theory to control the steering of the tractor based on the theory of the Ackerman Tractor Model, the researcher designed a hybrid controller composed of 2 inputs error e and differential de and 3 outputs of PID tuning tuning values. The error of in the hybrid control Fuzzy-PID system then the Fuzzy Controller will adjust the parameters real-time for PID Controller.

The first test by using matlab Simulink software that the results of the hybrid controller satisfied to be stable movements to reach at the target means achieve a given steering angle control goal and The next test the tractor steering can be tracking on provided path with good accuracy to reach the target destination.

Path-planning-based control for Ackerman's theoretical guidance robots the Fuzzy-PID hybrid controllers is the right choice for the application due to its quickly responding and working with output accuracy result. The test by matlab Simulink software results were satified by the test resualt.

4.10 Tractor Setup

The Ackermann theory for applied to the tractor's steering can be pareameters to input as an mathematic model block to simulate as a tractor's type and property. A tractor with a control system based on Ackermann's theory was used in this research that the design of the tractor has 4 wheels by divided into 2 wheels front controlled by steering and two wheels rear driven by tractor engine. There is an Ackerman type of steering, a type of tractor chassis as shown Figure 4.14 (a) (b) (c) shows the tractor used in this study.



(a) (b)

(c)

Figure 4.14 Front and side view of the fourwheeled tractor with front steering.

(a) Front View. (b) Steering. (c) Controller Box.

4.11 Four-Wheel Tractor Model with Front Steering

The theory applied for tractor autonomous steering system used the Kinematic mathematic model for a 2 wheels tractor commonly known as an bicycle. The 4 wheels based tractor where the steering controlled for 2 front wheels with the manual transmissions (Figure 4.15).

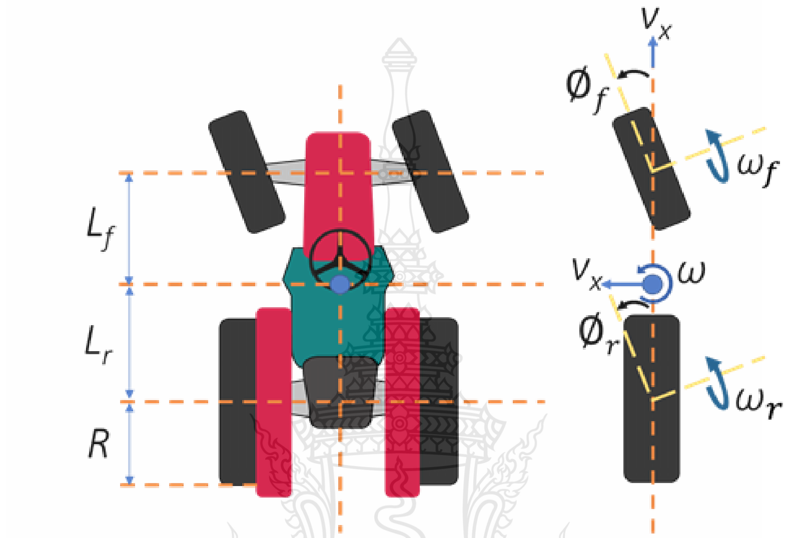


Figure 4.15 Model of the four-wheeled tractor with front steering

4.12 Tractor Kinematic Model

There are many input mathematic model for default parameters that the main parameters kind of the Ackermann Kinematic Model and the vehicle's speed of the limitation angle of steering for the tractor movement. The limit of the vehicle speed lower side can be defined between negative to upper limit as infinity. Thus the tractor movement speed is actual range limited by setting the steering angle to pi/4 to provide the maximum of turning radius.

The configulation to setup for matlab Simulink used inputs parameters for wheels speeds (rad/s) into [$\omega_f; \omega_r$] as shown in Equation 4.4 and wheels angles (rad) into[$\phi_f;\ \phi_r$] in Equation 4.5. The matlab Simulink parameters is inputting in m/s v_X and

v_y (Equations 4.1 and 4.22), and ω in rad/s (Equation 4.3) and the typical formular of of the Ackermann Kinematic Model [43, 49, 51, 52].

$$v_X = \frac{R}{2} . \left(\omega_f \cos\phi_f + \omega_r \cos\phi_r \right) \tag{4.1}$$

$$v_Y = \frac{R}{2} . \left(\omega_f \sin\phi_f + \omega_r \sin\phi_r \right) \tag{4.2}$$

$$\omega = \frac{R}{(L_f + L_r)} . (\omega_f \sin\phi_f - \omega_r \sin\phi_r) \tag{4.3}$$

The tractor's inverse kinetic model is expressed in the following formula with the tractor steering conditions. The inverse kinetic model used for the rear wheels only driving by engine and inputs to kinematics are v_X ,ω [49].

$$\omega_f = \frac{v_X}{R \cos\phi_f} , \qquad \omega_r = \frac{v_X}{R} \tag{4.4}$$

$$\phi_f = \operatorname{atan}\left(\frac{\omega\left(L_f + L_r\right)}{v_X} \right) , \phi_r = 0 \tag{4.5}$$

4.13 Electrical and Mechanical Designing

The steering system in the tractor test was equipped with a sensor for measurements by using an angle counting sensor couple to the tractor steering. Gennerally used an encoder because it is easy to buy online, inexpensive, and delivered throughout Thailand. This type of encoder has the advantage of designing a steering wheel of an autonomous tractor using a compass for navigation. The module consists of tractor steering hybrid fuzzy PID controller and installed DC motor coupling to tractor steering Figure 4.16 shown the application for steering control is shown in Figure 4.17.

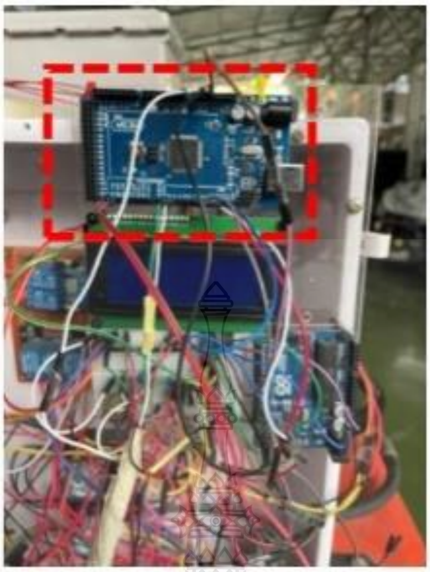


Figure 4.16 Wiring Diagram Implementation

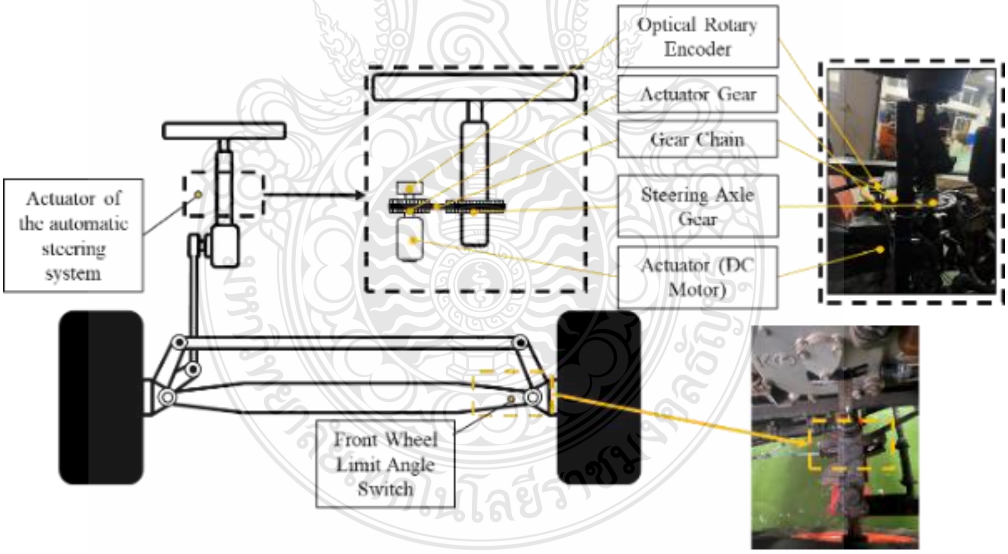


Figure 4.17 Mechanical Design for Tractor Steering Control

4.14 Design the Fuzzy PID controller

A block diagram of a PID-based fuzzy control system using an Arduino Mega 2560 for Fuzzy-PID controller, The block diagram and the system between target and feedback error composed of the difference between the change in the time interval. The output parameters for PID are used to control tractor steering DC drive motor to meet the setpoint in the track [53–57]. The target of this test is to apply the Hybrid theory control applied for a tractor steering with The PID tuning parameters adjusted by Fuzzy Logic output during running the operation of controller using a compass censor converted into degree of azimuth to be the setpoint/target value. Figure 4.18 shown the transfer function block of fuzzy-PID controlled system.

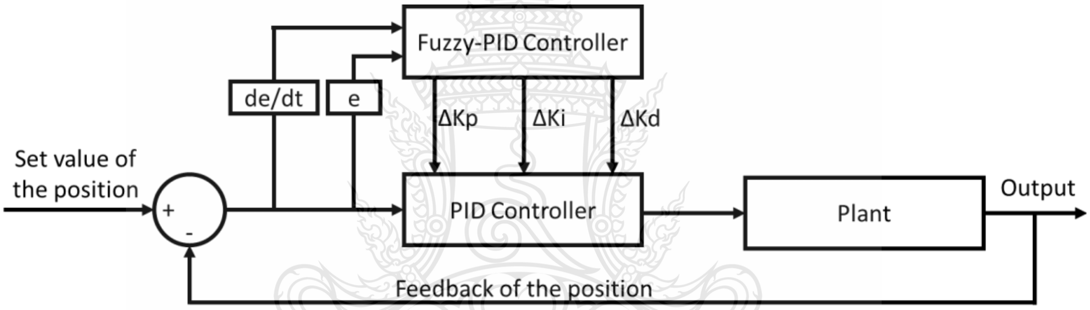


Figure 4.18 The Fuzzy-PID controller of Tractor

Developing a fuzzy controller to send a suitable input value to the PID controller by the compass sensor as The output tracks according to the set target value. Fuzzy logic is a widely used theory for motor control and automation [27, 58–60].

In the Fuzzy Logic Fuzzification control, It is the initial step that changes the value of each input and output in the membership function. Fuzzy assumptions are also carried out to include fuzzy facts. According to the rules required for fuzzy reasoning and the rules based on defined input and output variables. Fuzzy assumptions have various uses depending on the form of the membership function. The last part is defuzzification This section is intended to change the subset of results computed by inference tools.

Mamdani's fuzzy inference [37–40]. Figure 4.19 shown the structure of hybrid controller consisting of 2 types of error obtained from calculation by the feedback error (e) and rated error (de/dt) so the design of membership function applied to the fuzzification function block to calculate with output parameters (e) and (de/dt) membership and function characteristic form as three triangular shape consisting of positive error (Per) Negative error (Ner) and Zero and error (Z) shown as Figure 4.20.

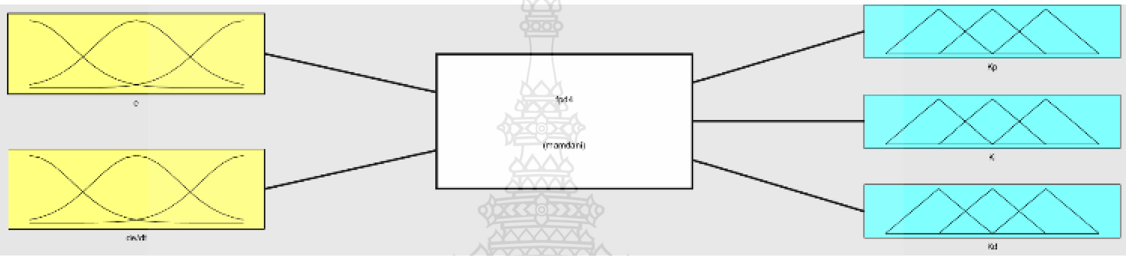


Figure 4.19 Structure of fuzzy controller

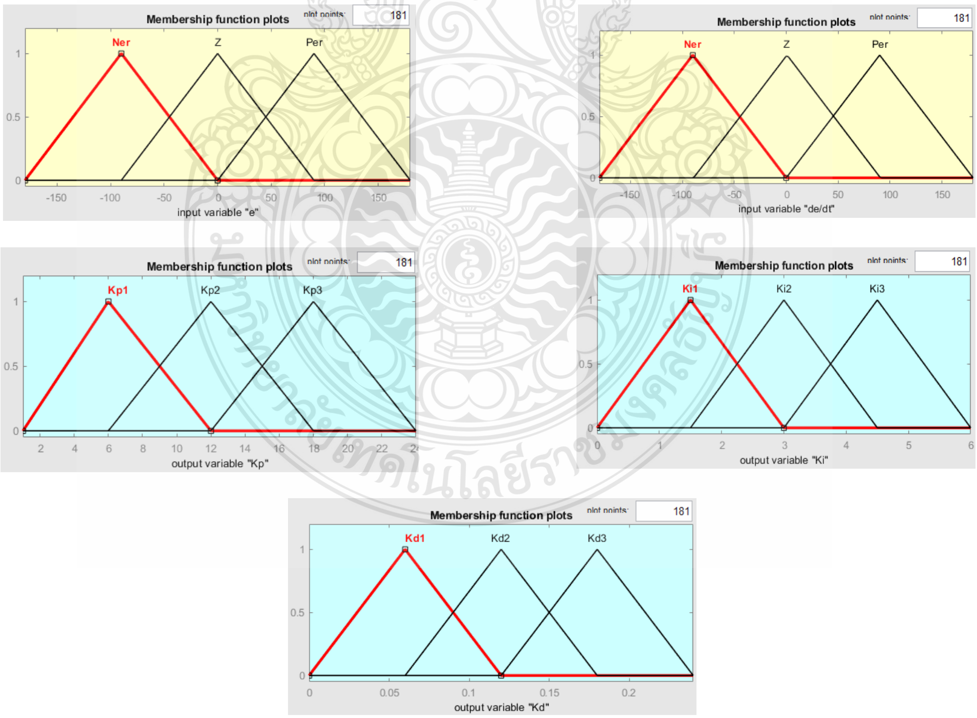
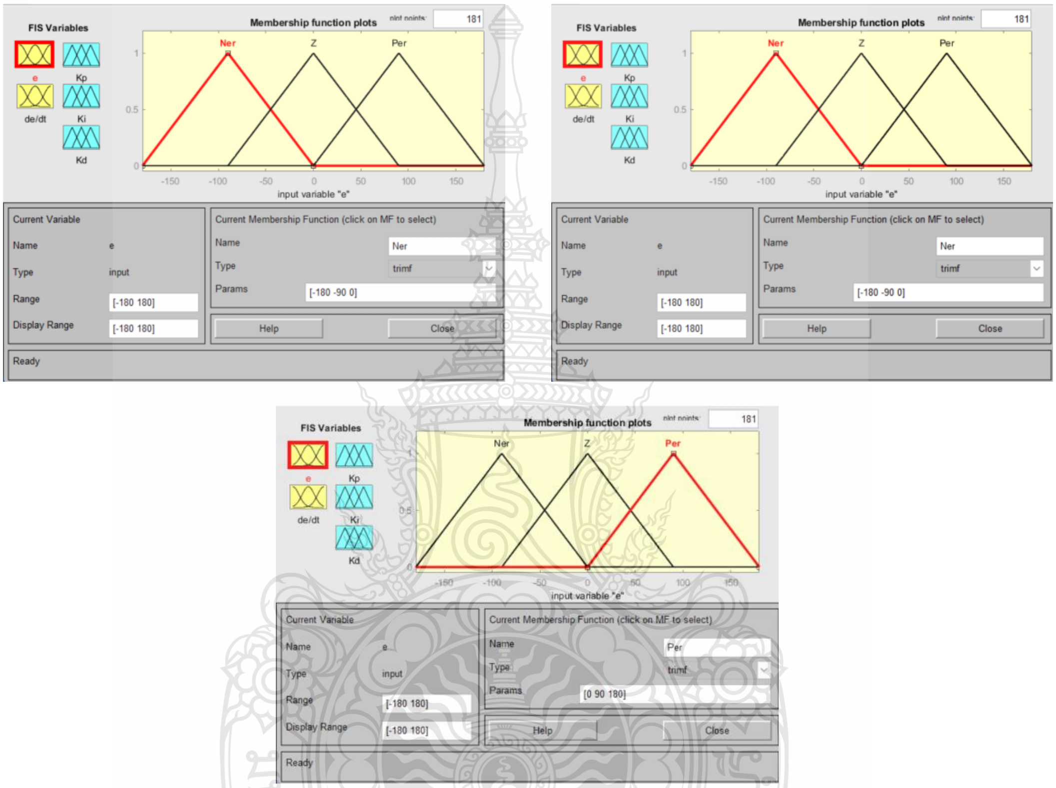


Figure 4.20 Membership function of input and output

The Fuzzy Logic Error Input design is divided into three parts to define the amount of input error the boundary value of the error from -180 to 180 degrees of the three azimuth ranges is divided as follows: Negative Error (Ner) -180 to 0 degrees Zero Error (Z) -90 to 90 degrees, and Positive Error (Per) 0 to 180 degrees. The membership function of Error Input as shown in Figure 4.21



plot points: 181

Current Variable
Name: e
Type: input
Range: [-180 180]
Display Range: [-180 180]

Current Membership Function (click on MF to select)
Name: Ner
Type: trimf
Params: [-180 -90 0]

Ready

plot points: 181

Current Variable
Name: e
Type: input
Range: [-180 180]
Display Range: [-180 180]

Current Membership Function (click on MF to select)
Name: Ner
Type: trimf
Params: [-180 -90 0]

Ready

plot points: 181

Current Variable
Name: e
Type: input
Range: [-180 180]
Display Range: [-180 180]

Current Membership Function (click on MF to select)
Name: Per
Type: trimf
Params: [0 90 180]

Ready

Figure 4.21 Fuzzy Logic Error Input Design

The Fuzzy Logic Differential Error Input is divided into three parts to define the amount of input error the boundary value of the error from -180 to 180 degrees of the three azimuth ranges is divided as follows: Negative Error (Ner) -180 to 0 degrees Zero Error (Z) -90 to 90 degrees, and Positive Error (Per) 0 to 180 degrees. The membership function of Differential Error Input as shown in Figure 4.22

Current Variable
Name de/dt
Type input
Range [-180 180]
Display Range [-180 180]

Current Membership Function (click on MF to select)
Name Ner
Type trimf
Params [-180 -90 0]

Selected variable "de/dt"

Current Variable
Name de/dt
Type input
Range [-180 180]
Display Range [-180 180]

Current Membership Function (click on MF to select)
Name Z
Type trimf
Params [-90 0 90]

Changing parameter for MF 2 to [-90 0 90]

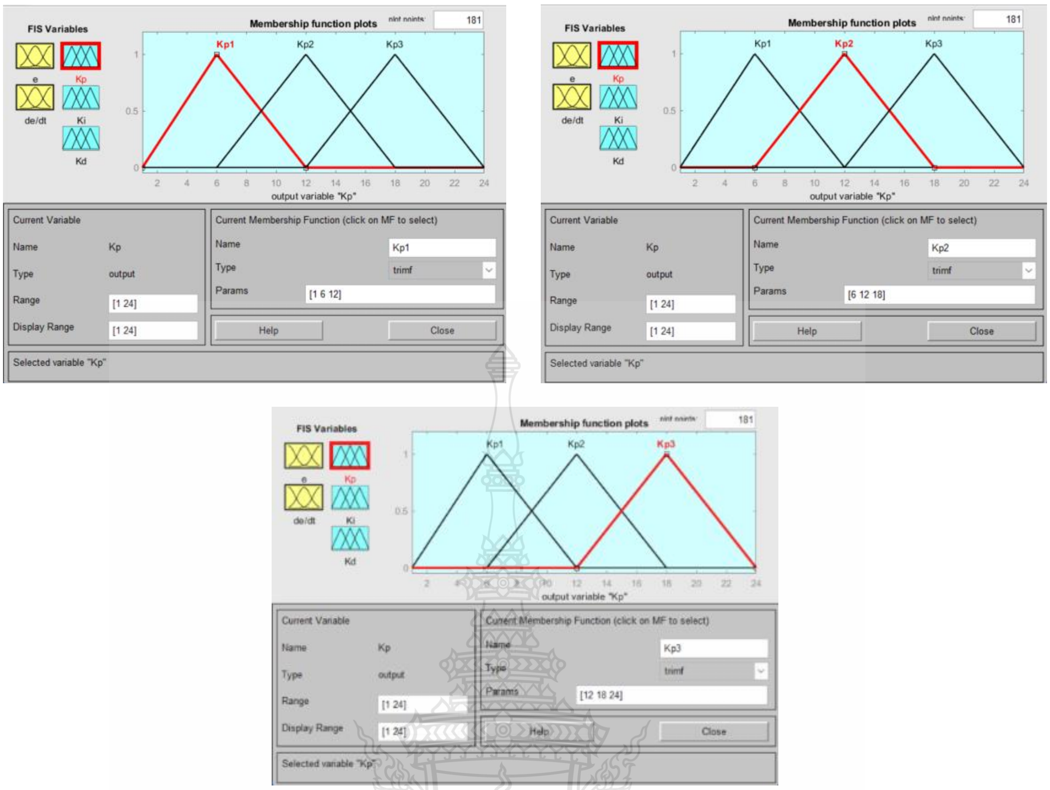
Current Variable
Name de/dt
Type input
Range [-180 180]
Display Range [-180 180]

Current Membership Function (click on MF to select)
Name Per
Type trimf
Params [0 90 180]

Changing parameter for MF 2 to [-90 0 90]

Figure 4.22 Fuzzy Logic Differential Error Input Design

The Fuzzy Logic Output for Kp is divided into three parts to define the amount of output the boundary value of the error from 1 to 24 values of the three Kp coefficient ranges is divided as follows: Kp1: 1 to 12, Kp2: 6 to 18, Kp3 12 to 24. The membership function of Output for Kp as shown in Figure 4.23



Current Variable
Name Kp
Type output
Range [1 24]
Display Range [1 24]

Current Membership Function (click on MF to select)
Name Kp1
Type trimf
Params [1 6 12]

Selected variable "Kp"

Current Variable
Name Kp
Type output
Range [1 24]
Display Range [1 24]

Current Membership Function (click on MF to select)
Name Kp2
Type trimf
Params [6 12 18]

Selected variable "Kp"

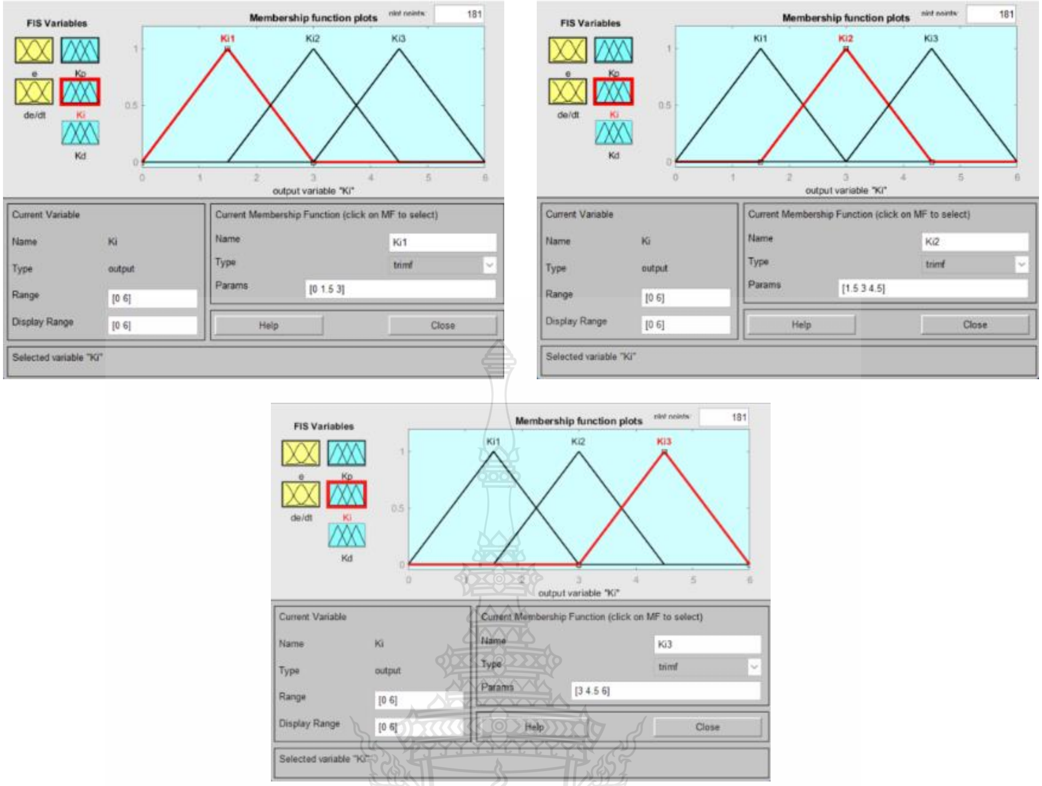
Current Variable
Name Kp
Type output
Range [1 24]
Display Range [1 24]

Current Membership Function (click on MF to select)
Name Kp3
Type trimf
Params [12 18 24]

Selected variable "Kp"

Figure 4.23 Fuzzy Logic Output for Kp Design

The Fuzzy Logic Output for Ki is divided into three parts to define the amount of output the boundary value of the error from 0 to 6 values of the three Ki coefficient ranges is divided as follows: Ki1: 1 to 3, Ki2: 1.5 to 4.5, Ki3 3 to 6. The membership function of Output for Ki as shown in Figure 4.23



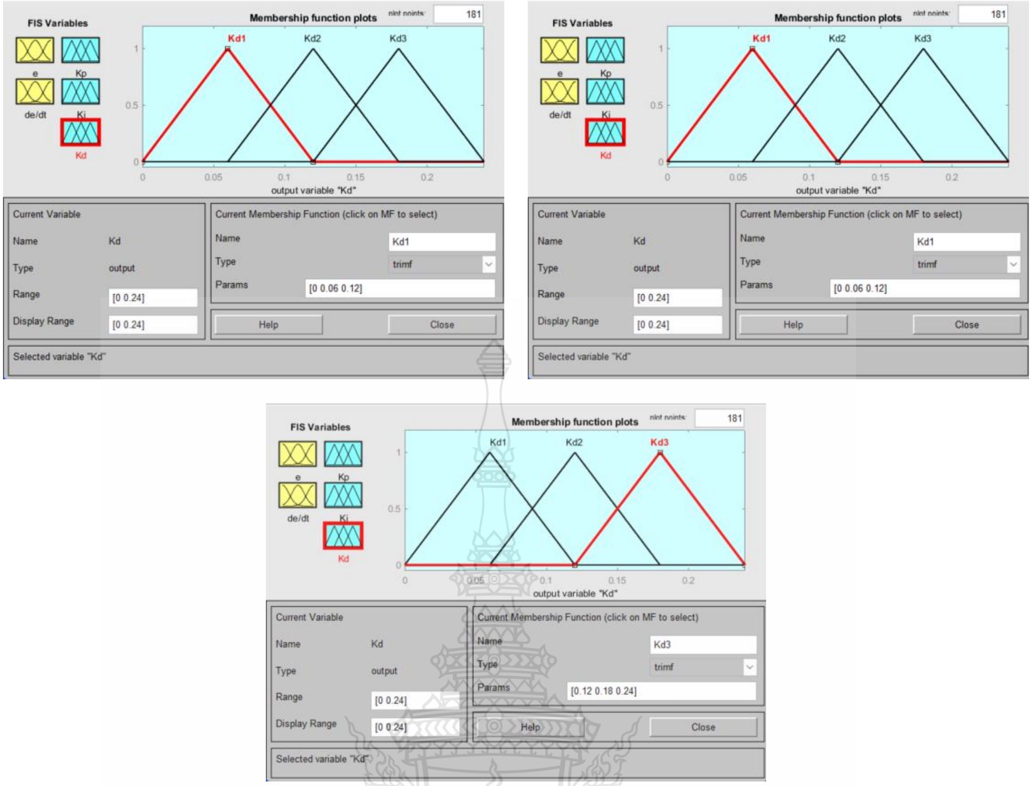
Name Ki
Type output
Range [0 6]
Display Range [0 6]
plot points: 181
Name Ki1
Type trimf
Params [0 1.5 3]
Selected variable "Ki"

Name Ki
Type output
Range [0 6]
Display Range [0 6]
plot points: 181
Name Ki2
Type trimf
Params [1.5 3 4.5]
Selected variable "Ki"

Name Ki
Type output
Range [0 6]
Display Range [0 6]
plot points: 181
Name Ki3
Type trimf
Params [3 4.5 6]
Selected variable "Ki"

Figure 4.24 Fuzzy Logic Output for Ki Design

The Fuzzy Logic Output for Kd is divided into three parts to define the amount of output the boundary value of the error from 0 to 0.24 values of the three Kd coefficient ranges is divided as follows: Kd1: 0 to 0.12, Ki2: 0.06 to 0.12, Ki3 0.12 to 0.24. The membership function of Output for Kd as shown in Figure 4.25



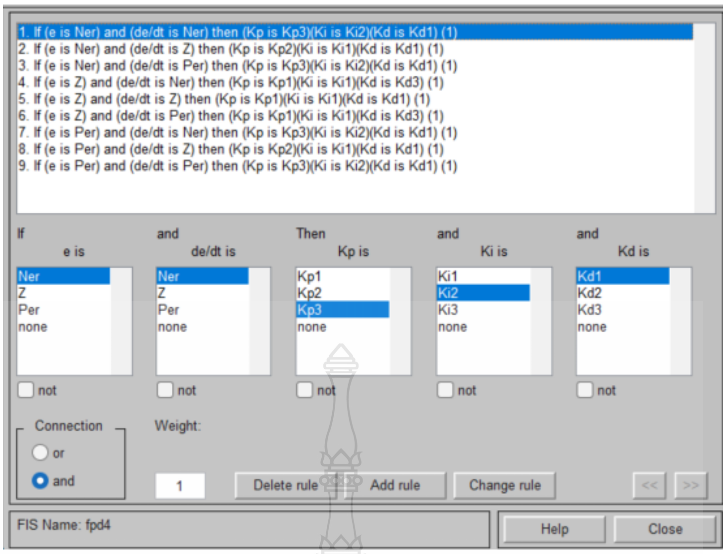
Name Kd
Type output
Range [0 0.24]
Display Range [0 0.24]
Name Kd1
Type trimf
Params [0 0.06 0.12]
Selected variable "Kd"

Name Kd
Type output
Range [0 0.24]
Display Range [0 0.24]
Name Kd1
Type trimf
Params [0 0.06 0.12]
Selected variable "Kd"

Name Kd
Type output
Range [0 0.24]
Display Range [0 0.24]
Name Kd3
Type trimf
Params [0.12 0.18 0.24]
Selected variable "Kd"

Figure 4.25 Fuzzy Logic Output for Kd Design

As the experimental by hand tuning of Kp, Ki, and Kd in Chapter 3 that was found when the error and differential error were high. There was a high demand for Kp and Ki for fast response to the setpoint but when approaching the setpoint, stability was required. Therefore, slightly increasing the value of Kd can reduce the steady error better than tuning only the PID. The principle was applied to the fuzzy logic to configure the fuzzy rule to send control values Kp, Ki, and Kd to respond to the system in real-time resulting in better results than only the PID tuning as shown in Figure 4.26.



```
1. If (e is Ner) and (de/dt is Ner) then (Kp is Kp3)(Ki is Ki2)(Kd is Kd1) (1)
2. If (e is Ner) and (de/dt is Z) then (Kp is Kp2)(Ki is Ki1)(Kd is Kd1) (1)
3. If (e is Ner) and (de/dt is Per) then (Kp is Kp3)(Ki is Ki2)(Kd is Kd1) (1)
4. If (e is Z) and (de/dt is Ner) then (Kp is Kp1)(Ki is Ki1)(Kd is Kd3) (1)
5. If (e is Z) and (de/dt is Z) then (Kp is Kp1)(Ki is Ki1)(Kd is Kd1) (1)
6. If (e is Z) and (de/dt is Per) then (Kp is Kp1)(Ki is Ki1)(Kd is Kd3) (1)
7. If (e is Per) and (de/dt is Ner) then (Kp is Kp3)(Ki is Ki2)(Kd is Kd1) (1)
8. If (e is Per) and (de/dt is Z) then (Kp is Kp2)(Ki is Ki1)(Kd is Kd1) (1)
9. If (e is Per) and (de/dt is Per) then (Kp is Kp3)(Ki is Ki2)(Kd is Kd1) (1)
```

Connection: and

Weight: 1

FIS Name: fpd4

Figure 4.26 Fuzzy Logic Output Rule Design

After completing the Input, Output, and Fuzzy Rules test the simulated value by entering Input with the value of error and differential error in ascending order to verify the correctness before the PID-Fuzzy Logic programming into the Arduino Mega Microcontroller. The test results during the error and differential error become 0, it can be seen that the PID tuning during the steady state period is appropriate according to the calculation from Fuzzy Logic as shown in Figure 4.27.

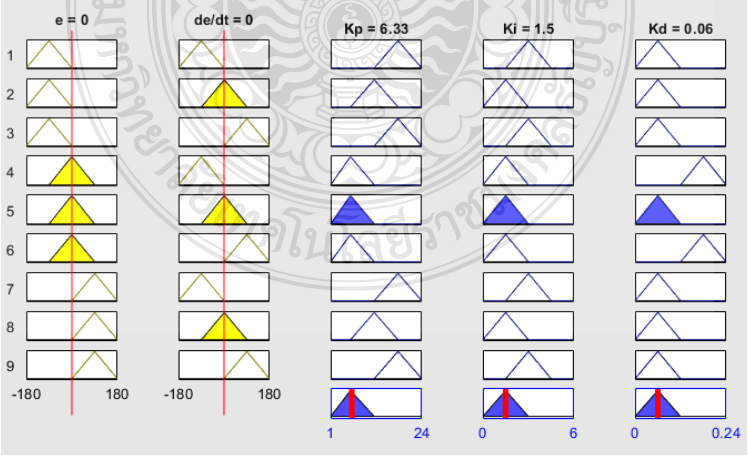


Figure 4.27 Fuzzy Logic Output Rule Test

The fuzzy logic control is designed to receive input from the tractor's steering system which is the degree of steering angular movement from azimuth sensor depending on actual conditions. Accordingly, the fuzzy rule was determined after performing a detailed procedure of the membership function in Figure 4.28. The fuzzy rule was used in this experiment.

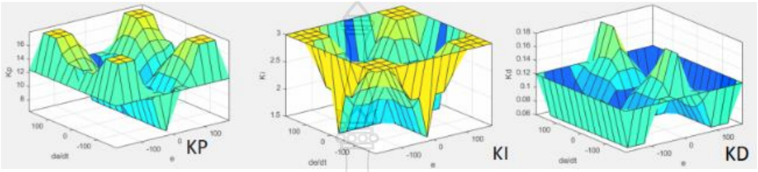


Figure 4.28 The Fuzzy rules for Kp/Ki/Kd

The simulation was conducted to obtain the motion to determine the optimal control of the tractor using a hybrid Fuzzy-PID controller prior to field trials. The assuming to do the first test with the input value specified as 45°. In the second scenario, The researcher uses the reference point concept [61–63], shown in Figure 4.29.

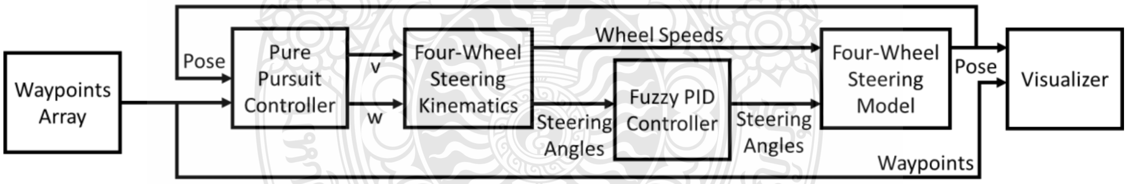


Figure 4.29 The Pure Pursuit Fuzzy-PID controller for Tractor Waypoint Simulation

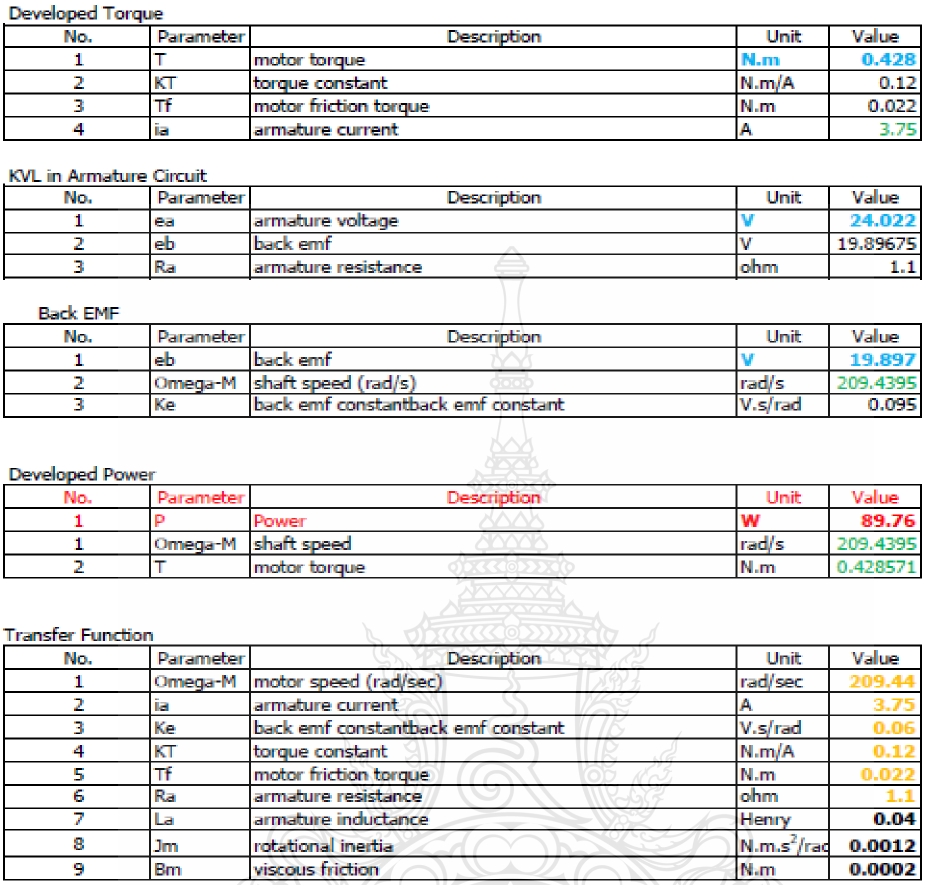
4.15 Simulation

Simulation of the steering control system in Matlab Simulink from reference to Equation 3.1 in Chapter 3 can be able to find various parameters of the Motor from the calculation by using the value from the Name Plate of the Motor to be calculated shown in Figure 4. 30, 4.31 and Table 4.4.

Figure 4.30 Motor 24 VDC Series

Figure 4.31 Steering Motor Drive System

Table 4.4 VDC Motor Parameter Calculation



Developed Torque

No.	Parameter	Description	Unit	Value
1	T	motor torque	N.m	0.428
2	KT	torque constant	N.m/A	0.12
3	Tf	motor friction torque	N.m	0.022
4	ia	armature current	A	3.75

KVL in Armature Circuit

No.	Parameter	Description	Unit	Value
1	ea	armature voltage	V	24.022
2	eb	back emf	V	19.89675
3	Ra	armature resistance	ohm	1.1

Back EMF

No.	Parameter	Description	Unit	Value
1	eb	back emf	V	19.897
2	Omega-M	shaft speed (rad/s)	rad/s	209.4395
3	Ke	back emf constantback emf constant	V.s/rad	0.095

Developed Power

No.	Parameter	Description	Unit	Value
1	P	Power	W	89.76
1	Omega-M	shaft speed	rad/s	209.4395
2	T	motor torque	N.m	0.428571

Transfer Function

No.	Parameter	Description	Unit	Value
1	Omega-M	motor speed (rad/sec)	rad/sec	209.44
2	ia	armature current	A	3.75
3	Ke	back emf constantback emf constant	V.s/rad	0.06
4	KT	torque constant	N.m/A	0.12
5	Tf	motor friction torque	N.m	0.022
6	Ra	armature resistance	ohm	1.1
7	La	armature inductance	Henry	0.04
8	Jm	rotational inertia	N.m.s^2/rad	0.0012
9	Bm	viscous friction	N.m	0.0002

The motor parameters derived from the calculation, This makes it possible to simulate experiments in Matlab Simulink by bringing the above parameters into the transfer function, which is an important part of simulating the control system with Fuzzy logic PID in order to get experimental values before being tested in the field to know in advance that this system can be used according to the designed.

Simulation of the generated motion and control design is implemented in Simulink. The design uses a series of block diagrams. The parameters are shown in Table 4.4. This data is calculated from the DCmotor nameplate data. The simulation system diagram for the first test is applied to determine the result output of hybrid controlled system and mapping between the mathermetic model and the steering model input of the tractor in the function block. The DC motor's transfer function applied is shown in Equation 4.6 and Equation 4.7.

$$G_{dcmotor}(s) = \frac{0.12}{0.04s + 1.1} \tag{4.6}$$

$$G_{motoroutput}(s) = \frac{1}{0.0012s + 0.0002} \tag{4.7}$$

Testing control system by using PID directly output to control the tractor steering without Fuzzy Logic system controller as following in Matlab Simulink shows in Figure 4. 32

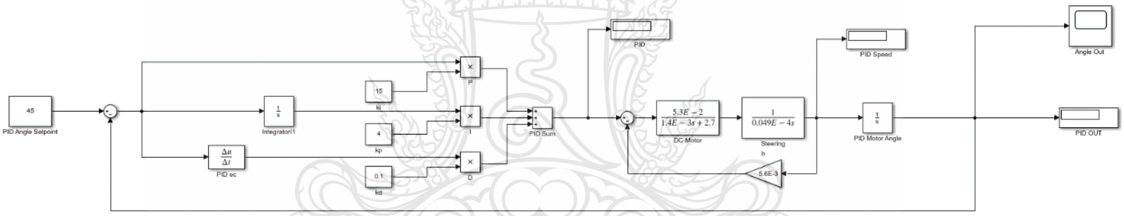
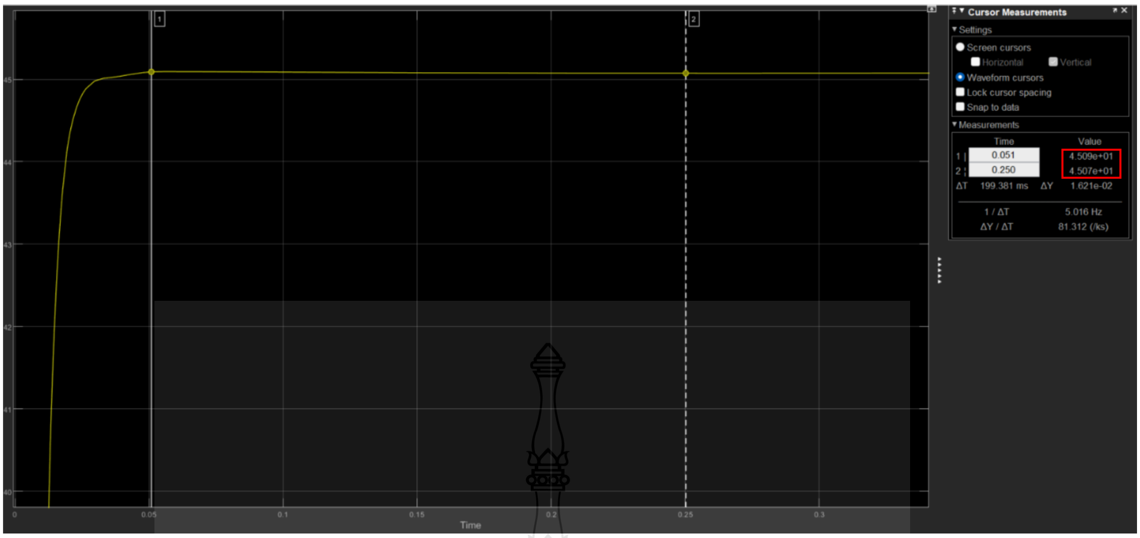


Figure 4.32 PID Controller for The Tractor Steering Control

The result of the control system by using PID directly at the setpoint 45 RAD output to control the tractor steering without Fuzzy Logic controller system as following in Matlab Simulink shows in Figure 4.33 . The control responding graph can be reached the setpoint quickly and achieved the target at 45 RAD with a little bit of steady-state error remaining.



Cursor Measurements

Settings

○ Screen cursors

☐ Horizontal ☑ Vertical

● Waveform cursors

☐ Lock cursor spacing

☐ Snap to data

Measurements

	Time		Value
1	0.051		4.509e+01
2	0.250		4.507e+01
ΔT	199.381 ms	ΔY	1.621e-02

1 / ΔT 5.016 Hz

ΔY / ΔT 81.312 (/ks)

Figure 4.33 Fuzzy at Setpoint 45 RAD

Testing control system by using Fuzzy Logic directly output to control the tractor steering without PID system as following in Matlab Simulink shows in Figure 4. 34

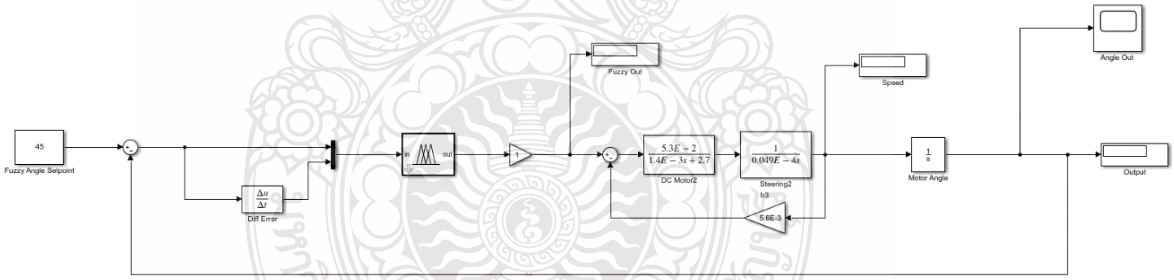
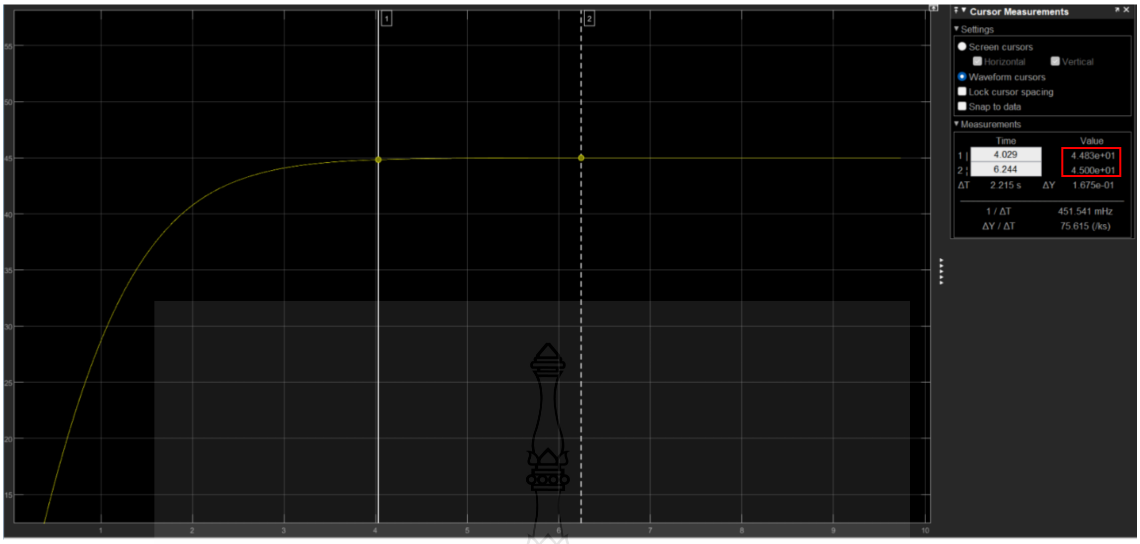


Figure 4.34 Fuzzy Logic Controller for The Tractor Steering Control

The result of the control system by using Fuzzy Logic directly at the setpoint 45 RAD output to control the tractor steering without PID system as following in Matlab Simulink shows in Figure 4.35 . The control responding graph can be reached the setpoint and achieved slower than PID responding to the target at 45 RAD with no steady-state error.



○ Screen cursors
☑ Horizontal ☑ Vertical
● Waveform cursors
☐ Lock cursor spacing
☐ Snap to data

Measurements

	Time	Value
1	4.029	4.483e+01
2	6.244	4.500e+01

ΔT 2.215 s ΔY 1.675e-01

1 / ΔT 451.541 mHz
ΔY / ΔT 75.615 (/ks)

Figure 4.35 Fuzzy at Setpoint 45 RAD

After experimenting with the fuzzy logic and PID control system together with the tractor steering model, the results show that the advantages of the two systems are different. While fuzzy logic control systems are more accurate. PID control system But PID control system can respond faster to control at Setpoint 45 RAD.

Experiments in Matlab Simulink initially simulate the response system. of the steering wheel of the tractor to compare between Fuzzy PID control system with the PID control shown in Figure 4.36

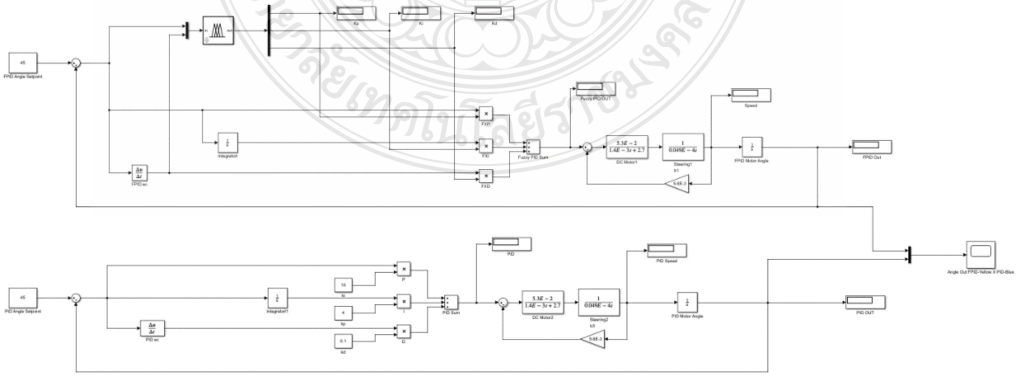
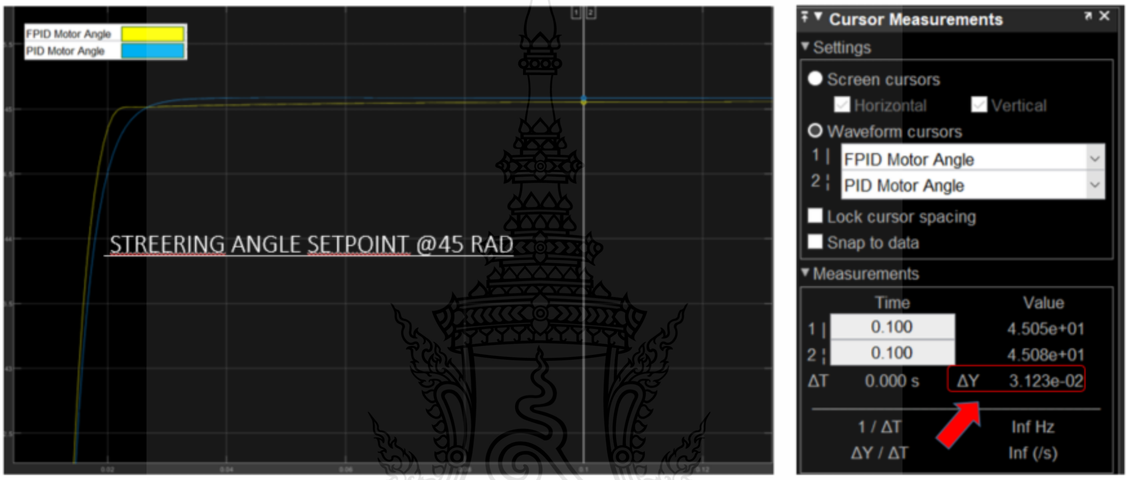


Figure 4.36 Fuzzy Logic PID vs PID Controller

Result of the fuzzy PID and PID-only control it can be seen that the Kp Ki Kd of the PID-only system has been customized to give the best possible system response. But compared to the fuzzy PID system designed to improve the PID system by changing the adjustment values in real-time, the experimental results fuzzy PID control system has better control response in terms of speed and steady-state accuracy in all three pattern at Setpoint 45, 90, 135 RAD shown in Figure 4. 37, Figure 4.38, Figure 4.39



Settings
● Screen cursors
☑ Horizontal ☑ Vertical
○ Waveform cursors
1 FPID Motor Angle
2 PID Motor Angle
☐ Lock cursor spacing
☐ Snap to data

Measurements

	Time		Value
1	0.100		4.505e+01
2	0.100		4.508e+01
ΔT	0.000 s	ΔY	3.123e-02
	1 / ΔT		Inf Hz
	ΔY / ΔT		Inf (/s)

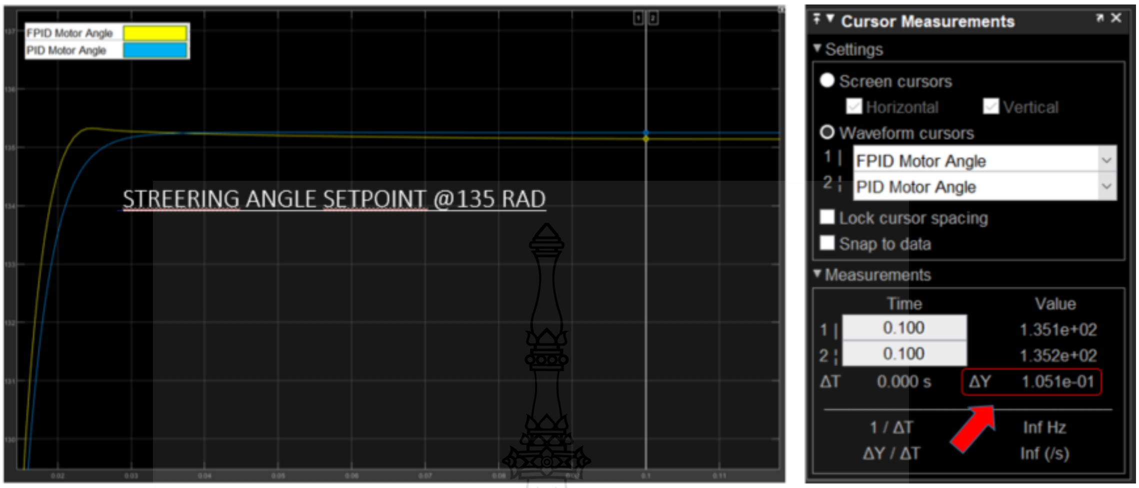
Figure 4.37 Fuzzy+Pid vs Pid Controller at Setpoint 45 RAD

Settings
● Screen cursors
☑ Horizontal ☑ Vertical
○ Waveform cursors
1 FPID Motor Angle
2 PID Motor Angle
☐ Lock cursor spacing
☐ Snap to data

Measurements

	Time		Value
1	0.100		9.009e+01
2	0.100		9.017e+01
ΔT	0.000 s	ΔY	7.149e-02
	1 / ΔT		Inf Hz
	ΔY / ΔT		Inf (/s)

Figure 4.38 Fuzzy+Pid vs Pid Controller at Setpoint 90 RAD



Cursor Measurements

▾ Settings

● Screen cursors

☑ Horizontal ☑ Vertical

○ Waveform cursors

1 FPID Motor Angle

2 PID Motor Angle

☐ Lock cursor spacing

☐ Snap to data

▾ Measurements

	Time	Value
1	0.100	1.351e+02
2	0.100	1.352e+02
ΔT	0.000 s	ΔY 1.051e-01
1 / ΔT		Inf Hz
ΔY / ΔT		Inf (/s)

Figure 4.39 Fuzzy+Pid vs Pid Controller at Setpoint 135 RAD

In Figure 4.40 shows the tractor body measurement for inputing in the simulation of matlab simmulink. Tractor body dimention measuring for simulation such as wheel base, wheel angle following The Ackermann Kinematic Model also steering wheel motor dirve gear ratio to input in the part of motor output related to the motor speed and wheel angle speed directly.

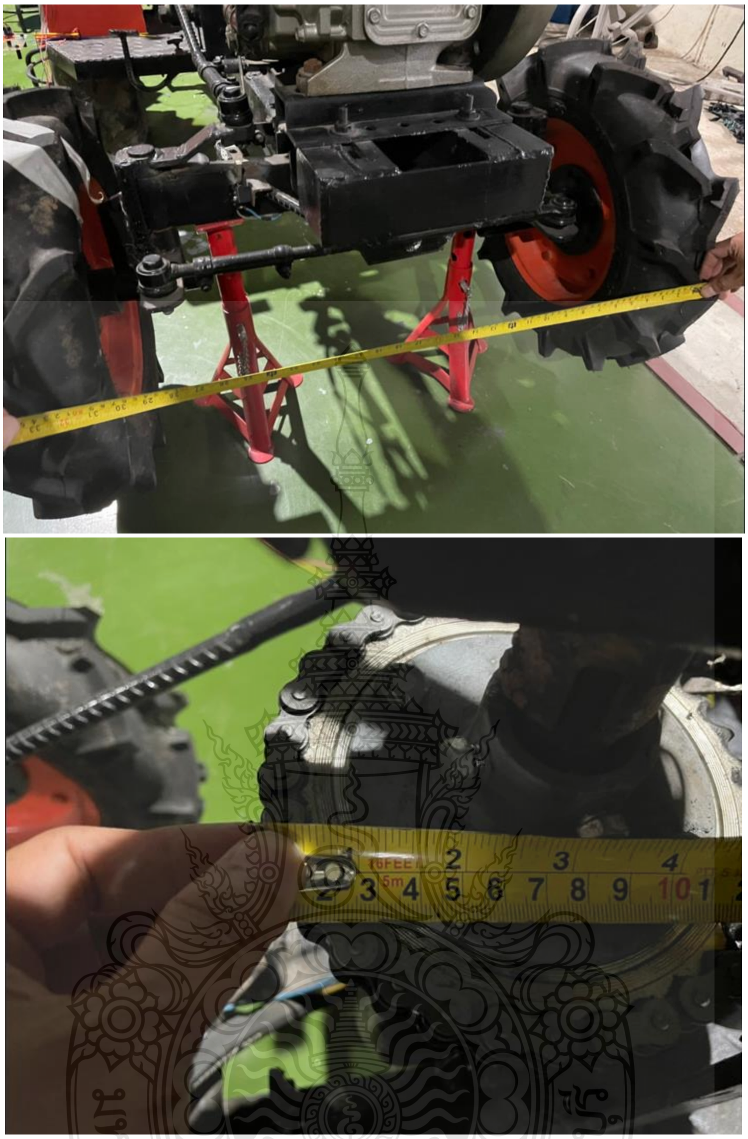


Figure 4.40 Tractor Measurement for Simulation

The result of the movement creating a circle with a steering angle of 45° is shown in Figure 4.41 as a targeting point. The graph shows an increment time of 0.068 seconds which is the fastest time to reach the setpoint. The test operation reached time was 0.12 second and setting time of 8 second with a tractor before being used in field trials. The test experimental with second scenario by planning a chase-control pathway of the tracking system.

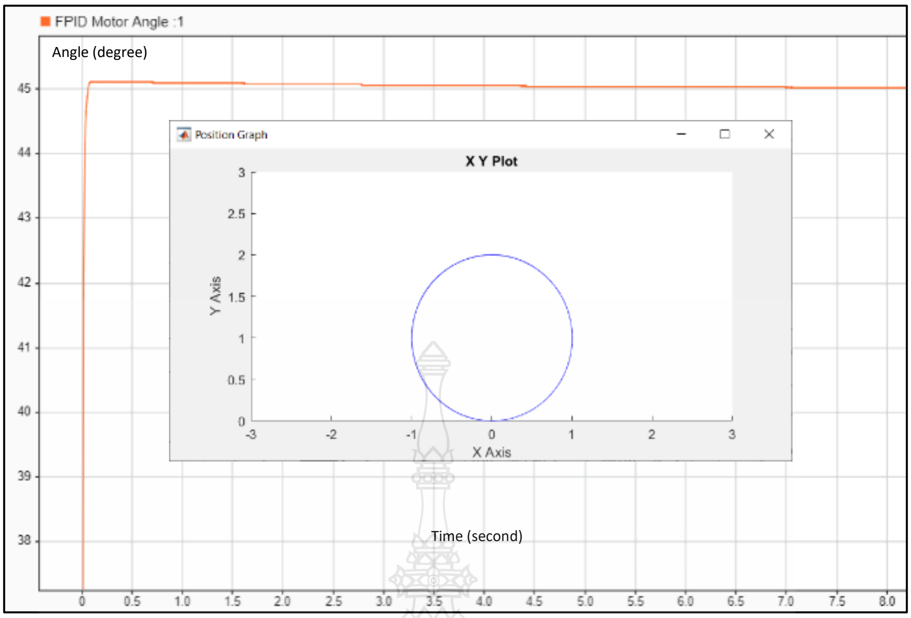


Figure 4.41 First simulation scenario result

From Figure 4.42, the actual chase control is second testto be obtained for testing performance of hybrid controller control system along the pahtway point. Represents the input position and reference point by inputing package pahtwat coordinates format expression [x y : xn1,yn1;……;xn,yn] as defined in the block diagram. The output of the the tractor speed and steering control are used for inputting to the kinematic model which is related to the hybrid controller to control tractor steering. The tractor movement recorded direction and position of the tractor control output in the form of linear and angular velocities will become inputs for the inverse movement block of the four steering wheels shown in Figure 4.43.

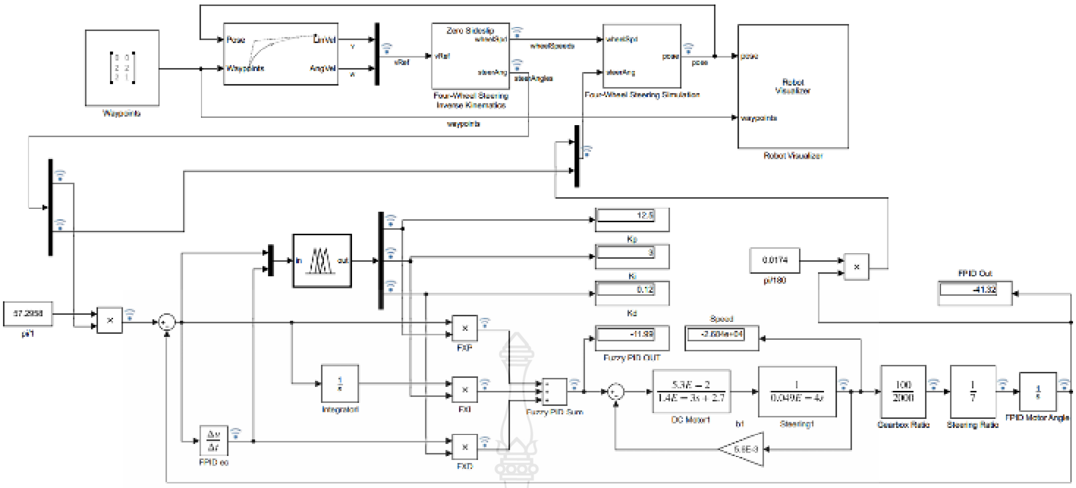


Figure 4.42 Simulink block diagram of pure pursuit and fuzzy pid waypoint simulation

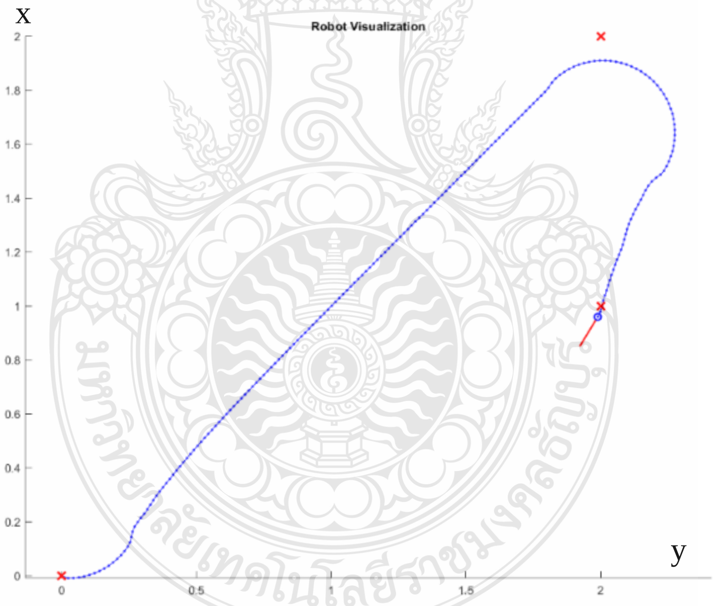


Figure 4.43 Tractor waypoint simulation visualization

Tractor movement direction negative way side is left turning and the positive is right turning. Figure 4.44 shows how the steering controller works to control the tractor direction and position on the pahtway.

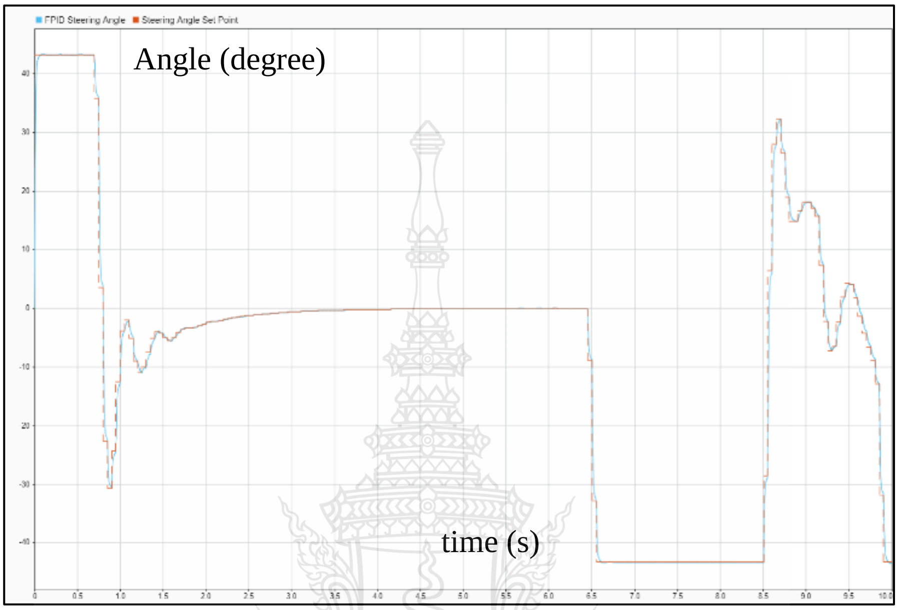


Figure 4.44 Graph for Fuzzy PID and Set Point Comparison

4.16 Experiment

Furthermore, to validate the simulation results, the tractor controlled by steering to control direction and position on tracing process is initiated from the default mode, i.e. PID tuning paramenters with not any nebulous to turn the wheel moved at zero position then reached up to limit sensor detected to restart steering wheel counting angle sensor to sense position signal to main controller to drive DC motor controlled fornt wheels to the middle position then changed mode into navigation mode to respect input with compass sensor and parameters of Kp2, Ki2, and Kd2 are determined by the control unit as shown in Figure 4.45.

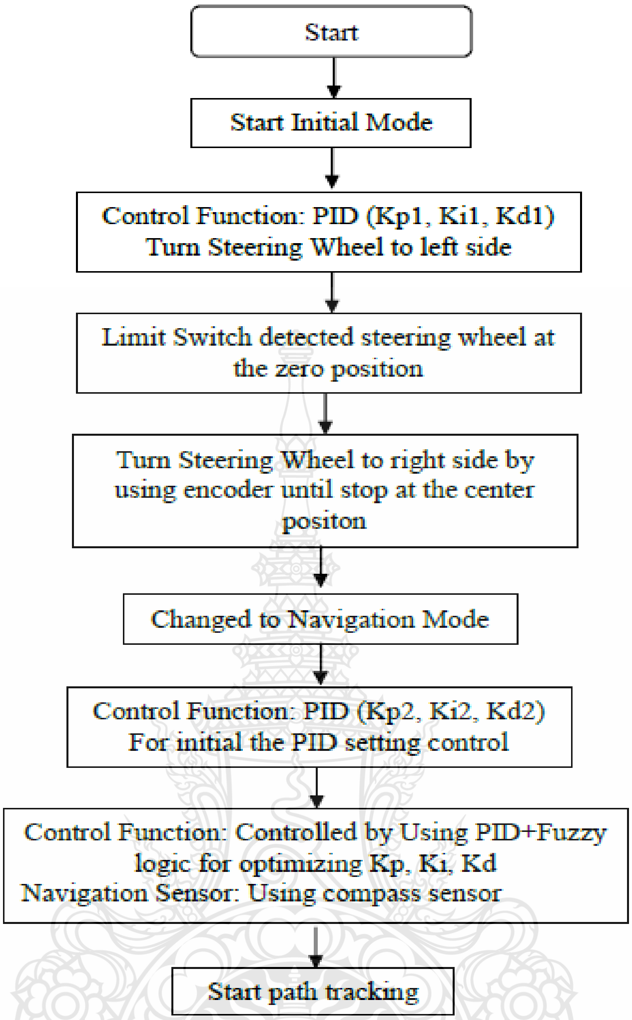


Figure 4.45 Field Trial Experimental Scenario

Before testing the movement of the tractor with a test speed of about 5-10 kilometers per hour for readiness. Therefore tested the navigator function from the compass sensor at 360 degrees of azimuth which is angled to the north. The test results of the steering wheel can respond to the operation according to the control procedures in both the initial Mode and Navigation Mode very well. This test is different from the actual test in the field because the front wheel of the tractor is not actually weighted and does not use the test speed as shown in Figure 4.46.

The results of the test in the workshop will confirm the operation of the operation according to the instructions set to control the tractor steering wheel programmed in the MCU Arduino Mega 2560.

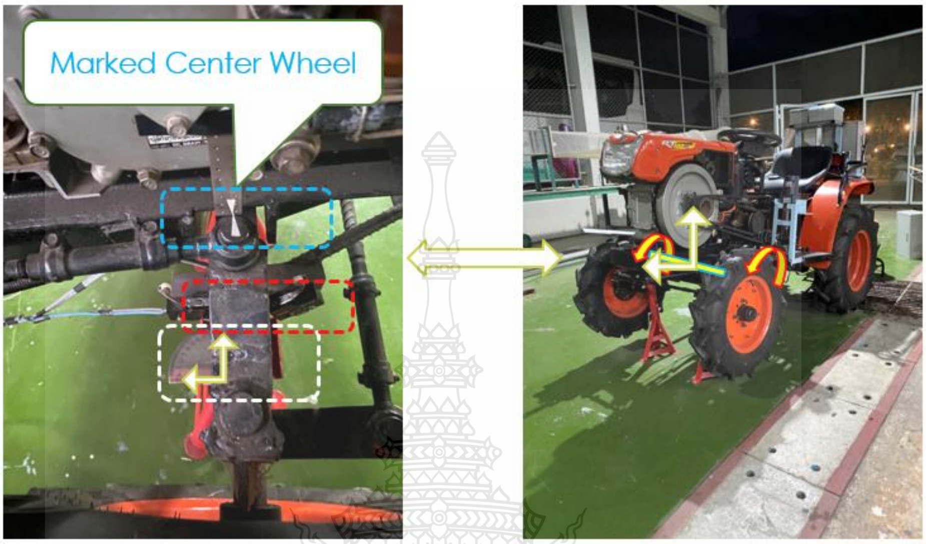


Figure 4.46 Work Shop Test

The control system of the tractor can be displayed in real-time while operating to control the steering as the following flowchart for initial mode and navigation mode to acknowledge and monitor the tractor status. The LCD display is shown in Figure 4.47 including the parameters status of encoder, Azimuth Degree, Setpiont destination, Control Value, operation Mode Initial or navigation mode to be monitored step by step operation correctly.

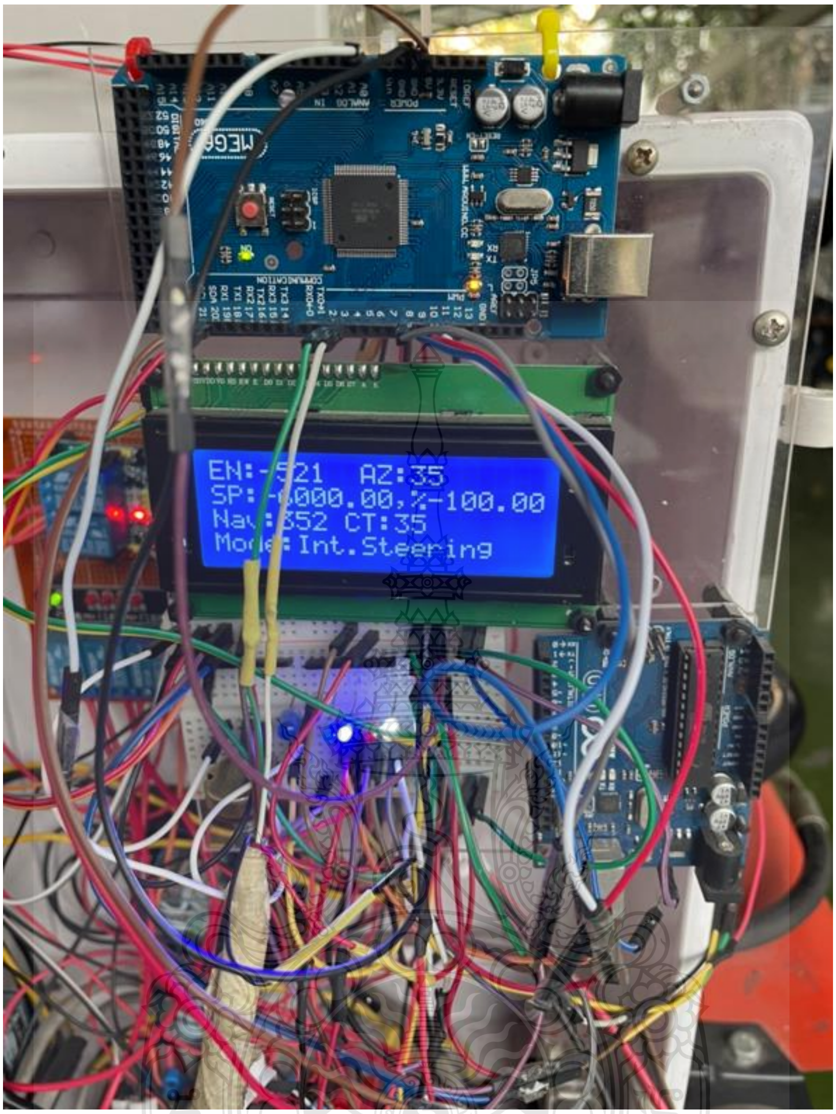


Figure 4.47 Tractor Steering Control Status Display

From Figure 4.48 the workshop test before going to the experimental field results show that the steering angle navigation target is 357 degrees azimuth. Initially, position of azimuth degree was determined by the compass sensor. The navigation process works then tractor steering turing the front wheels to left side when reached to touch the zero reset switch the countroller counting positon setting to be zero then driving tractor steering to middle position to prepare before changing into navigation mode to tracking on the pathway points the parameters recorded showns in the summay graph following Figure 4.49.

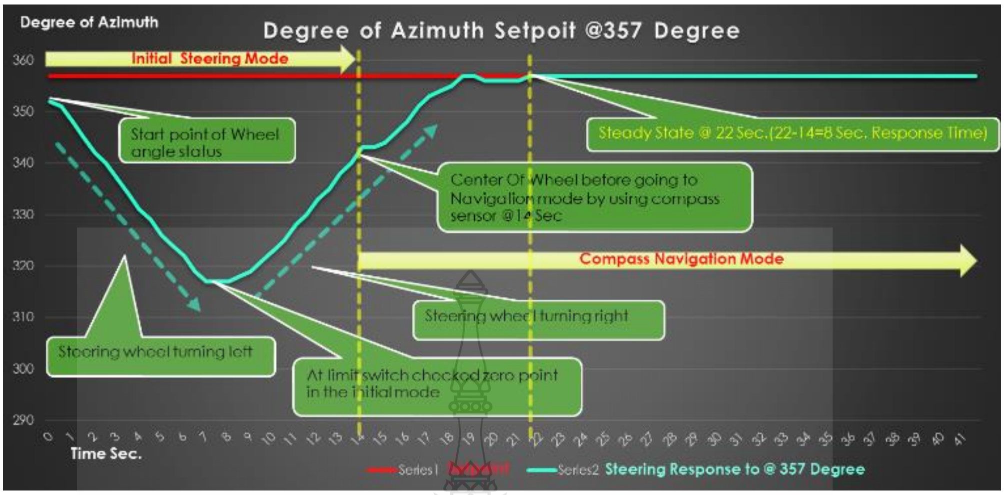


Figure 4.48 Degree of Azimuth of Fuzzy PID Control (Initial Mode)

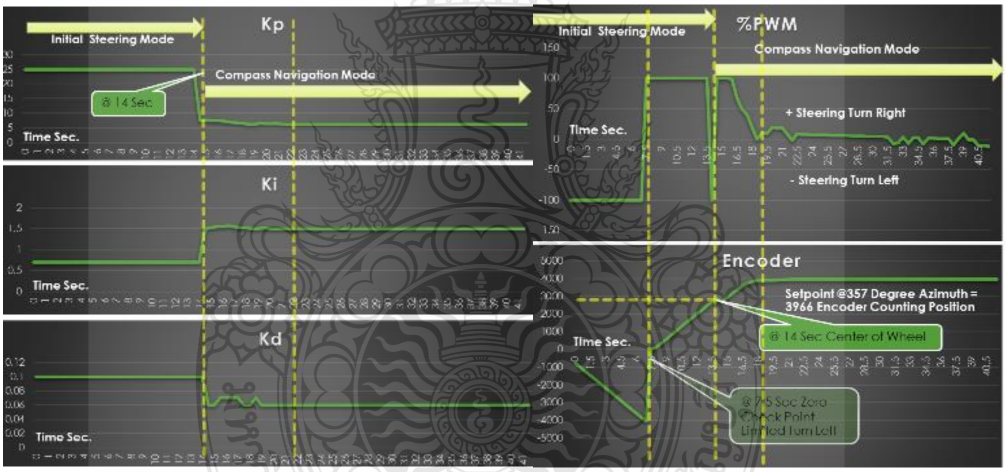


Figure 4.49 Fuzzy PID, PWM, and Encoder Value Record (Initial Mode)

After testing the operating procedures of the tractor steering control system both Initial Mode and Compass Sensor Navigation Mode are working properly. The next test brought the tractor to run at the test speed with a manual remote control using a Radio Frequency (RF) between joystick to Main Control Box to test speed and steering properly working to make sure the tractor that can be running on the test area smoothly before testing the tractor running by itself along the predetermined test route.The testing area shape is the oval looping route there are straight lines and curve to test the direction changes with using a method to change the navigation value according to the degree of azimuth angle.

The results of the test the tractor could be running by using manaul remote control joy stick and found that the steering speed ratio and the relationship with the test speed of the tractor be able to control the steering in the test route by looping as well.

In addition, testing used remote control tractor movement in the test area. The experimental area as shown in Figure 4.50 recored data of tractor movement by using GPS sensor with an Arduino to record data into Microsoft Excel application.

Figure 4.50 GPS Tracking Field Trial Result

The problem occurred strong vibration from the Tractor engine directly impacted to control box has been fixed by separating the control box from the tractor body shown in Figure 4. 51.

Figure 4.51 Separating The Control Box From The Tractor Body

Figure 4.52 the installation of the control box and GPS recorder was modified for experimental to avoid tractor vibration effected to electronics control devices and data recorder. After recoreded data during running test in the teat area by the path way point the result parameters data recorded shown in Figure 4.53.

Figure 4.52 Wagon Installation on Tractor

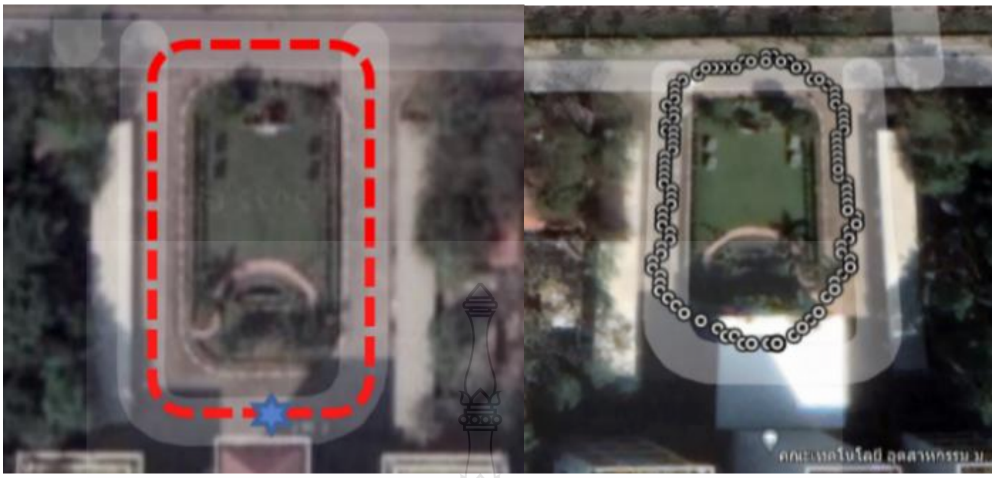
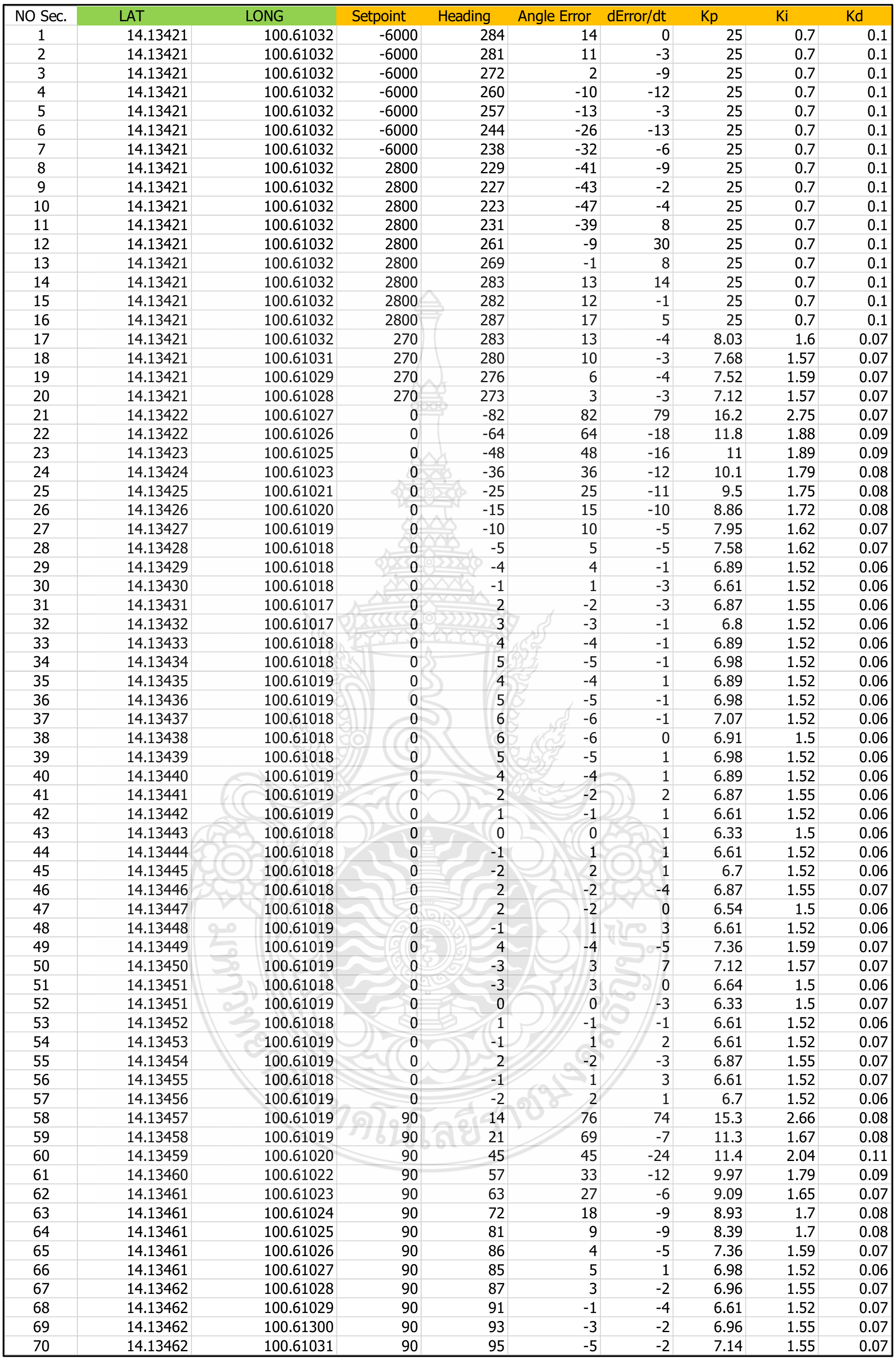


Figure 4.53 Second Trial GPS Tracking

The data recorded from the data recorder collected the information necessary for evaluating the effectiveness of the experimental results when used to test running in a circle on a flat road, relying on navigation with the azimuth degree obtained from the compass sensor. The parameters recorded in the data recorder include latitude, Longitude, Setpoint, Azimuth, Error, Differential Error, Kp, Ki, and Kd Mode to set up the steering wheel position. Setpoint values come from Encoder. After that, when the steering wheel enters the Center, it will change to navigation mode automatically as shown in Figure 4.54.



NO Sec.	LAT	LONG	Setpoint	Heading	Angle Error	dError/dt	Kp	Ki	Kd
1	14.13421	100.61032	-6000	284	14	0	25	0.7	0.1
2	14.13421	100.61032	-6000	281	11	-3	25	0.7	0.1
3	14.13421	100.61032	-6000	272	2	-9	25	0.7	0.1
4	14.13421	100.61032	-6000	260	-10	-12	25	0.7	0.1
5	14.13421	100.61032	-6000	257	-13	-3	25	0.7	0.1
6	14.13421	100.61032	-6000	244	-26	-13	25	0.7	0.1
7	14.13421	100.61032	-6000	238	-32	-6	25	0.7	0.1
8	14.13421	100.61032	2800	229	-41	-9	25	0.7	0.1
9	14.13421	100.61032	2800	227	-43	-2	25	0.7	0.1
10	14.13421	100.61032	2800	223	-47	-4	25	0.7	0.1
11	14.13421	100.61032	2800	231	-39	8	25	0.7	0.1
12	14.13421	100.61032	2800	261	-9	30	25	0.7	0.1
13	14.13421	100.61032	2800	269	-1	8	25	0.7	0.1
14	14.13421	100.61032	2800	283	13	14	25	0.7	0.1
15	14.13421	100.61032	2800	282	12	-1	25	0.7	0.1
16	14.13421	100.61032	2800	287	17	5	25	0.7	0.1
17	14.13421	100.61032	270	283	13	-4	8.03	1.6	0.07
18	14.13421	100.61031	270	280	10	-3	7.68	1.57	0.07
19	14.13421	100.61029	270	276	6	-4	7.52	1.59	0.07
20	14.13421	100.61028	270	273	3	-3	7.12	1.57	0.07
21	14.13422	100.61027	0	-82	82	79	16.2	2.75	0.07
22	14.13422	100.61026	0	-64	64	-18	11.8	1.88	0.09
23	14.13423	100.61025	0	-48	48	-16	11	1.89	0.09
24	14.13424	100.61023	0	-36	36	-12	10.1	1.79	0.08
25	14.13425	100.61021	0	-25	25	-11	9.5	1.75	0.08
26	14.13426	100.61020	0	-15	15	-10	8.86	1.72	0.08
27	14.13427	100.61019	0	-10	10	-5	7.95	1.62	0.07
28	14.13428	100.61018	0	-5	5	-5	7.58	1.62	0.07
29	14.13429	100.61018	0	-4	4	-1	6.89	1.52	0.06
30	14.13430	100.61018	0	-1	1	-3	6.61	1.52	0.06
31	14.13431	100.61017	0	2	-2	-3	6.87	1.55	0.06
32	14.13432	100.61017	0	3	-3	-1	6.8	1.52	0.06
33	14.13433	100.61018	0	4	-4	-1	6.89	1.52	0.06
34	14.13434	100.61018	0	5	-5	-1	6.98	1.52	0.06
35	14.13435	100.61019	0	4	-4	1	6.89	1.52	0.06
36	14.13436	100.61019	0	5	-5	-1	6.98	1.52	0.06
37	14.13437	100.61018	0	6	-6	-1	7.07	1.52	0.06
38	14.13438	100.61018	0	6	-6	0	6.91	1.5	0.06
39	14.13439	100.61018	0	5	-5	1	6.98	1.52	0.06
40	14.13440	100.61019	0	4	-4	1	6.89	1.52	0.06
41	14.13441	100.61019	0	2	-2	2	6.87	1.55	0.06
42	14.13442	100.61019	0	1	-1	1	6.61	1.52	0.06
43	14.13443	100.61018	0	0	0	1	6.33	1.5	0.06
44	14.13444	100.61018	0	-1	1	1	6.61	1.52	0.06
45	14.13445	100.61018	0	-2	2	1	6.7	1.52	0.06
46	14.13446	100.61018	0	2	-2	-4	6.87	1.55	0.07
47	14.13447	100.61018	0	2	-2	0	6.54	1.5	0.06
48	14.13448	100.61019	0	-1	1	3	6.61	1.52	0.06
49	14.13449	100.61019	0	4	-4	-5	7.36	1.59	0.07
50	14.13450	100.61019	0	-3	3	7	7.12	1.57	0.07
51	14.13451	100.61018	0	-3	3	0	6.64	1.5	0.06
52	14.13451	100.61019	0	0	0	-3	6.33	1.5	0.07
53	14.13452	100.61018	0	1	-1	-1	6.61	1.52	0.06
54	14.13453	100.61019	0	-1	1	2	6.61	1.52	0.07
55	14.13454	100.61019	0	2	-2	-3	6.87	1.55	0.07
56	14.13455	100.61018	0	-1	1	3	6.61	1.52	0.07
57	14.13456	100.61019	0	-2	2	1	6.7	1.52	0.06
58	14.13457	100.61019	90	14	76	74	15.3	2.66	0.08
59	14.13458	100.61019	90	21	69	-7	11.3	1.67	0.08
60	14.13459	100.61020	90	45	45	-24	11.4	2.04	0.11
61	14.13460	100.61022	90	57	33	-12	9.97	1.79	0.09
62	14.13461	100.61023	90	63	27	-6	9.09	1.65	0.07
63	14.13461	100.61024	90	72	18	-9	8.93	1.7	0.08
64	14.13461	100.61025	90	81	9	-9	8.39	1.7	0.08
65	14.13461	100.61026	90	86	4	-5	7.36	1.59	0.07
66	14.13461	100.61027	90	85	5	1	6.98	1.52	0.06
67	14.13462	100.61028	90	87	3	-2	6.96	1.55	0.07
68	14.13462	100.61029	90	91	-1	-4	6.61	1.52	0.07
69	14.13462	100.61300	90	93	-3	-2	6.96	1.55	0.07
70	14.13462	100.61031	90	95	-5	-2	7.14	1.55	0.07

Figure 4.54 Steering Control Data Recording

Graph analysis of experimental error and differential error in navigation mode control by using the compass sensor to measure azimuth. The loop tractor must change all 4 setpoint values, namely 0, 90, 180, 270, and back to 0 degrees in order to travel in a loop. The results show that The tractor can be guided in the right direction within 10 seconds while the turning time is adjustable as shown in Figure 4.55. It is satisfactory to use to control the steering wheel of the tractor. The steering response in use is 5-10 km/h but this experiment can not be tested faster due to safety reasons which can be used for further development in the future.

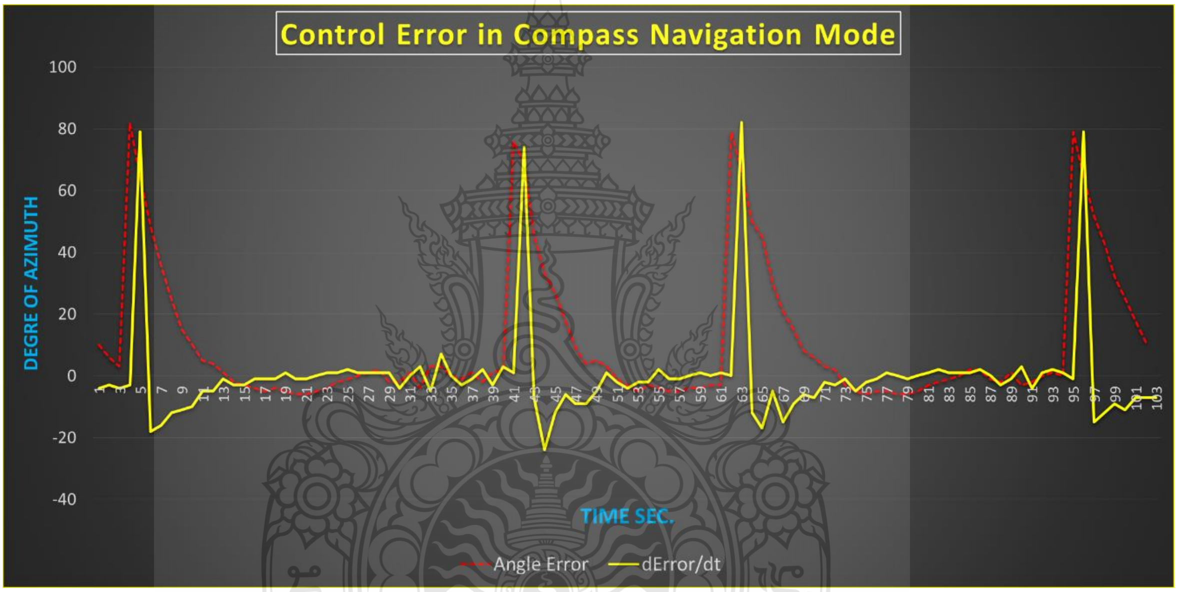


Figure 4.55 Control Error in Compass Navigation Mode

The analysis of Kp found that at the beginning It increases rapidly to a peak of about 16 then decreases and stabilizes as the tractor moves in a straight line at about 7 at steady state control as shown in Figure 4.56.

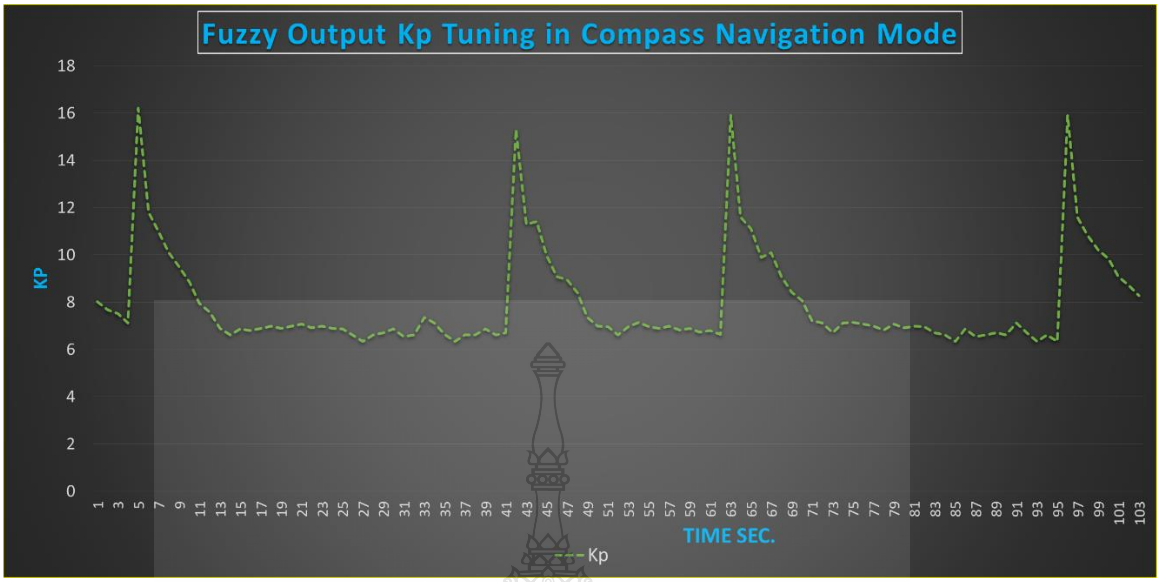


Figure 4.56 Fuzzy Output Kp Tuning in Compass Navigation Mode

The analysis of Ki found that at the beginning It increases rapidly to a peak of about 2.75 then decreases and stabilizes as the tractor moves in a straight line at about 1.5 at steady state control as shown in Figure 4.57.

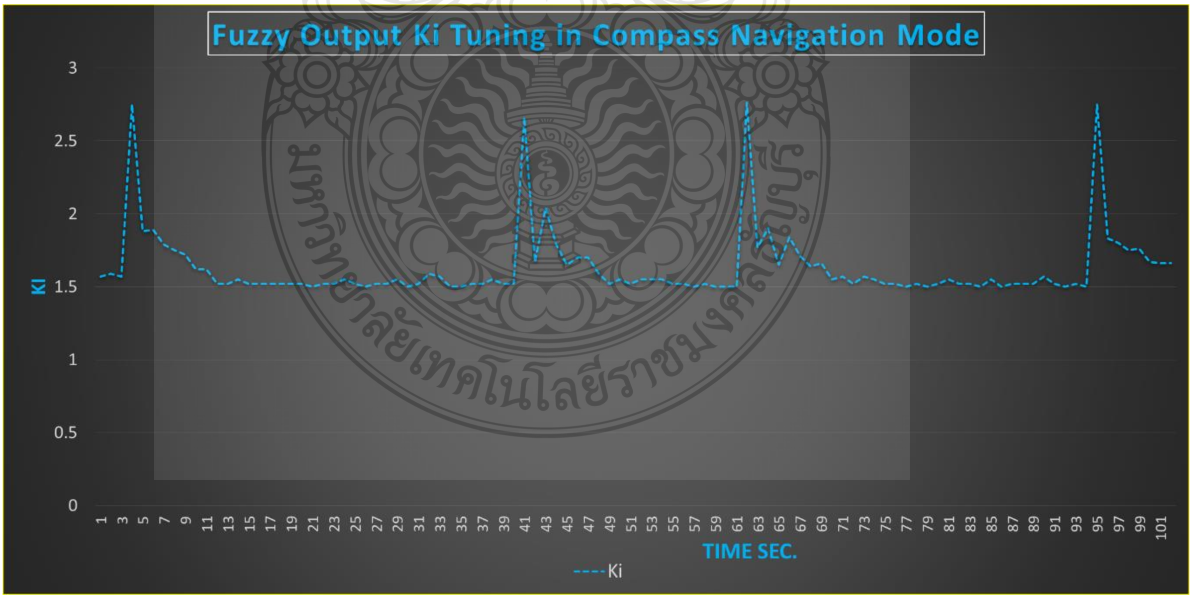


Figure 4.57 Fuzzy Output Ki Tuning in Compass Navigation Mode

The analysis of Kd reveals a oscillating range of 0.06 to 0.11 in an attempt to keep the steady state error to a minimum.as shown in Figure 4.58.

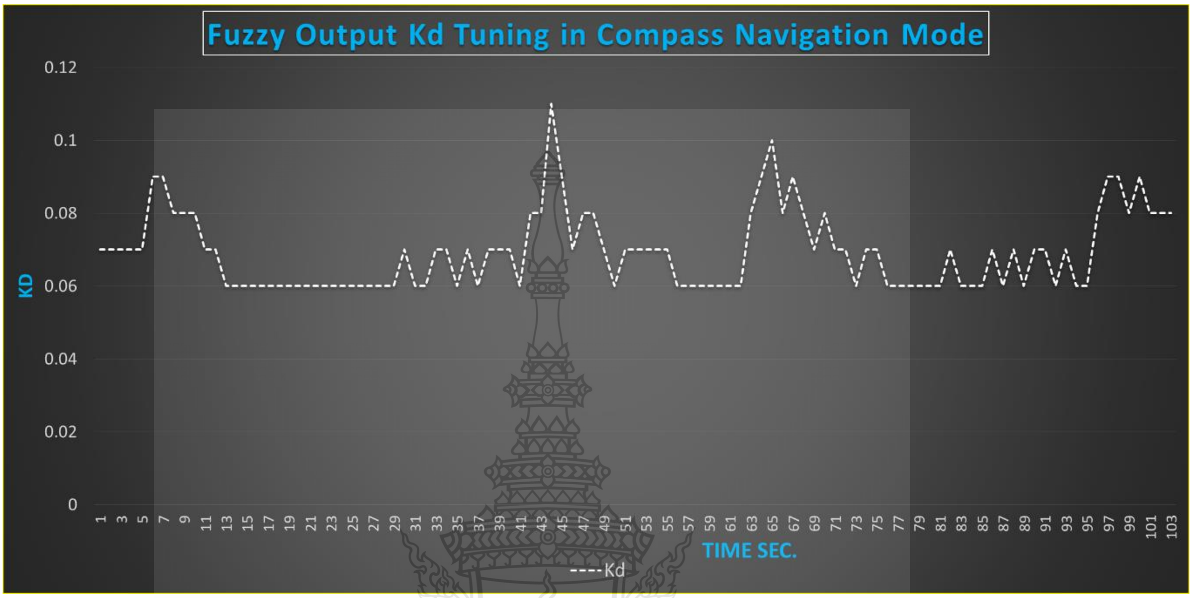


Figure 4.58 Fuzzy Output Kd Tuning in Compass Navigation Mode

Figure 4.59 shown the graph of next test The P, I, and D parameter values in the steering controller were recorded and Figure 4.60 shown the graph to compare navigation target by navigation output in term of degree of azimuth.

Adjusting the value of Kp Ki Kd in real-time from Fuzzy Logic Output that the Kp Ki value increases rapidly as the bend turns according to the change. Azimuth degree consists of 4 directions 0, 90, 180, and 270 degrees. It is close to the steady state because there is little change also only the Kd decreases when the tractor is running in a straight line. This is consistent with the Rule Base design in Fuzzy Logic.

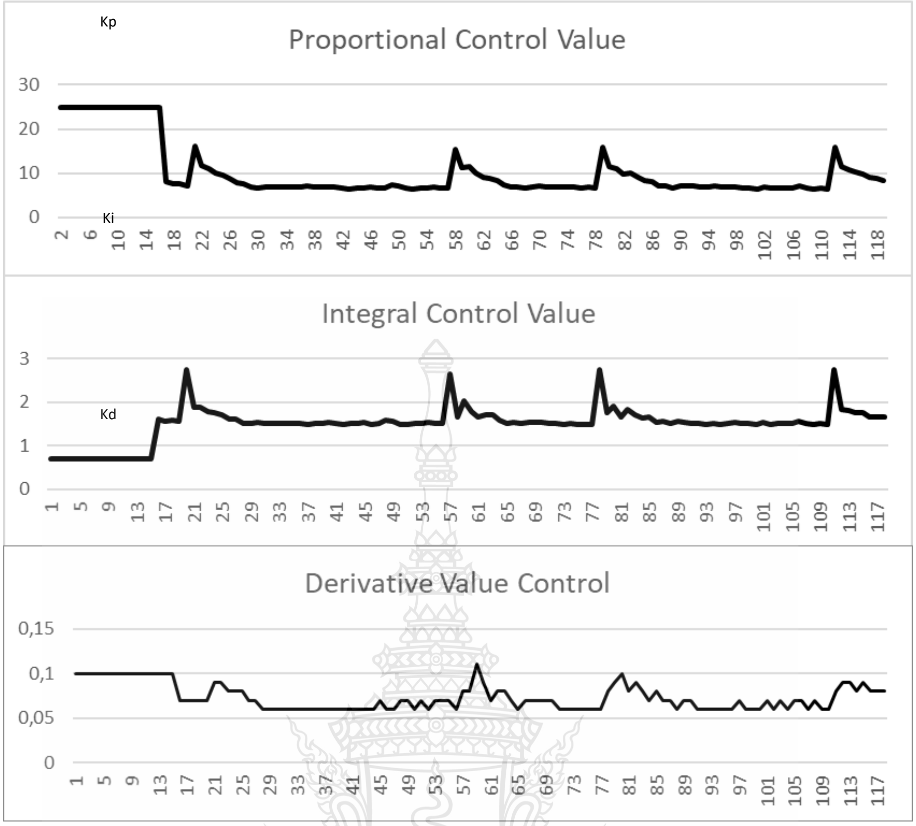


Figure 4.59 Graph for PID Value

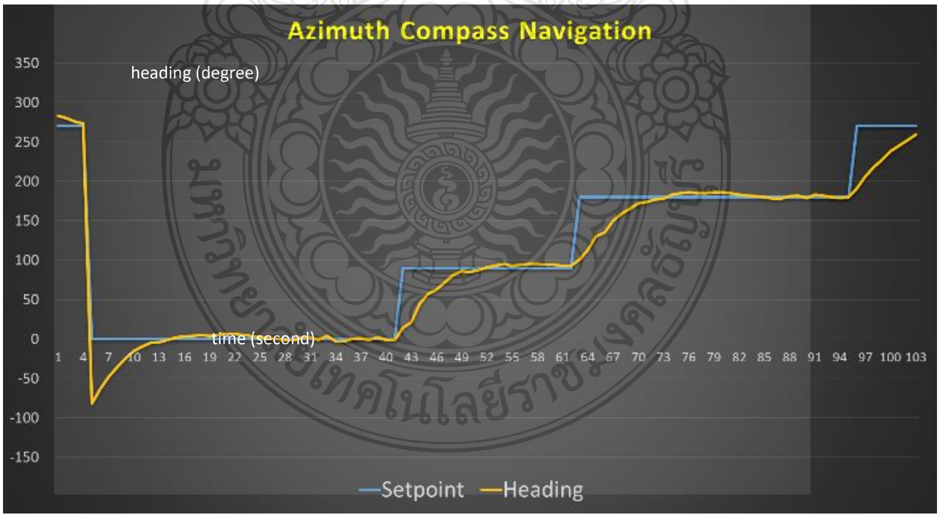


Figure 4.60 Field Trial Graph for Fuzzy PID and Set Point (Compass) Comparison

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

Modifying the two-wheel tractor to four wheels has been successfully carried out by implementing several changes and additions to the Chassis Design, Transmission, Drive, Steering, Brake, and Remote-Control System sections.

The experimental by hand tunning of Kp, Ki, and Kd in Chapter 3 that was found when the error and differential error were high. There was a high demand for Kp and Ki for fast response to the setpoint but when approaching the setpoint, stability was required. Therefore, slightly increasing the value of Kd can reduce the steady error better than tuning only the PID. The principle was applied to the fuzzy logic to configure the fuzzy rule to send control values Kp, Ki, and Kd to respond to the system in real-time resulting in better results than only the PID tuning.

The result of the control system by using PID directly at the setpoint 45 RAD output to control the tractor steering without Fuzzy Logic controller system as following in Matlab Simulink. The control responding graph can be reached the setpoint quickly and achieved the target at 45 RAD with a little bit of steady-state error remaining.

The result of the control system by using Fuzzy Logic directly at the setpoint 45 RAD output to control the tractor steering without PID system as following in Matlab Simulink. The control responding graph can be reached the setpoint and achieved slower than PID responding to the target at 45 RAD.

Hybrid control and PID-only control the Kp Ki Kd of the PID-only system has been customized to give the best possible system response compared to the fuzzy PID system designed to improve the PID system by changing the adjustment values in real-time, the experimental results fuzzy PID control system has better control response in terms of speed and steady-state accuracy in all three pattern at Setpoint 45, 90, 135 RAD

The main device for controlling the steering wheel of an intelligent automatic tractor has a compass sensor that reports the movement direction of the tractor and sends the data to the MCU Arduino Mega 2560 for real-time processing with the Fuzzy Logic calculation process to find the control value. Real-time suitable Kp, Ki, Kd for PID control system to command the rotation of the 24 VDC motor by supplying 0-100% control voltage with a 0-5 Volt VDC signal through the 24 VDC Motor PWM Drive, which acts as an Actuator to control the automatic steering and various real-time operating parameters is programmed on the LCD Display. For the first time, the results of the simulation show that the fuzzy-PID hybrid controller Stable movements can be generated to achieve a given steering angle control goal.

Testing of steering systems with remote control embedded with GPS tracker is being carried out by simply traveling in the GPS direction with a 97.75 percent assigned route. GPS control results in good directional control and efficiency. All adjustments involving mechanical design, actuators, and sensors have been functionally tested. Field test findings indicate that this tractor has excellent steering maneuverability when driven remotely, as demonstrated by the tractor passing all specified checkpoints. This machine's design is not yet comprehensive enough to operate safely, so fine detail is needed to consider RF remote control failures such as signal loss, low battery power, and obstacle detection. Further research is required to create a tractor that can move automatically.

The experimental error and differential error in navigation mode control by using the compass sensor to measure azimuth. The loop tractor must change all 4 setpoint values, namely 0, 90, 180, 270, and back to 0 degrees in order to travel in a loop. The results show that the tractor can be guided in the right direction to be satisfactory to use to control the steering wheel of the tractor. The steering response in use is 5-10 km/h but this experiment cannot be tested faster due to safety reasons which can be used for further development in the future.

In conclusion, this research has fulfilled all of the proposed objectives by designing and develop an automatic steering equipment for new intelligent agricultural tractor steering control based on compass sensor and wheel rotation.

List of Bibliography

Weeranuch Wijit, Nirote Sinnarong, Katesuda Sittisuntikul, Changing in Agricultural Population Age Structure and Production Efficiency of Important Economic Crops in Thailand (2019), **Economics and Public Policy Journal**, 10 (19): 1-17. [1]

Podder AK, Bukhari A al, Islam S, Mia S, Mohammed MA, Kumar NM, Cengiz K, Abdulkareem KH (2021) IoT based smart agrotech system for verification of Urban farming parameters, **Microprocess Microsyst**., https://doi.org/10.1016/j.micpro.2021.104025 . [2]

Shyrokau B, de Winter J, Stroosma O, Dijksterhuis C, Loof J, van Paassen R, Happee R (2018) The effect of steering-system linearity, simulator motion, and truck driving experience on steering of an articulated tractor-semitrailer combination, **Appl Ergon**, 71:17–28. [3]

Thunyalak W (2019) Automation and Required Skills for Thai Suppliers in the Automobile Industry, **Journal of Social Work**, 17:. [4]

Panupong T, Repeepong S, Thanit R, Thinakorn N (2020) Projection of the Number of Elderly in Different Health States in Thailand in the Next Ten Years, 2020-2030: **International Journal of Environmental Reseach and Public Health**, https://www.mdpi.com/1660-4601/17/22/8703 . [5]

Kraipornsak P (2018) Good Governance And Economic Growth: An Investigation Of Thailand And Selected Asian Countries. **Eurasian Journal of Economics and Finance**, 6:93–106. [6]

Sunusi II, Zhou J, Zhen Wang Z, Sun C, Eltayeb Ibrahim I, Opiyo S, korohou T, Ahmed Soomro S, Alhaji Sale N, Olanrewaju TO (2020) Intelligent tractors: Review of online traction control process, **Comput Electron Agric** https://doi.org/10.1016/j.compag.2019.105176 . [7]

Boysen N, de Koster R, Weidinger F (2019) Warehousing in the e-commerce era: A survey, **Eur J Oper Res**, 277:396–411. [8]

Yue G, Qiu T, Dai H, Lei Y, Zhao N (2018) Rail pressure control strategy based on pumping characteristics for the common rail fuel system, **Advances in Mechanical Engineering**, https://doi.org/10.1177/1687814018795591 . [9]

Osipowicz T, Abramek KF, Matuszak Z, Jaskiewicz M, Ludwinek K, Poliak M (2018) The analysis of technical condition common rail fuel system components. In: 11th International Science and Technical Conference Automotive Safety, AUTOMOTIVE SAFETY 2018, **Institute of Electrical and Electronics Engineers Inc.**, pp 1–8. [10]

Renius KT (2019) Fundamentals of Tractor Design, First Edition. **Springer, Baldham Germany**. [11]

Nakazawa T, Hattori H, Tarutani I, Yasuhara S, Inoue T (2020) Influence of pin profile curve on continuously variable transmission (CVT) chain noise and vibration, **Mech Mach Theory**, https://doi.org/10.1016/j.mechmachtheory.2020.104027 . [12]

Xiao MH, Zhao J, Wang YW, Zhang HJ, Lu ZX, Wei WH (2018) Fuel economy of multiple conditions self-adaptive tractors with hydro-mechanical CVT, **International Journal of Agricultural and Biological Engineering**, 11:102–109. [13]

Jiangxue C (2017) **Research on Hydraulic Suspension Technology of Tractor**. [14]

Kassaeiyan P, Alipour K, Tarvirdizadeh B (2020) A full-state trajectory tracking controller for tractor-trailer wheeled mobile robots, **Mech Mach Theory**, https://doi.org/10.1016/j.mechmachtheory.2020.103872 . [15]

Tian G, Gu B, Chen K, Liu Y, Wei J (2019) Method of automatic steering system design and parameter optimisation for small tractors, **The Journal of Engineering**, 2019:8353–8358. [16]

Gomez-Gil J, Alonso-Garcia S, Gómez-Gil FJ, Stombaugh T (2011) A simple method to improve autonomous GPS positioning for tractors, **Sensors**, 11:5630–5644. [17]

Li B, Lai W, Yang C, Zheng S (2016) **Design of Electronic Compass**. [18]

Livada B, Vujić S, Radić D, Unkašević T, Banjac Z (2019) Digital magnetic compass integration with stationary, land-based electro-optical multi-sensor surveillance system, **Sensors (Switzerland)**, https://doi.org/10.3390/s19194331 . [19]

Singh Kaswan K, Pal Singh S, Sagar S (2020) Role Of Arduino In Real World Applications, **INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH**, 9:1. [20]

Rahimoon AA, Abdullah MN, Soomro DM, Nassar MY, Memon ZA, Shaikh PH (2019) Design of parabolic solar dish tracking system using arduino. **Indonesian Journal of Electrical Engineering and Computer Science** ,17:914–921. [21]

Shrenika RM, Chikmath SS, Ravi Kumar A v., Divyashree Y v., Swamy RK (2017) Non-contact Water Level Monitoring System Implemented Using LabVIEW and Arduino. In: Proceedings - 2017 International Conference on Recent Advances in Electronics and Communication Technology, ICRAECT 2017, **Institute of Electrical and Electronics Engineers Inc.**, pp 306–309. [22]

Elfasi A, Shawesh MA, Shanab WaidT, Khaledthabet A (2017) Oscilloscope using Arduino interface LabVIEW, In: GECS’2017, **International Conference on Green Energy & Conversion Systems**, pp 23–25. [23]

Parikh P, Sheth S, Vasani R, Gohil JK (2018) Implementing Fuzzy Logic Controller and PID Controller to a DC Encoder Motor - “a case of an Automated Guided Vehicle.” In: Procedia Manuf, **Elsevier B.V.**, pp 219–226. [24]

Berrabah SA, Baudoin Y (2011) GPS data correction using encoders and inertial navigation system (INS) sensors. In: Using Robots in Hazardous Environments, **Elsevier**, pp 269–282. [25]

Kayacan E, Member S, Kayacan E, Member S, Ramon H, Kaynak O, Saeys W (2015), Trajectory Control of an Autonomous Tractor Using Type-2 Fuzzy Logic Controllers, **Towards Agrobots**, 20:287–298. [26]

das Sharma K, Chatterjee A, Rakshit A (2014) Harmony search-based hybrid stable adaptive fuzzy tracking controllers for vision-based mobile robot navigation, **Mach Vis Appl**, 25:405–419. [27]

Ahmed H, Singh G, Bhardwaj V, Saurav S, Agarwal S (2013) Controlling of D.C. Motor using Fuzzy Logic Controller, **Conference on Advances in Communication and Control Systems**. [28]

Yin X, Wang Y, Chen Y, Jin C, Du J (2020) Development of autonomous navigation controller for agricultural vehicles, **International Journal of Agricultural and Biological Engineering**, 13:70–76. [29]

Tomera M (2016) Hybrid real-time way-point controller for ships. In: 2016 21st International Conference on Methods and Models in Automation and Robotics, MMAR 2016, **Institute of Electrical and Electronics Engineers Inc.**, pp 630–635. [30]

Upaphai W, Bunyawanichakul P, Janthong (2017) Trajectory tracking control design for an autonomous tractor using fuzzy PID controller, **International Journal of Agricultural Technology**, 13:501–519. [31]

Abdullah NA (2020) Fuzzy Logic based Real Time Go to Goal Controller for Mobile Robot, **Int J Comput Appl**,176:975–8887. [32]

Kapsalis D, Sename O, Milanes V, Martinez Molina JJ (2021) Design and Experimental Validation of an LPV Pure Pursuit Automatic Steering Controller. In: IFAC-PapersOnLine, **Elsevier B.V.**, pp 63–68. [33]

Budiharto W, Irwansyah E, Suroso JS, Gunawan AAS (2020) Design of object tracking for military robot using pid controller and computer vision, **ICIC Express Letters**, 14:289–294. [34]

Shi L, Hu Y, Su S, Guo S, Xing H, Hou X, Liu Y, Chen Z, Li Z, Xia D (2020) A Fuzzy PID Algorithm for a Novel Miniature Spherical Robots with Three-dimensional Underwater Motion Control, **J Bionic Eng**, 17:959–969. [35]

Mai TA, Dang TS, Duong DT, Le VC, Banerjee S (2021) A combined backstepping and adaptive fuzzy PID approach for trajectory tracking of autonomous mobile robots, **Journal of the Brazilian Society of Mechanical Sciences and Engineering**, https://doi.org/10.1007/s40430-020-02767-8. [36]

Zulfikar WB, Jumadi, Prasetyo PK, Ramdhani MA (2018) Implementation of Mamdani Fuzzy Method in Employee Promotion System, **IOP Conf Ser Mater Sci Eng**, https://doi.org/10.1088/1757-899X/288/1/012147. [37]

Selvachandran G, Quek SG, Lan LTH, Son LH, Giang NL, Ding W, Abdel-Basset M, de Albuquerque VHC (2021) A New Design of Mamdani Complex Fuzzy Inference System for Multiattribute Decision Making Problems, **IEEE Transactions on Fuzzy Systems**, 29:716–730. [38]

Kacimi MA, Guenounou O, Brikh L, Yahiaoui F, Hadid N (2020) New mixed-coding PSO algorithm for a self-adaptive and automatic learning of Mamdani fuzzy rules, **Eng Appl Artif Intell**, https://doi.org/10.1016/j.engappai.2019.103417 . [39]

Yanar T, Kocaman S, Gokceoglu C (2020) Use of Mamdani fuzzy algorithm for multi-hazard susceptibility assessment in a developing urban settlement (Mamak, Ankara, Turkey), **ISPRS Int J Geoinf**, https://doi.org/10.3390/ijgi9020114 . [40]

Bowman DA (2022) Considerations in Tractor Chassis Design. In: 2022 Agricultural Equipment Technology Conference, **American Society of Agricultural and Biological Engineers (ASABE)**, pp 1–8. [41]

Bonnick A, Newbold D (2011) A Practical Approach to Motor Vehicle Engineering and Maintenance, **Oxford**. [42]

Okunev AP, Borovkov AI, Karev AS, Lebedev DO, Kubyshkin VI, Nikulina SP, Kiselev AA (2019) Digital Modeling and Testing of Tractor Characteristics, **Russian Engineering Research**, 39:453–458. [43]

Zhao X, Wang J, Zhang Y, Tang J, Zhao X (2019) Gear ratio optimization of two-speed transmission in electric off-road vehicle. In: Proceedings of the 31st Chinese Control and Decision Conference (2019 CCDC), **IEEE**, Nanchang, pp 4810–4815. [44]

Sato K, Matsubara O, Hase E, Minamikawa T, Yasui T (2019) Quantitative in situ time-series evaluation of osteoblastic collagen synthesis under cyclic strain using second-harmonic-generation microscopy, **J Biomed Opt**, 24:1. [45]

Nasathit N, Azli M, Salim B, Photong C, **Design and Development of An Electric Tractor using Simple Remote Control**, doi: 10.14456/mijet.2022.16. [46]

Yin J, Zhu D, Liao J, Zhu G, Wang Y, Zhang S (2019) Automatic steering control algorithm based on compound fuzzy PID for rice transplanter, **Applied Sciences (Switzerland)**, https://doi.org/10.3390/app9132666. [47]

Yu M, Gong X, Fan G, Zhang Y (2020) Trajectory Planning and Tracking for Carrier Aircraft-Tractor System Based on Autonomous and Cooperative Movement, **Math Probl Eng**, https://doi.org/10.1155/2020/6531984. [48]

Tiep DK, Lee K, Im DY, Kwak B, Ryoo YJ (2018) Design of fuzzy-PID controller for path tracking of mobile robot with differential drive, **International Journal of Fuzzy Logic and Intelligent Systems**, 18:220–228. [49]

Omrane H, Masmoudi MS, Masmoudi M (2016) Fuzzy Logic Based Control for Autonomous Mobile Robot Navigation, **Comput Intell Neurosci**, https://doi.org/10.1155/2016/9548482. [50]

Siciliano B, Sciavicco L, Villani L,, Oriolo G (2009) Modelling, planning and control. Advanced Textbooks in Control and Signal Processing, **Springer**. [51]

Antal D, Szabó T (2012) Controlling and modeling of an automated guided vehicle. In: Proceedings of the 2012 13th International Carpathian Control Conference : **ICCC. [IEEE]**, Podbanské, Slovak Republic, pp 1–6. [52]

Xiang X, Yu C, Lapierre L, Zhang J, Zhang Q (2018) Survey on Fuzzy-Logic-Based Guidance and Control of Marine Surface Vehicles and Underwater Vehicles, **International Journal of Fuzzy Systems**, 20:572–586. [53]

Singh NH, Thongam K (2018) Mobile Robot Navigation Using Fuzzy Logic in Static Environments In: **Procedia Comput Sci. Elsevier B.V.**, pp 11–17. [54]

Castillo O, Melin P (2014) A review on interval type-2 fuzzy logic applications in intelligent control, **Inf Sci (N Y) 279**,:615–631. [55]

Karar ME, El-Garawany AH, El-Brawany M (2020) Optimal adaptive intuitionistic fuzzy logic control of anti-cancer drug delivery systems, **Biomed Signal Process Control**, https://doi.org/10.1016/j.bspc.2020.101861. [56]

Thuy PX, Cuong NT (2015) Vision Based Autonomous Path/Line Following of a Mobile Robot Using a Hybrid Fuzzy PID Controller, VCCA-2015, https://doi.org/10.15625/vap.2015.0012. [57]

Jiangqiang H, Tieshan L, Chen G (2006) Design of GA-based fuzzy control for ship steering. In: **Proceedings of the World Congress on Intelligent Control and Automation (WCICA)**, pp 3594–3598. [58]

Sun YL, Er MJ (2004) Hybrid fuzzy control of robotics systems, **IEEE Transactions on Fuzzy Systems**, 12:755–765. [59]

Salhi K, Alimi AM (2013) Fuzzy-PID hybrid controller for mobile robot using point cloud and low cost depth sensor. In: 2013 International Conference on Individual and Collective Behaviors in Robotics, **Proceedings of ICBR 2013**, pp 92–97. [60]

Aydogmus O, Boztas G (2021) Implementation of Pure Pursuit Algorithm for Nonholonomic Mobile Robot using Robot Operating System, **Balkan Journal of Electrical and Computer Engineering**, 9:337–341. [61]

Rains GC, Faircloth AG, Thai C, Raper RL (2014) Evaluation of a simple pure pursuit path-following algorithm for an autonomous, articulated-steer vehicle, **Appl Eng Agric**, 30:367–374. [62]

Yang Y, Li Y, Wen X, Zhang G, Ma Q, Cheng S, Qi J, Xu L, Chen L (2022) An optimal goal point determination algorithm for automatic navigation of agricultural machinery: Improving the tracking accuracy of the Pure Pursuit algorithm, **Comput Electron Agric**, https://doi.org/10.1016/j.compag.2022.106760. [63]

APPENDICES

APPENDIX A

C++ Language coding embedded in PID Arduino Module

```
//PID+Encoder Feedback
#include <PID_v1.h>

double Setpoint=-10, Input=0, Output=0;
//PID Tunning
double Kp=25, Ki=.7, Kd=2;
//double Kp=10, Ki=1, Kd=.1;
PID myPID(&Input, &Output, &Setpoint, Kp, Ki, Kd, DIRECT);
//PID myPID(&Input, &Output, &Setpoint, Kp, Ki, Kd,
REVERSE);

#include <QMC5883LCompass.h>

QMC5883LCompass compass;

// LCD I2C
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
//LiquidCrystal_I2C lcd(0x27, 16, 2);
LiquidCrystal_I2C lcd(0x27, 20, 5);//Code Address:0x27, 20
Char., 4Line.
//Motor Var.
int motorPin1 = 8;//CW/CCW
int motorPin2 = 9;//CW/CCW
int PWM= 10; //PWM PIN 10
int Automode =0;

//Encoder Syste,=m
enum PinAssignments {
  encoderPinA = 2, // Pin1
  encoderPinB = 3, // Pin2
  clearButton = 11,  // Reset to Zero position

              };
  //volatile unsigned int encoderPos = 0;  // reserve for
unsigned int type
  volatile int encoderPos = 0;  // using int type
unsigned int lastReportedPos = 1;   // change management
static boolean rotating = false;    // debounce management

boolean A_set = false;
boolean B_set = false;
//Compass Variable
 int DA;
 int a;
 int b;
```

```
 int Nav;
 int CT;
 int Q1;

/////// Encoder

void setup() {
  compass.init();
  pinMode(motorPin1, OUTPUT);
  pinMode(motorPin2, OUTPUT);
  pinMode(PWM, OUTPUT);
  Serial.begin(115200);
//  LCD Initial
   initialDisplay();

//PID

  myPID.SetMode(AUTOMATIC);
  //myPID.SetSampleTime(1);
  myPID.SetOutputLimits(-255,255);
  ////Encoder setup
  pinMode(encoderPinA, INPUT_PULLUP); // Input pullup
  pinMode(encoderPinB, INPUT_PULLUP);
  pinMode(clearButton, INPUT_PULLUP);

  attachInterrupt(0, doEncoderA, CHANGE); // interrupt
logic 0 for
pin 2
  attachInterrupt(1, doEncoderB, CHANGE); // interrupt
logic 1 for
pin 3
  Serial.begin(115200);
  //encoder setup end
  //Start value
  encoderPos = 0;

}
void loop() {
   // Read compass values
  compass.read();

  // Return Azimuth reading
  DA = compass.getAzimuth();
  //delay(100);<---delay for DA
  a=DA;
  //Overturn fucntion 0-365 Degree of Azimuth
```

```
//Setpoint Quadrant
if (Nav<=180) {Q1=1;}
if (Nav>180) {Q1=0;}

CT=a;

if (Q1==1) {
if (a>180) {CT=a-360;}}
if (Q1==0) {
if (a>=0)  {b=a+360;}
if (b<449) {CT=b;}}
///Encoder Loop
  rotating = true;  // reset the debouncer

  if (lastReportedPos != encoderPos) {
    Serial.print("Index:");
    Serial.println(encoderPos, DEC);
    lastReportedPos = encoderPos;

  }
if (digitalRead(clearButton) == LOW )  {
    encoderPos = 0;
   Serial.println("Click:Reset Index");
   Setpoint=12;
  }
 if (Automode==0) {Input = encoderPos;}
 if (Automode==1) {
Kp=10; Ki=.7; Kd=.5;
  Input = CT;
  Setpoint=Nav;
  }
 if (encoderPos == 11) {Automode=1;}
////////////////////////////////
int val = analogRead(A0);
  Nav= int((358./1020.) *val);
////////////////////////////////
/*Serial.print("Automode:");
    Serial.println(Automode);
Serial.print("Azimuth:");
    Serial.println(a);
Serial.print("Setpoint:");
    Serial.println(Setpoint);
Serial.print("Input:");
    Serial.println(Input);
Serial.print("Navigation Setpoint:");
    Serial.println(Nav);
```

```
Serial.print("P:");
    Serial.println(Kp);
Serial.print("I:");
    Serial.println(Ki);
Serial.print("D:");
    Serial.println(Kd);
Serial.print("CT:");
    Serial.println(CT);
Serial.print("Q1:");
    Serial.println(Q1);
Serial.print("b:");
    Serial.println(b);*/


///////////////////////////////
lcd.setCursor(0,1);
lcd.print("SP:");
lcd.print(Setpoint);
lcd.print(",%");
lcd.print(Output*100/255);
lcd.print("    ");
lcd.setCursor(0,2);
lcd.print("Nav:");
lcd.print(Nav);
lcd.print("  ");
//<-----------------------------------
lcd.setCursor(8,2);
lcd.print("CT:");
lcd.print(CT);
lcd.print("  ");
//<------------------------------
if (Automode==0) {
lcd.setCursor(0,3);
lcd.print("Mode:");
lcd.print("Int.Steering");}

if (Automode==1) {
lcd.setCursor(0,3);
lcd.print("Mode:");
lcd.print("Compass Nav.   ");}
///////////////////////////////////////////////////////
 //Input = encoderPos;//Inputdata
////////////////////////////////////////////////////////
  myPID.Compute();
  pwmOut(Output);
 lcd.setCursor(0,0);
```

```
    lcd.print("EN:");
  lcd.print(encoderPos);
  lcd.print("  ");
//  lcd.setCursor(8,0);
 lcd.print("AZ:");
 lcd.print(a);
 lcd.print("  ");
}

void pwmOut (int out){
if (out>0){
    analogWrite(PWM, out);
    cw ();
}
else {
  analogWrite(PWM, abs(out));
    ccw ();
}
  }

  void initialDisplay(){
  lcd.init();
  lcd.backlight();
 }
  void cw () {
   digitalWrite(motorPin1, HIGH);
  digitalWrite(motorPin2, LOW);
  }
  void ccw () {
   digitalWrite(motorPin1, LOW);
  digitalWrite(motorPin2, HIGH);
  }
  void off () {
   digitalWrite(motorPin1, LOW);
  digitalWrite(motorPin2, LOW);
  }

 //Encoder Functions

// interrupt when start rotating
void doEncoderA() {
  // debounce
  if ( rotating ) delay (1);  // for eliminating  debounce
signal

  // bit switch check
```

```
  if ( digitalRead(encoderPinA) != A_set ) { // debounce
once more
    A_set = !A_set;
    // adjust counter + if A leads B
    if ( A_set && !B_set )
      encoderPos += 1;
    rotating = false;  // no more debouncing until loop()
hits again
  }
}

// Interrupt on B changing state, same as A above
void doEncoderB() {
  if ( rotating ) delay (1);
  if ( digitalRead(encoderPinB) != B_set ) {
    B_set = !B_set;
    //  adjust counter - 1 if B leads A
    if ( B_set && !A_set )
      encoderPos -= 1;
    rotating = false;
  }
}
```

APPENDIX B
FUZZY PID Arduino Code

```
//PID+Encoder Feedback
#include <PID_v1.h>
//<--------------------------
#include <Fuzzy.h>
// Fuzzy
Fuzzy *fuzzy = new Fuzzy();
//<----------------------------

double Setpoint=-6000, Input=0, Output=0;
//PID Tunning
double Kp=25, Ki=.7, Kd=.1;
//double Kp=10, Ki=1, Kd=.1;
PID myPID(&Input, &Output, &Setpoint, Kp, Ki, Kd, DIRECT);
//PID myPID(&Input, &Output, &Setpoint, Kp, Ki, Kd, REVERSE);
////////////
#include <QMC5883LCompass.h>

QMC5883LCompass compass;

// LCD I2C
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
//LiquidCrystal_I2C lcd(0x27, 16, 2);
LiquidCrystal_I2C lcd(0x27, 20, 5);//Code Address:0x27, 20 Char., 4Line.
//Motor Var.
int motorPin1 = 8;//CW/CCW
int motorPin2 = 9;//CW/CCW
```

```
int PWM= 10; //PWM PIN 10
int Automode =0;

//Encoder Syste,=m
enum PinAssignments {
  encoderPinA = 2, // ขา S1
  encoderPinB = 3, // ขา S2
  clearButton = 11,  // Reset to Zero position

                };
  //volatile unsigned int encoderPos = 0;  // สำหรับนับจำนวน
  volatile int encoderPos = 0;  // สำหรับนับจำนวน
unsigned int lastReportedPos = 1;   // change management
static boolean rotating = false;    // debounce management

boolean A_set = false;
boolean B_set = false;
//Compass Variable
 int DA;
 int a;
 int b;
 int angle_error; //Angle Error
 int Nav;
 int CT;
 int Q1;
 int printindex=0;
```

```
/////// Encoder


void setup() {


  compass.init();
  pinMode(motorPin1, OUTPUT);
  pinMode(motorPin2, OUTPUT);
  pinMode(PWM, OUTPUT);
 Serial.begin(9600);
 Serial.println("CLEARDATA");
Serial.println("LABEL,Time,Index,Int.Setpoint,Encoder,%PWM,Nav.Setpoint,Azimuth
,Angle Error,dError/dt,Kp,Ki,Kd");
//Serial.println("LABEL,Time,Index,SensorValueA0,SensorValueA1,SensorValueA2,S
ensorValueA3");


//  LCD Initial
   initialDisplay();
    //<----------------------------FZ
    randomSeed(analogRead(0));
 // FuzzyInput error range -180 to 180
FuzzySet *Ner = new FuzzySet(-180, -90, -90, 0);
FuzzySet *Z = new FuzzySet(-90, 0, 0, 90);
FuzzySet *Per = new FuzzySet(0, 90, 90, 180);


// FuzzyInput d error/dt range -180 to 180
FuzzySet *dNer = new FuzzySet(-180, -90, -90, 0);
FuzzySet *dZ = new FuzzySet(-90, 0, 0, 90);
FuzzySet *dPer = new FuzzySet(0, 90, 90, 180);
```

```
// FuzzyOutput Kp range 1 to 24
FuzzySet *Kp1 = new FuzzySet(1, 6, 6, 12);
FuzzySet *Kp2 = new FuzzySet(6, 12, 12, 18);
FuzzySet *Kp3 = new FuzzySet(12, 18, 18, 24);

// FuzzyOutput Ki range 0 to 6
FuzzySet *Ki1 = new FuzzySet(0, 1.5, 1.5, 3);
FuzzySet *Ki2 = new FuzzySet(1.5, 3, 3, 4.5);
FuzzySet *Ki3 = new FuzzySet(3, 4.5, 4.5, 6);

// FuzzyOutput Kd range 0 to 0.24
FuzzySet *Kd1 = new FuzzySet(0, 0.06, 0.06, 0.12);
FuzzySet *Kd2 = new FuzzySet(0.06, 0.12, 0.12, 0.18);
FuzzySet *Kd3 = new FuzzySet(0.12, 0.18, 0.18, 0.24);
//--------------------------------------------------------------------------//
 // FuzzyInput----------->Set Name *error adding Input set
  FuzzyInput *error = new FuzzyInput(1);

  error->addFuzzySet(Ner);
  error->addFuzzySet(Z);
  error->addFuzzySet(Per);
  fuzzy->addFuzzyInput(error);

  // FuzzyInput----------->Set Name *d error/dt  adding Input set
  FuzzyInput *derror = new FuzzyInput(2);
```

```
derror->addFuzzySet(dNer);
derror->addFuzzySet(dZ);
derror->addFuzzySet(dPer);
fuzzy->addFuzzyInput(derror);

// FuzzyOutput----------->Set Name *KpOutput adding Output set(Kp1,Kp2,Kp3)
FuzzyOutput *Kp = new FuzzyOutput(1);

Kp->addFuzzySet(Kp1);
Kp->addFuzzySet(Kp2);
Kp->addFuzzySet(Kp3);
fuzzy->addFuzzyOutput(Kp);

// FuzzyOutput----------->Set Name*KiOutput adding Output set(Ki1,Ki2,Ki3)
FuzzyOutput *Ki = new FuzzyOutput(2);

Ki->addFuzzySet(Ki1);
Ki->addFuzzySet(Ki2);
Ki->addFuzzySet(Ki3);
fuzzy->addFuzzyOutput(Ki);

// FuzzyOutput----------->Set Name*KiOutput adding Output set(Kd1,Kd2,Kd3)
FuzzyOutput *Kd = new FuzzyOutput(3);

Kd->addFuzzySet(Kd1);
Kd->addFuzzySet(Kd2);
Kd->addFuzzySet(Kd3);
```

```
  fuzzy->addFuzzyOutput(Kd);

//---------------------------------------------------------------------------//
 // Building FuzzyRule

  //Case1=eNerXdeNer
  FuzzyRuleAntecedent *eNerXdeNer = new FuzzyRuleAntecedent();
   eNerXdeNer->joinWithAND(Ner, dNer);
  //Output Setting
  FuzzyRuleConsequent *OuteNerXdeNer = new FuzzyRuleConsequent();
   OuteNerXdeNer->addOutput(Kp3);
    OuteNerXdeNer->addOutput(Ki2);
     OuteNerXdeNer->addOutput(Kd1);
  //Fuzzy Rule1
  FuzzyRule *fuzzyRule1 = new FuzzyRule(1, eNerXdeNer, OuteNerXdeNer);
   fuzzy->addFuzzyRule(fuzzyRule1);
//---------------------------------------------------------------------------//
   //Case2=eNerXdeZ
  FuzzyRuleAntecedent *eNerXdeZ = new FuzzyRuleAntecedent();
   eNerXdeZ->joinWithAND(Ner, dZ);
  //Output Setting
  FuzzyRuleConsequent *OuteNerXdeZ = new FuzzyRuleConsequent();
   OuteNerXdeZ->addOutput(Kp2);
    OuteNerXdeZ->addOutput(Ki1);
     OuteNerXdeZ->addOutput(Kd1);
  //Fuzzy Rule2
  FuzzyRule *fuzzyRule2 = new FuzzyRule(2, eNerXdeZ, OuteNerXdeZ);
```

```
   fuzzy->addFuzzyRule(fuzzyRule2);
//-----------------------------------------------------------------------------//
    //Case3=eNerXdePer
  FuzzyRuleAntecedent *eNerXdePer = new FuzzyRuleAntecedent();
   eNerXdePer->joinWithAND(Ner, dPer);
  //Output Setting
  FuzzyRuleConsequent *OuteNerXdePer = new FuzzyRuleConsequent();
   OuteNerXdePer->addOutput(Kp3);
    OuteNerXdePer->addOutput(Ki2);
     OuteNerXdePer->addOutput(Kd1);
  //Fuzzy Rule3
  FuzzyRule *fuzzyRule3 = new FuzzyRule(3, eNerXdePer, OuteNerXdePer);
   fuzzy->addFuzzyRule(fuzzyRule3);
//-----------------------------------------------------------------------------//
    //Case4=eZXdeNer
  FuzzyRuleAntecedent *eZXdeNer = new FuzzyRuleAntecedent();
   eZXdeNer->joinWithAND(Z, dNer);
  //Output Setting
  FuzzyRuleConsequent *OuteZXdeNer = new FuzzyRuleConsequent();
   OuteZXdeNer->addOutput(Kp1);
    OuteZXdeNer->addOutput(Ki1);
     OuteZXdeNer->addOutput(Kd3);
  //Fuzzy Rule4
  FuzzyRule *fuzzyRule4 = new FuzzyRule(4, eZXdeNer, OuteZXdeNer);
   fuzzy->addFuzzyRule(fuzzyRule4);
//-----------------------------------------------------------------------------//
    //Case5=eZXdeZ
```

```
FuzzyRuleAntecedent *eZXdeZ = new FuzzyRuleAntecedent();
 eZXdeZ->joinWithAND(Z, dZ);
//Output Setting
FuzzyRuleConsequent *OuteZXdeZ = new FuzzyRuleConsequent();
 OuteZXdeZ->addOutput(Kp1);
  OuteZXdeZ->addOutput(Ki1);
   OuteZXdeZ->addOutput(Kd1);
//Fuzzy Rule5
FuzzyRule *fuzzyRule5 = new FuzzyRule(5, eZXdeZ, OuteZXdeZ);
 fuzzy->addFuzzyRule(fuzzyRule5);
//-------------------------------------------------------------------------------//
  //Case6=eZXdePer
FuzzyRuleAntecedent *eZXdePer = new FuzzyRuleAntecedent();
 eZXdePer->joinWithAND(Z, dPer);
//Output Setting
FuzzyRuleConsequent *OuteZXdePer = new FuzzyRuleConsequent();
 OuteZXdePer->addOutput(Kp1);
  OuteZXdePer->addOutput(Ki1);
   OuteZXdePer->addOutput(Kd3);
//Fuzzy Rule6
FuzzyRule *fuzzyRule6 = new FuzzyRule(6, eZXdeZ, OuteZXdePer);
 fuzzy->addFuzzyRule(fuzzyRule6);
//-------------------------------------------------------------------------------//
  //Case7=ePerXdeNer
FuzzyRuleAntecedent *ePerXdeNer = new FuzzyRuleAntecedent();
 ePerXdeNer->joinWithAND(Per, dNer);
//Output Setting
```

```
 FuzzyRuleConsequent *OutePerXdeNer = new FuzzyRuleConsequent();
  OutePerXdeNer->addOutput(Kp3);
   OutePerXdeNer->addOutput(Ki2);
    OutePerXdeNer->addOutput(Kd1);
 //Fuzzy Rule7
 FuzzyRule *fuzzyRule7 = new FuzzyRule(7, ePerXdeNer, OutePerXdeNer);
  fuzzy->addFuzzyRule(fuzzyRule7);
//-----------------------------------------------------------------------------//
   //Case8=ePerXdeZ
 FuzzyRuleAntecedent *ePerXdeZ = new FuzzyRuleAntecedent();
  ePerXdeZ->joinWithAND(Per, dZ);
 //Output Setting
 FuzzyRuleConsequent *OutePerXdeZ = new FuzzyRuleConsequent();
 OutePerXdeZ->addOutput(Kp2);
   OutePerXdeZ->addOutput(Ki1);
    OutePerXdeZ->addOutput(Kd1);
 //Fuzzy Rule8
 FuzzyRule *fuzzyRule8 = new FuzzyRule(8, ePerXdeZ, OutePerXdeZ);
  fuzzy->addFuzzyRule(fuzzyRule8);
//-----------------------------------------------------------------------------//
   //Case9=ePerXdeNer
 FuzzyRuleAntecedent *ePerXdePer = new FuzzyRuleAntecedent();
  ePerXdePer->joinWithAND(Per, dPer);
 //Output Setting
 FuzzyRuleConsequent *OutePerXdePer = new FuzzyRuleConsequent();
 OutePerXdePer->addOutput(Kp3);
   OutePerXdePer->addOutput(Ki2);
```

```
    OutePerXdePer->addOutput(Kd1);
  //Fuzzy Rule9
  FuzzyRule *fuzzyRule9 = new FuzzyRule(9, ePerXdePer, OutePerXdePer);
   fuzzy->addFuzzyRule(fuzzyRule9);

 //<---------------------------FZ
//PID

  myPID.SetMode(AUTOMATIC);
  //myPID.SetSampleTime(1);
  myPID.SetOutputLimits(-255,255);
  ////Encoder setup
  pinMode(encoderPinA, INPUT_PULLUP); // กำหนดโหมดเป็นแบบ Input pullup
  pinMode(encoderPinB, INPUT_PULLUP);
  pinMode(clearButton, INPUT_PULLUP);

  attachInterrupt(0, doEncoderA, CHANGE); //ทำงานแบบ interrupt เบอร์ 0 ในนี้คือขา
pin 2
  attachInterrupt(1, doEncoderB, CHANGE); //ทำงานแบบ interrupt เบอร์ 1 ในนี้คือขา
pin 3

  encoderPos = 0;

}
//<---------------------------FZ
float previouserror=0 ;
unsigned long previousTime;
unsigned long time;
```

```
//<--------------------------FZ


void loop() {
   // Read compass values
  compass.read();

  // Return Azimuth reading
  DA = compass.getAzimuth();
  a=DA;//callibration -250 degree
  CT=a;

  //Overturn fucntion 0-365 Degree of Azimuth
  angle_error = CT - Nav ;
  if (angle_error < -180) angle_error += 360 ;
  if (angle_error > 180) angle_error -= 360 ;



///Encoder Loop
  rotating = true;  // reset the debouncer

  if (lastReportedPos != encoderPos) {
    lastReportedPos = encoderPos;


  }
if (digitalRead(clearButton) == LOW )  {
    encoderPos = 0;
```

```
   Setpoint=2800;
  }
 if (Automode==0) {Input = encoderPos;}
 if (Automode==1) {

//Kp=45, Ki=1, Kd=.1;//Nav Mode existing Kp=10; Ki=.7; Kd=.5;
  //Input = CT;
  Input=angle_error;
  //Setpoint=Nav;
    Setpoint=0;
  }
 if (encoderPos > 2800) {Automode=1;}
////////////////////////////////
int val = analogRead(A0);
  Nav= int((358./1020.) *val);
///////////////////////////////
lcd.setCursor(0,1);
lcd.print("SP:");
lcd.print(Setpoint);
lcd.print(",%");
lcd.print(Output*100/255);
lcd.print("    ");
lcd.setCursor(0,2);
lcd.print("Nav:");
lcd.print(Nav);
lcd.print("  ");
//<----------------------------------
```

```
lcd.setCursor(8,2);
lcd.print("CT:");
lcd.print(CT);
lcd.print("  ");
//<------------------------------
if (Automode==0) {
lcd.setCursor(0,3);
lcd.print("Mode:");
lcd.print("Int.Steering");}

if (Automode==1) {
lcd.setCursor(0,3);
lcd.print("Mode:");
lcd.print("Compass Nav.   ");}
//////////////////////////////////////////////////////
 //Input = encoderPos;//Inputdata
////////////////////////////////////////////////////////
  myPID.Compute();
  pwmOut(Output);
 lcd.setCursor(0,0);
    lcd.print("EN:");
  lcd.print(encoderPos);
  lcd.print("  ");
 lcd.print("AZ:");
 if (a>0) {b=(a);}
 if (a<0) {b=(a+360);}
 lcd.print(b);
```

```
lcd.print("  ");
////////////////////////////////////////////////



 //float Error = random(-180, 180);
 float Error = angle_error;
 float dError ;
 previousTime = time;
 time = millis();
 float interval = (time - previousTime)/1000;
 //dError =(Error- previouserror )/ interval;
 dError =(Error- previouserror );
 previouserror=Error;



Serial.print("Previous RAD error: ");
 Serial.println(previouserror);



 Serial.print("Degree of error: ");
 Serial.print(Error);
 Serial.println(" Rad.");

 Serial.print("Degree d error/dt: ");
 Serial.print(dError);
 Serial.println(" Rad./Sec.");
```

```
 Serial.print("Time: ");
 Serial.print(time/1000);
 Serial.println(" Sec.");

 Serial.print("previousTime: ");
 Serial.print(previousTime/1000);
 Serial.println(" Sec.");

 Serial.print("interval: ");
 Serial.print(interval);
 Serial.println(" Sec.");


 // Print serial for recording (Tunning, Kp,ki,kd),(Fuzzy Ki Kp kd),Hybrid PID+Fuzzy Control
 //PWM steering , Compass Control, Speed 25 km/hr: 42m/min: 0.69 m/s
printindex++;
Serial.print("DATA,TIME");
Serial.print(",");
Serial.print(printindex);//no.
Serial.print(",");Serial.print(Setpoint);//Int.Setpoint
Serial.print(","); Serial.print(encoderPos);//Encoder Position
Serial.print(","); Serial.print(Output*100/255);//PWM %
Serial.print(",");Serial.print(Nav);//Nav.Setpoint
Serial.print(","); Serial.print(b);// AZimuth
Serial.print(","); Serial.print(angle_error);// Angle Error
Serial.print(","); Serial.print(dError);// Angle Error
Serial.print(","); Serial.print(Kp);// Kp
```

```
Serial.print(","); Serial.print(Ki);// Ki
Serial.print(","); Serial.println(Kd);// Kd
//delay(100);
//<----------------------------FZ

if (Automode==1) {
  fuzzy->setInput(1, Error);
  fuzzy->setInput(2, dError);

  fuzzy->fuzzify();
  float output1 = fuzzy->defuzzify(1);
  float output2 = fuzzy->defuzzify(2);
  float output3 = fuzzy->defuzzify(3);
  float FKp =output1;
  float FKi =output2;
  float FKd =output3;
  if (FKp==0){Kp=Kp;} else {Kp = output1;}
  if (FKi==0){Ki=Ki;} else {Ki = output2;}
  if (FKd==0){Kd=Kd;} else {Kd = output3;}
}

  Serial.println("PID Parameter Setting: ");
  Serial.print("Kp: ");
  Serial.println(Kp);
  Serial.print("Ki: ");
  Serial.println(Ki);
  Serial.print("Kd: ");
```

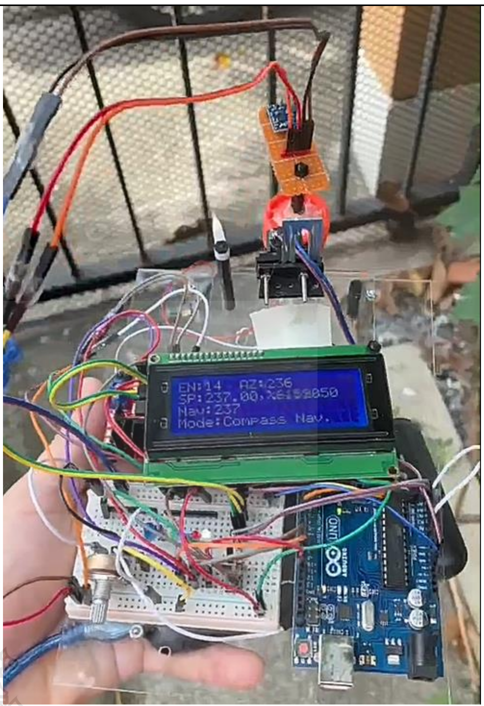
```
  Serial.println(Kd);
  Serial.println("--------------------------------------------------");



  // Sampling Rate Every 1 Sec.
  delay(100);
//<-----------------------------FZ
}

void pwmOut (int out){
if (out>0){
    analogWrite(PWM, out);
    cw ();
}
else {
  analogWrite(PWM, abs(out));
    ccw ();
}
  }

  void initialDisplay(){
  lcd.init();
  lcd.backlight();
 }
  void cw () {
   digitalWrite(motorPin1, HIGH);
```

```
  digitalWrite(motorPin2, LOW);
  }
  void ccw () {
   digitalWrite(motorPin1, LOW);
  digitalWrite(motorPin2, HIGH);
  }
  void off () {
   digitalWrite(motorPin1, LOW);
  digitalWrite(motorPin2, LOW);
  }

 //Encoder Functions

// คำสั่งทำงานแบบ interrupt เมื่อมีการหมุน
void doEncoderA() {
  // debounce
  if ( rotating ) delay (1);  // หน่วงเวลาป้องกันสัญญาณบกวน debounce

  // เช็คว่ามีบิดสวิตช์
  if ( digitalRead(encoderPinA) != A_set ) { // debounce once more
    A_set = !A_set;
    // adjust counter + if A leads B
    if ( A_set && !B_set )
      encoderPos += 1;
    rotating = false;  // no more debouncing until loop() hits again
  }
}
```

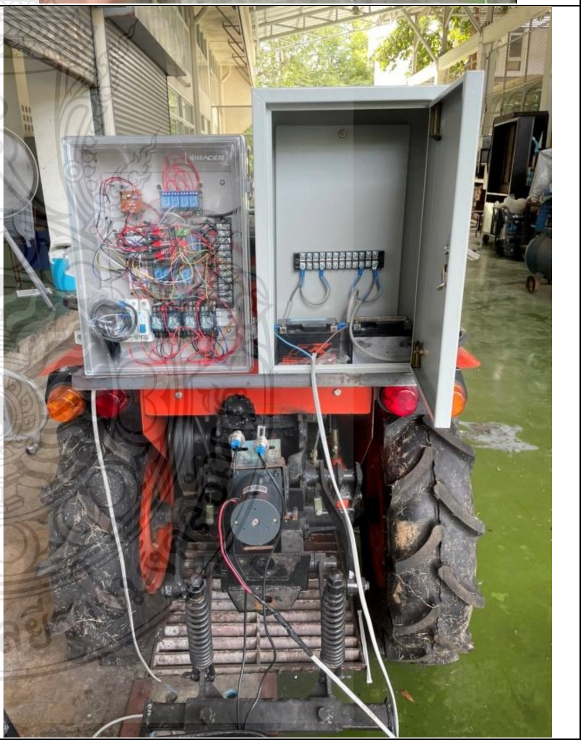
```
// Interrupt on B changing state, same as A above
void doEncoderB() {
  if ( rotating ) delay (1);
  if ( digitalRead(encoderPinB) != B_set ) {
    B_set = !B_set;
    //  adjust counter - 1 if B leads A
    if ( B_set && !A_set )
      encoderPos -= 1;
    rotating = false;
  }
}
```

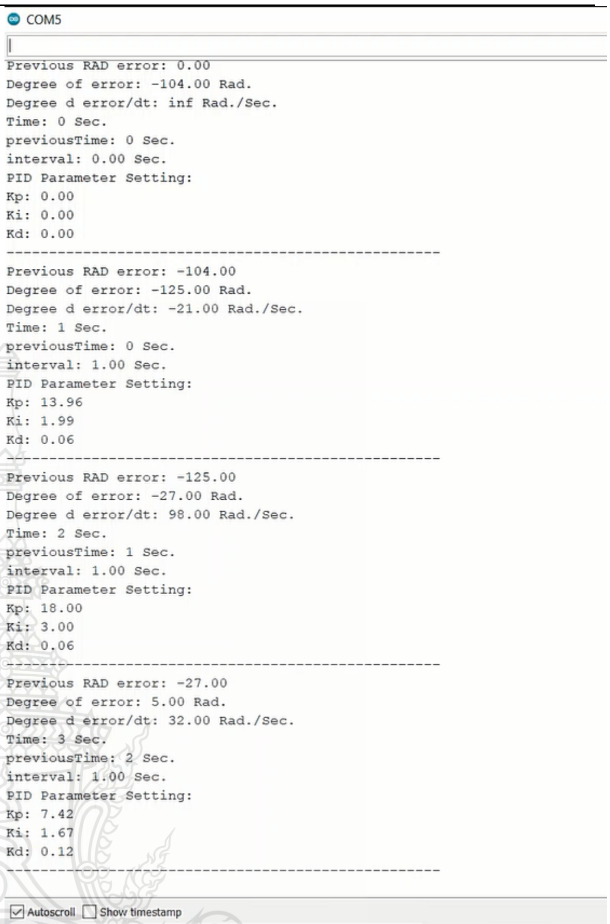
APPENDIX C

Pictures Documentation

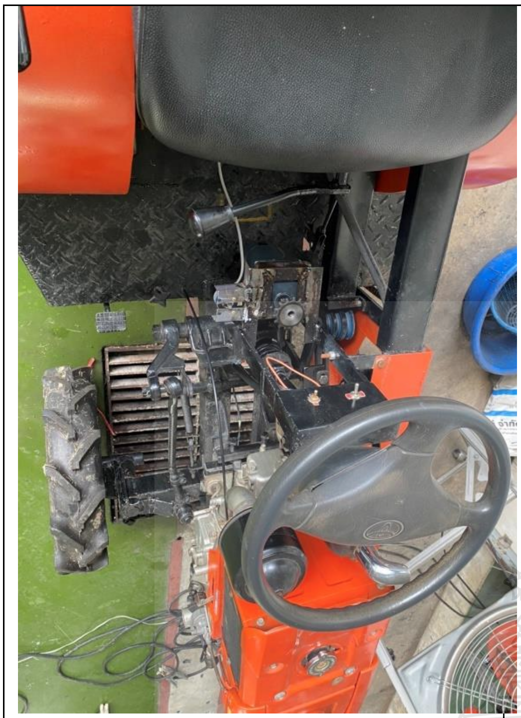


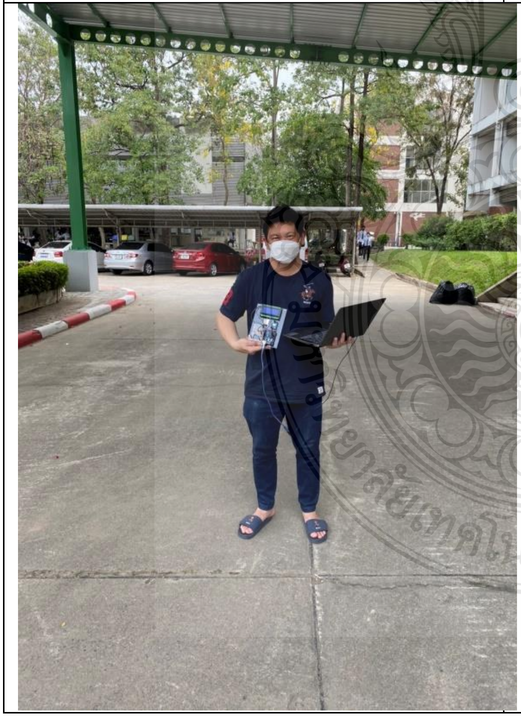
```
EN:14  AZ:236
SP:237.00,X[illegible]
Nav:237
Mode:Compass Nav.
```

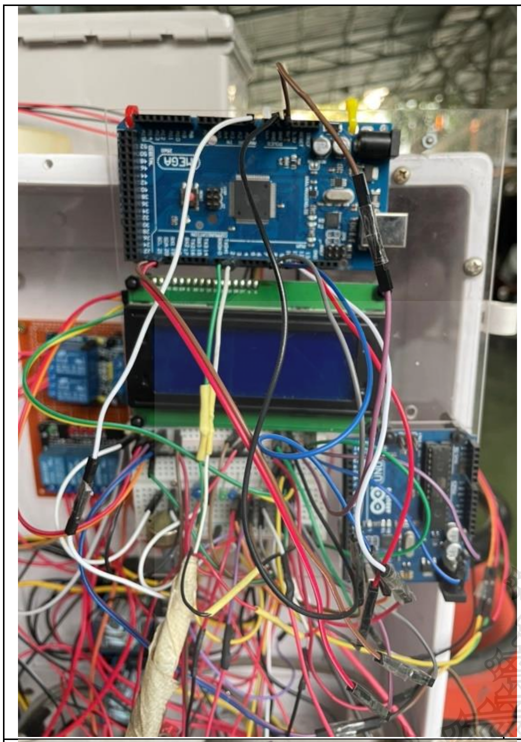


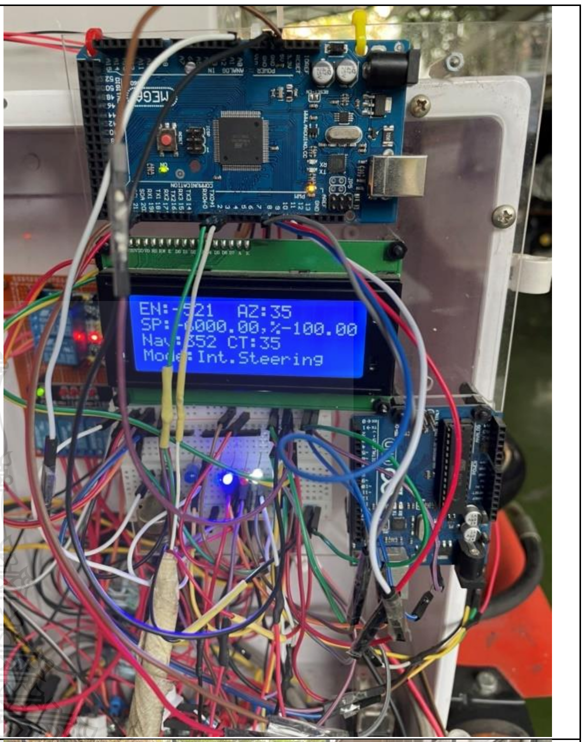


```
Previous RAD error: 0.00
Degree of error: -104.00 Rad.
Degree d error/dt: inf Rad./Sec.
Time: 0 Sec.
previousTime: 0 Sec.
interval: 0.00 Sec.
PID Parameter Setting:
Kp: 0.00
Ki: 0.00
Kd: 0.00
--------------------------------------------------
Previous RAD error: -104.00
Degree of error: -125.00 Rad.
Degree d error/dt: -21.00 Rad./Sec.
Time: 1 Sec.
previousTime: 0 Sec.
interval: 1.00 Sec.
PID Parameter Setting:
Kp: 13.96
Ki: 1.99
Kd: 0.06
--------------------------------------------------
Previous RAD error: -125.00
Degree of error: -27.00 Rad.
Degree d error/dt: 98.00 Rad./Sec.
Time: 2 Sec.
previousTime: 1 Sec.
interval: 1.00 Sec.
PID Parameter Setting:
Kp: 18.00
Ki: 3.00
Kd: 0.06
--------------------------------------------------
Previous RAD error: -27.00
Degree of error: 5.00 Rad.
Degree d error/dt: 32.00 Rad./Sec.
Time: 3 Sec.
previousTime: 2 Sec.
interval: 1.00 Sec.
PID Parameter Setting:
Kp: 7.42
Ki: 1.67
Kd: 0.12
--------------------------------------------------
```

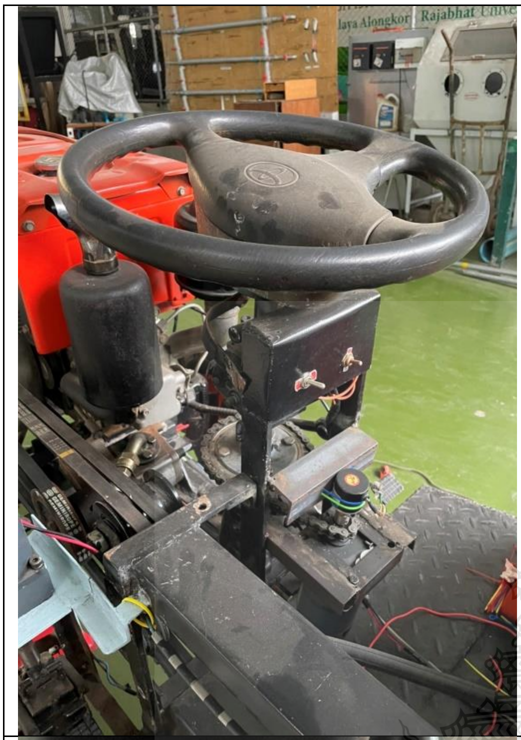








```
EN:-521  AZ:35
SP:-6000.00,%-100.00
Nav:352 CT:35
Mode:Int.Steering
```

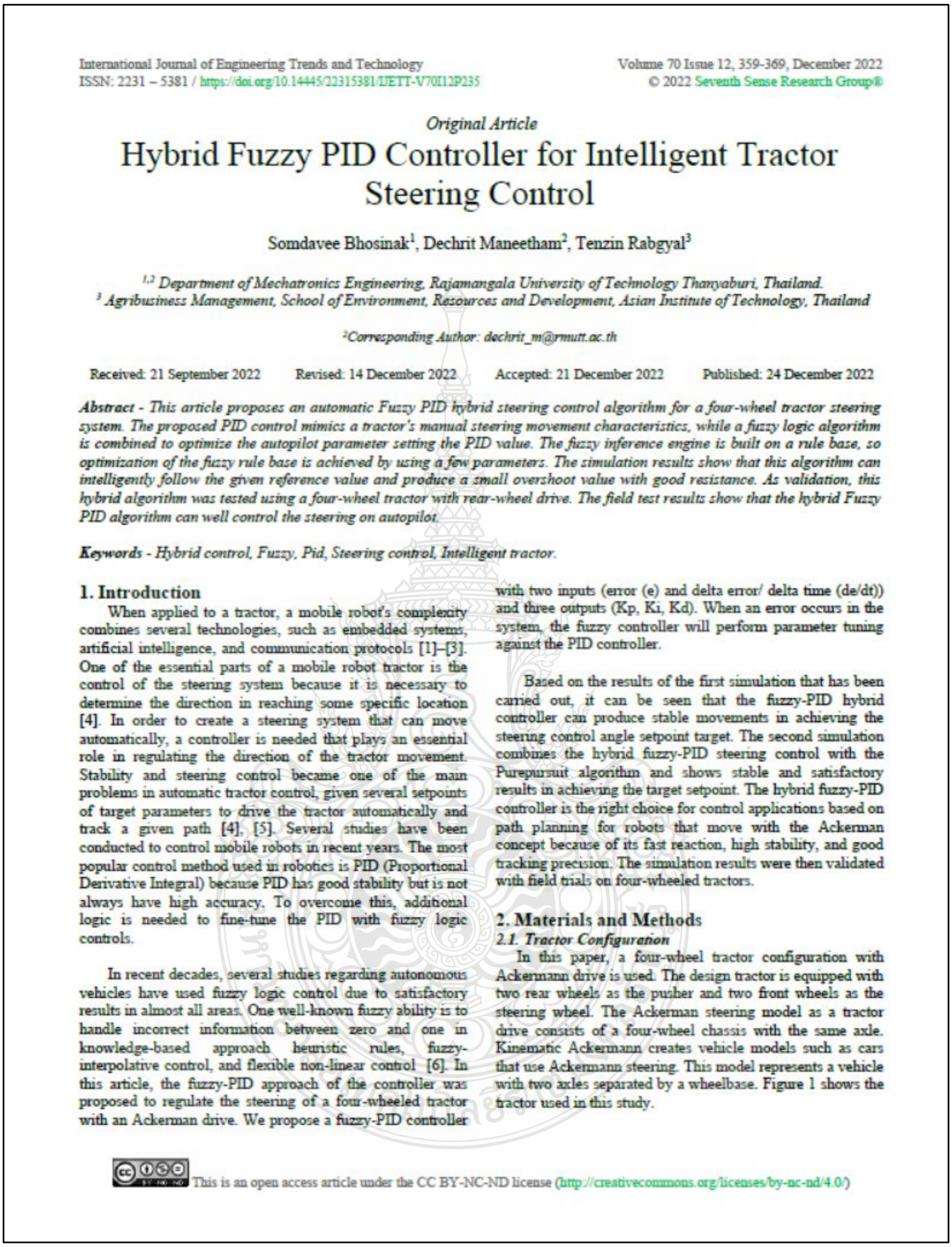
	
ZYTD80S-9F1-022-190404 DC 24V 2000RPM	

Appendix D

International Publications

Somdavee B, Maneetham D, Tenzin : Hybrid Fuzzy PID Controller for Intelligent Tractor Steering Control. International Journal of Engineering Trends and Technology. 24 Dec 2022, Volume 70 Issue 12, 359-369. https://doi.org/10.14445/22315381/IJETT-V70I12P235 (Scopus Q4)

Somdavee B, Maneetham D, Tenzin : Design and testing of remote four wheeled tractor with steering control. International Conference on Heat Transfer, Energy and Mechanical Innovations (ICHTEMI 2022) AIP Publishing LLC (Scopus)



International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 / https://doi.org/10.14445/22315381/IJETT-V70I12P235

Volume 70 Issue 12, 359-369, December 2022

Original Article

Hybrid Fuzzy PID Controller for Intelligent Tractor Steering Control

Somdavee Bhosinak[1], Dechrit Maneetham[2], Tenzin Rabgyal[3]

[1,2] Department of Mechatronics Engineering, Rajamangala University of Technology Thanyaburi, Thailand.
[3] Agribusiness Management, School of Environment, Resources and Development, Asian Institute of Technology, Thailand

[2]Corresponding Author: dechrit_m@rmutt.ac.th

Received: 21 September 2022 Revised: 14 December 2022 Accepted: 21 December 2022 Published: 24 December 2022

Abstract *- This article proposes an automatic Fuzzy PID hybrid steering control algorithm for a four-wheel tractor steering system. The proposed PID control mimics a tractor's manual steering movement characteristics, while a fuzzy logic algorithm is combined to optimize the autopilot parameter setting the PID value. The fuzzy inference engine is built on a rule base, so optimization of the fuzzy rule base is achieved by using a few parameters. The simulation results show that this algorithm can intelligently follow the given reference value and produce a small overshoot value with good resistance. As validation, this hybrid algorithm was tested using a four-wheel tractor with rear-wheel drive. The field test results show that the hybrid Fuzzy PID algorithm can well control the steering on autopilot.*

Keywords *- Hybrid control, Fuzzy, Pid, Steering control, Intelligent tractor.*

1. Introduction

When applied to a tractor, a mobile robot's complexity combines several technologies, such as embedded systems, artificial intelligence, and communication protocols [1]–[3]. One of the essential parts of a mobile robot tractor is the control of the steering system because it is necessary to determine the direction in reaching some specific location [4]. In order to create a steering system that can move automatically, a controller is needed that plays an essential role in regulating the direction of the tractor movement. Stability and steering control became one of the main problems in automatic tractor control, given several setpoints of target parameters to drive the tractor automatically and track a given path [4], [5]. Several studies have been conducted to control mobile robots in recent years. The most popular control method used in robotics is PID (Proportional Derivative Integral) because PID has good stability but is not always have high accuracy. To overcome this, additional logic is needed to fine-tune the PID with fuzzy logic controls.

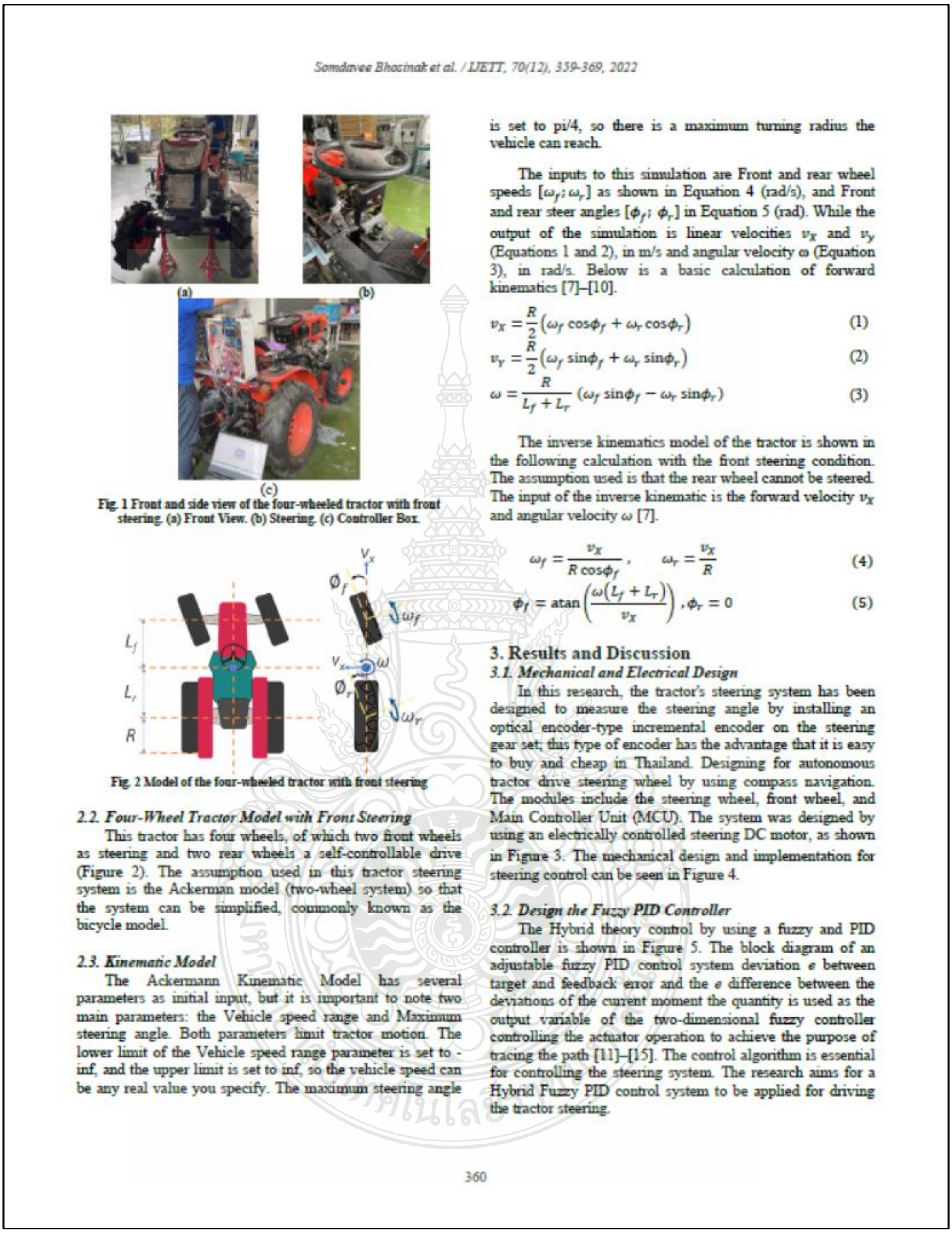
In recent decades, several studies regarding autonomous vehicles have used fuzzy logic control due to satisfactory results in almost all areas. One well-known fuzzy ability is to handle incorrect information between zero and one in knowledge-based approach heuristic rules, fuzzy-interpolative control, and flexible non-linear control [6]. In this article, the fuzzy-PID approach of the controller was proposed to regulate the steering of a four-wheeled tractor with an Ackerman drive. We propose a fuzzy-PID controller with two inputs (error (e) and delta error/ delta time (de/dt)) and three outputs (Kp, Ki, Kd). When an error occurs in the system, the fuzzy controller will perform parameter tuning against the PID controller.

Based on the results of the first simulation that has been carried out, it can be seen that the fuzzy-PID hybrid controller can produce stable movements in achieving the steering control angle setpoint target. The second simulation combines the hybrid fuzzy-PID steering control with the Purepursuit algorithm and shows stable and satisfactory results in achieving the target setpoint. The hybrid fuzzy-PID controller is the right choice for control applications based on path planning for robots that move with the Ackerman concept because of its fast reaction, high stability, and good tracking precision. The simulation results were then validated with field trials on four-wheeled tractors.

2. Materials and Methods

2.1. Tractor Configuration

In this paper, a four-wheel tractor configuration with Ackermann drive is used. The design tractor is equipped with two rear wheels as the pusher and two front wheels as the steering wheel. The Ackerman steering model as a tractor drive consists of a four-wheel chassis with the same axle. Kinematic Ackermann creates vehicle models such as cars that use Ackermann steering. This model represents a vehicle with two axles separated by a wheelbase. Figure 1 shows the tractor used in this study.



(a) (b)

(c)

Fig. 1 Front and side view of the four-wheeled tractor with front steering. (a) Front View. (b) Steering. (c) Controller Box.

Fig. 2 Model of the four-wheeled tractor with front steering

2.2. Four-Wheel Tractor Model with Front Steering

This tractor has four wheels, of which two front wheels as steering and two rear wheels a self-controllable drive (Figure 2). The assumption used in this tractor steering system is the Ackerman model (two-wheel system) so that the system can be simplified, commonly known as the bicycle model.

2.3. Kinematic Model

The Ackermann Kinematic Model has several parameters as initial input, but it is important to note two main parameters: the Vehicle speed range and Maximum steering angle. Both parameters limit tractor motion. The lower limit of the Vehicle speed range parameter is set to -inf, and the upper limit is set to inf, so the vehicle speed can be any real value you specify. The maximum steering angle is set to pi/4, so there is a maximum turning radius the vehicle can reach.

The inputs to this simulation are Front and rear wheel speeds $[\omega_f; \omega_r]$ as shown in Equation 4 (rad/s), and Front and rear steer angles $[\phi_f; \phi_r]$ in Equation 5 (rad). While the output of the simulation is linear velocities v_X and v_y (Equations 1 and 2), in m/s and angular velocity ω (Equation 3), in rad/s. Below is a basic calculation of forward kinematics [7]–[10].

$$v_X = \frac{R}{2}\left(\omega_f \cos\phi_f + \omega_r \cos\phi_r\right) \tag{1}$$

$$v_Y = \frac{R}{2}\left(\omega_f \sin\phi_f + \omega_r \sin\phi_r\right) \tag{2}$$

$$\omega = \frac{R}{L_f + L_r}\left(\omega_f \sin\phi_f - \omega_r \sin\phi_r\right) \tag{3}$$

The inverse kinematics model of the tractor is shown in the following calculation with the front steering condition. The assumption used is that the rear wheel cannot be steered. The input of the inverse kinematic is the forward velocity v_X and angular velocity ω [7].

$$\omega_f = \frac{v_X}{R\cos\phi_f}, \qquad \omega_r = \frac{v_X}{R} \tag{4}$$

$$\phi_f = \operatorname{atan}\left(\frac{\omega\left(L_f + L_r\right)}{v_X}\right), \phi_r = 0 \tag{5}$$

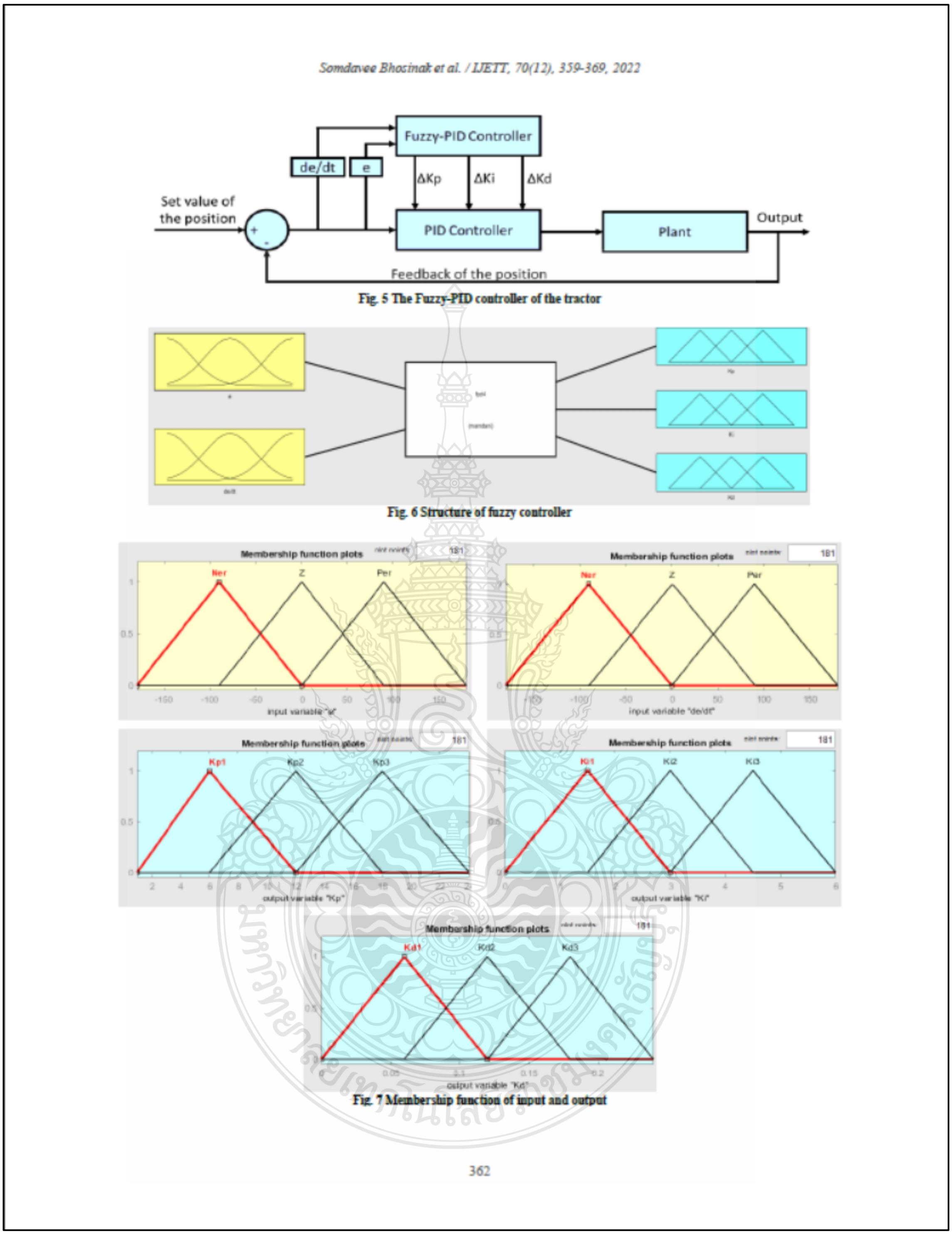
3. Results and Discussion

3.1. Mechanical and Electrical Design

In this research, the tractor's steering system has been designed to measure the steering angle by installing an optical encoder-type incremental encoder on the steering gear set; this type of encoder has the advantage that it is easy to buy and cheap in Thailand. Designing for autonomous tractor drive steering wheel by using compass navigation. The modules include the steering wheel, front wheel, and Main Controller Unit (MCU). The system was designed by using an electrically controlled steering DC motor, as shown in Figure 3. The mechanical design and implementation for steering control can be seen in Figure 4.

3.2. Design the Fuzzy PID Controller

The Hybrid theory control by using a fuzzy and PID controller is shown in Figure 5. The block diagram of an adjustable fuzzy PID control system deviation *e* between target and feedback error and the *e* difference between the deviations of the current moment the quantity is used as the output variable of the two-dimensional fuzzy controller controlling the actuator operation to achieve the purpose of tracing the path [11]–[15]. The control algorithm is essential for controlling the steering system. The research aims for a Hybrid Fuzzy PID control system to be applied for driving the tractor steering.



Somdavee Bhosinak et al. / IJETT, 70(12), 359-369, 2022

Fig. 5 The Fuzzy-PID controller of the tractor

Fig. 6 Structure of fuzzy controller

Fig. 7 Membership function of input and output

362

The developed fuzzy controller manages the PID controller's input value based on the compass sensor's target setpoint. Fuzzy logic is a theory widely used in academic studies of controllable robots [16]–[19]. The fuzzy control system has three basic structural blocks: fuzzification, inference machine, and defuzzification.

Fuzzification is an initial stage in fuzzy control that makes changes to each real value of inputs and outputs into a membership function. Furthermore, fuzzy inference is carried out to combine the facts of the rule-based fuzzification needed in the fuzzy reasoning process. The fuzzy inference has various applications depending on the form of membership function. One form of fuzzy is IF antecedents), THEN conclusions), and rules based on predefined input and output variables. The last part is defuzzification, which changes a subset of the output calculated by the inference engine.

This study used the Mamdani fuzzy inference system [20]–[23]. Figure 6 shows the Fuzzy-PID controller structure with two inputs in the form of error (e) and delta error/delta time (de/dt). Triangular membership function used on fuzzification block. The variable e dan de/dt is defined by three triangular membership functions: negative error (Ner), zero (Z), and positive error (Per). For Kp, Ki, and Kd, each is defined by three triangular membership functions, as shown in Figure 7.

The input from the tractor steering system (fuzzy logic control) is based on real conditions in the form of an angular value generated from the compass sensor. The fuzzy rule base is defined after the detailed process of membership functions is performed. In Figure 8, you can see the fuzzy rules used in this study.

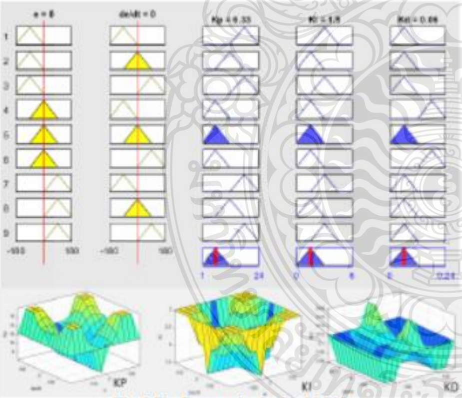


Fig. 8 The Fuzzy rules for Kp/Ki/Kd

Before field trials, it is necessary to test through simulations to obtain tractor movement using a hybrid Fuzzy-PID controller. The first test scenario is applied by providing an input value of 45°. Meanwhile, in the second simulation scenario, we use the waypoint concept with a pure pursuit [24]–[26] as an additional control system, as shown in Figure 9.

3.3. Simulation

Kinematic models and control designs that have been made are then implemented in Simulink using several interconnected block diagrams. Table 1 shows the DC Motor specification. Figure 10 shows the block diagram of the first scenario simulation with the parameters shown in Table 2. The first scenario is used to see the performance of the Fuzzy-PID design. The transfer function of the DC motor used can be seen in Equation 6. At the same time, the steering model used in the tractor is described in the transfer function of Equation 7.

$$G_{dcmotor}(s) = \frac{0.12}{0.04s + 1.1} \quad (6)$$

$$G_{motoroutput}(s) = \frac{1}{0.0012s + 0.0002} \quad (7)$$

Table 1. DC Motor Specifications

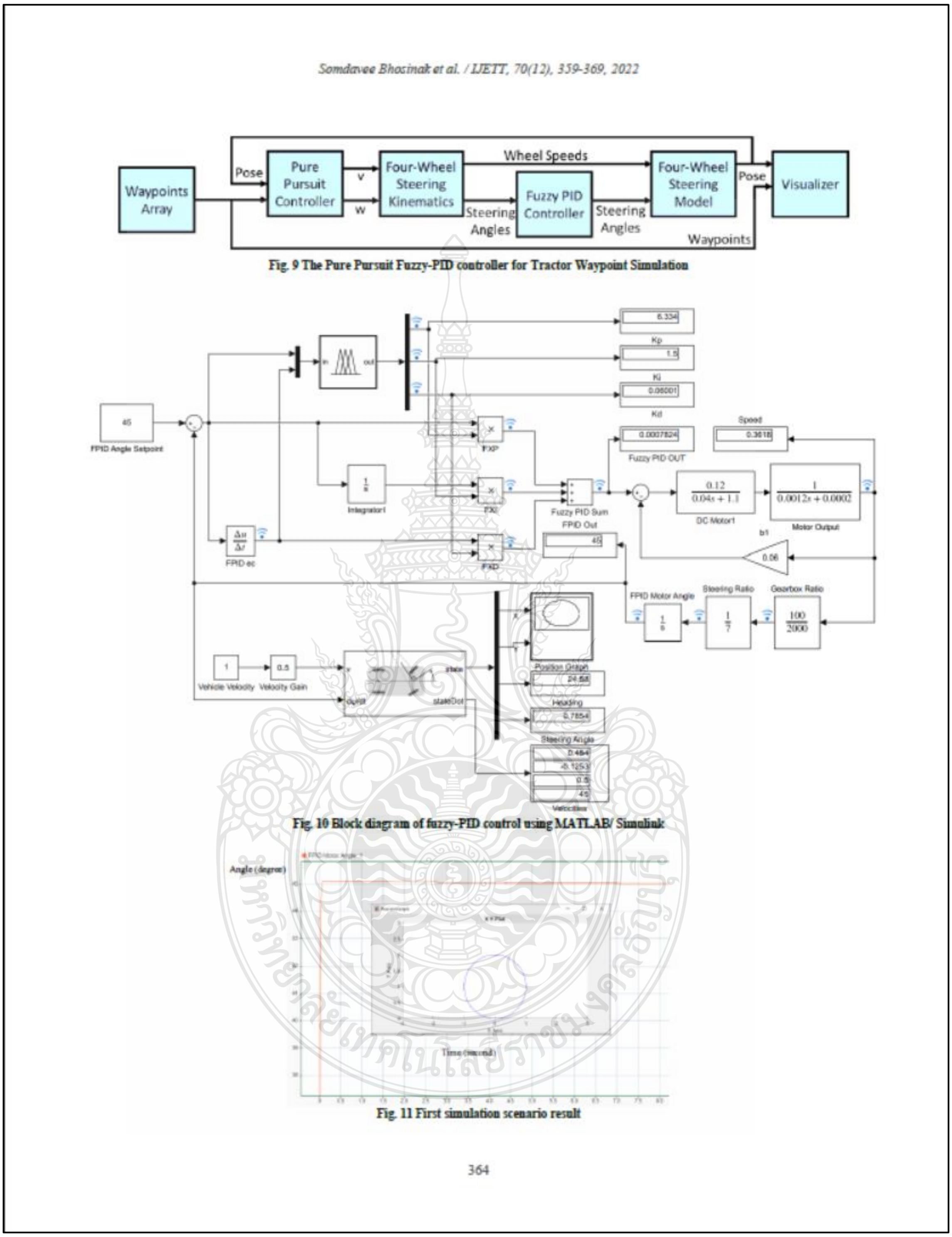
DC motor	W	V	A	N.M	RPM	rad/s
ZYTD-80SRZ-9F1	90	24	3.75	0.429	2000	209

Table 2. Parameters Value for First Scenario Simulation

Parameters		Value	Parameters		Value
FPID Angle Setpoint/ Target	:	45 °	**Maximum Steering Angle**	:	pi/4 rad
Vehicle Speed Range	:	0.25 m/s	**Initial State**	:	[0,0,0,0]
Wheel Base	:	1 m			

In Figure 11, the movement results form a circle with a 45 ° steering angle as the target setpoint. The graph shows the rise time value of 0.068s, a fast time to reach the setpoint even though there is an overshoot of 0.11 degrees (tolerable). In addition, the peak time achieved is 0.11 seconds with a setting time of 7 seconds. From this graph, the fuzzy PID design can reach the target setpoint to be implemented on the tractor. Before being implemented in the field trial, we simulated the second scenario by adding a pure pursuit control waypoint navigation system.

Pure pursuit control is applied to the second simulation scenario to get the results of the tractor movement based on the target coordinate points. Figure 12 shows the input poses and waypoints in the form of an array of coordinates [x,y; x_1,y_1;……;x_n,y_n], which is linked to the pure pursuit block diagram.



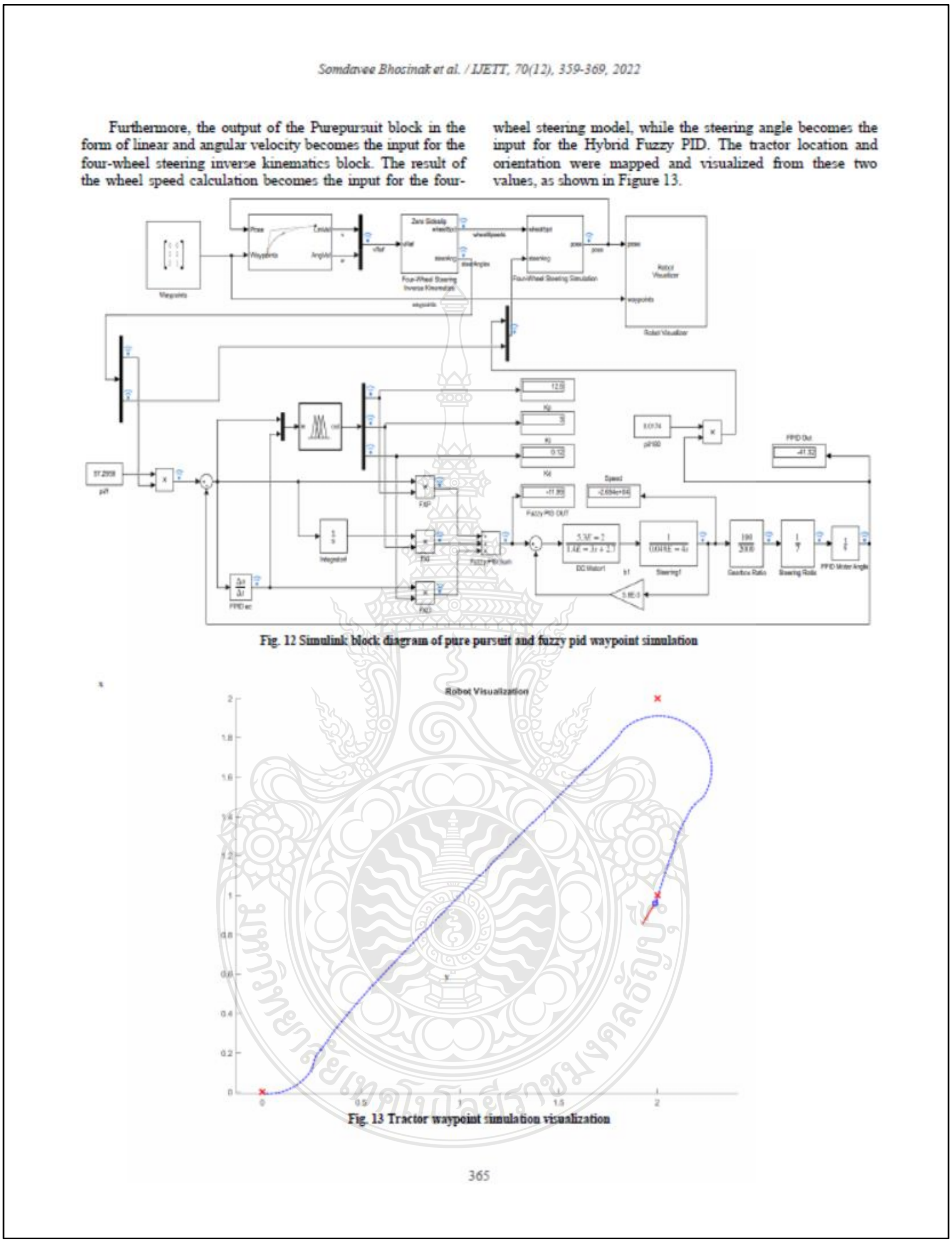
Somdavee Bhosinak et al. / IJETT, 70(12), 359-369, 2022

Fig. 9 The Pure Pursuit Fuzzy-PID controller for Tractor Waypoint Simulation

Fig. 10 Block diagram of fuzzy-PID control using MATLAB/ Simulink

Fig. 11 First simulation scenario result

364



Furthermore, the output of the Purepursuit block in the form of linear and angular velocity becomes the input for the four-wheel steering inverse kinematics block. The result of the wheel speed calculation becomes the input for the four-wheel steering model, while the steering angle becomes the input for the Hybrid Fuzzy PID. The tractor location and orientation were mapped and visualized from these two values, as shown in Figure 13.

Fig. 12 Simulink block diagram of pure pursuit and fuzzy pid waypoint simulation

Fig. 13 Tractor waypoint simulation visualization

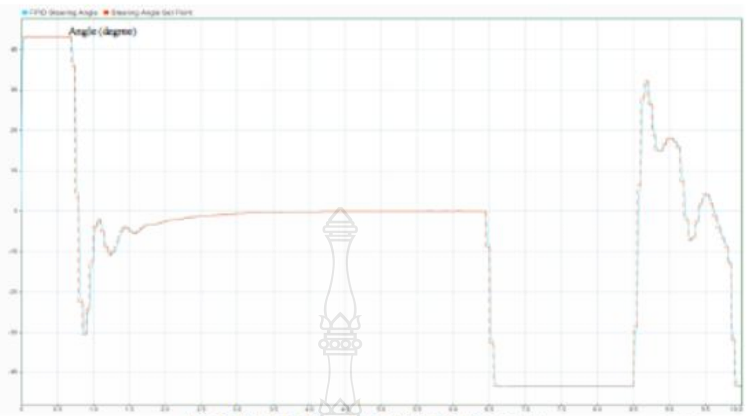


Fig. 14 Graph for Fuzzy PID and Set Point Comparison

The graph shown in Figure 14 shows that the Hybrid Fuzzy PID controller can achieve the target setpoint smoothly. The negative value is the movement of the tractor turning left, while the positive value is the movement of the tractor turning right.

3.4. Experiment

Furthermore, we conducted a field test using a scenario to validate the simulation results, as shown in Figure 15. The path-tracking process starts from the initial mode, namely, the steering control unit is controlled by Kp1, Ki1, and Kd1 (constant) values without fuzzy influence to reset the wheel rotation. Steering to the starting point (move left) until the limit switch is touched (zero position). Next, the encoder sensor calculates the steering position starting from zero to turn the steering wheel (moves to the right) to the middle position. When the steering wheel is in the middle position, the navigation mode is activated so that the steering wheel moves automatically based on the compass sensor as a direction detector where the control unit with PID hybrid control theory and fuzzy logic determines the values of Kp2, Ki2, and Kd2.

The field test results are shown in Figure 16, where the target setpoint of the steering angle is a degree of the azimuth of 357 degrees. The start point of the wheel angle comes from the compass sensor readings. Initial steering mode starts from zero seconds which then turns the steering wheel towards the left until the limit switch is triggered at eight seconds. After that, the steering wheel is turned towards the right to reach the center of the wheel before finally being switched to compass navigation mode at fourteen seconds. After switching modes, Hybrid Fuzzy-PID is activated to reach the target setpoint.

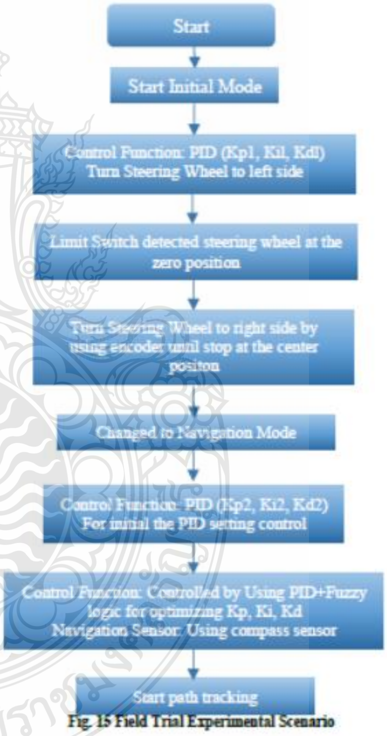


Fig. 15 Field Trial Experimental Scenario

Fig. 16 Degree of Azimuth of Fuzzy PID Control (Initial Mode)

Fig. 17 Fuzzy PID, PWM, and Encoder Value Record (Initial Mode)

The response time required is 8 seconds, with a difference of 1 second between the simulation (Figure 11) and the field test. Figure 17 shows changes in the values of Kp, Ki, Kd, PWM, and Encoder from time to time.

Furthermore, the steering control test on the tractor was carried out using a remote control. The test was carried out at the parking lot of the Industrial Technology Faculty, Valaya Alongkorn Rajabhat University. As shown, Figure 18 is the result of GPS tracking of a tractor controlled using a Radio Frequency (RF) remote; the red line shows the recorded track.

Modifications were made to the positioning of sensors and data recording devices based on the initial test results, as the vibration from the tractor's engine is so intense that it influences sensor readings. As shown in Figure 19, the sensors and data recording equipment were relocated to the tractor's rear by adding a small wagon. Figure 20 depicts the results of tracking the location of the tractor's movement.

During the second test, the parameter values P, I, and D in the fuzzy PID controller of the steering robot controller were obtained in real-time, as shown in the graph in Figure 21. A comparison between the angular and actual target setpoints was performed and is shown in Figure 22.

Fig. 18 GPS Tracking Field Trial Result

Fig. 19 Wagon Installation on Tractor

Fig. 20 Second Trial GPS Tracking

Fig. 21 Graph for PID Value

Fig. 22 Field Trial Graph for Fuzzy PID and Set Point (Compass) Comparison

4. Conclusion

This research proposes a Hybrid fuzzy PID-based tractor steering control based on goal parameters. The experimental findings demonstrate that the suggested algorithm effectively controls routes with cement pavement. Because of its quick response, high stability, and excellent tracking precision, a hybrid fuzzy-PID controller is an optimal choice for control applications based on robot waypoints utilizing the Ackerman principle. The presented algorithm has promising application prospects in agricultural working settings that are complex and harsh for agricultural machines.

Acknowledgments

This research was supported by Rajamangala University of Technology Thanyaburi (RMUTT) and Valaya Alongkorn Rajabat University (VRU). The authors acknowledge Phummarin Thavitchasri for his crucial support throughout the data gathering of the tractor.

References

[1] Idris IdrisSunusi et al., "Intelligent Tractors: Review of Online Traction Control Process," *Computers and Electronics in Agriculture*, vol. 170, 2020. *Crossref*, https://doi.org/10.1016/j.compag.2019.105176

[2] Witcha Upaphai, Pracha Bunyawanichakul, and Maunsak Janthong, "Trajectory Tracking Control Design for An Autonomous Tractor Using Fuzzy PID Controller," *International Journal of Agricultural Technology*, vol. 13, no. 4, pp. 501–519, 2017.

[3] Nattaphol Nasathit, Mohd Azli Bin Salim and Choulatee Photong, "Design and Development of An Electric Tractor Using Simple Remote Control," *Engineering Access*, vol. 8, no. 1, 2022. *Crossref*, https://doi.org/10.14456/mijet.2022.16

[4] Junnan Yin et al., "Automatic Steering Control Algorithm Based on Compound Fuzzy PID for Rice Transplanter," *Applied Sciences (Switzerland)*, vol. 9, no. 13, pp. 2-14, 2019. *Crossref*, https://doi.org/10.3390/app9132666

[5] Minghui Yu et al., "Trajectory Planning and Tracking for Carrier Aircraft-Tractor System Based on Autonomous and Cooperative Movement," *Mathematical Problems in Engineering*, vol. 2020, pp. 1-24, 2020, *Crossref*, https://doi.org/10.1155/2020/6531984

[6] Hajer Omrane, Mohamed Slim Masmoudi and Mohamed Masmoudi, "Fuzzy Logic Based Control for Autonomous Mobile Robot Navigation," *Computational Intelligence and Neuroscience*, vol. 2016, p. 9548482. 2016, *Crossref*, https://doi.org/10.1155/2016/9548482

[7] Do Khac Tiep et al., "Design of Fuzzy-PID Controller for Path Tracking of Mobile Robot With Differential Drive," *International Journal of Fuzzy Logic and Intelligent Systems*, vol. 18, no. 3, pp. 220–228, 2018, *Crossref*, http://dx.doi.org/10.5391/IJFIS.2018.18.3.220

[8] Bruno Siciliano et al., *Robotics Modelling, Planning and Control*, Advanced Textbooks in Control and Signal Processing, Springer, 2009.

[9] A. P. Okunev et al., "Digital Modeling and Testing of Tractor Characteristics," *Russian Engineering Research*, vol. 39, no. 6, pp. 453–458, Jun. 2019, *Crossref*, http://dx.doi.org/10.3103/S1068798X19060157

[10] Daniel Antal and Tamás Szabó, "Controlling and Modeling of an Automated Guided Vehicle," *Proceedings of the 2012 13th International Carpathian Control Conference : ICCC*, pp. 1–6, 2012. *Crossref*, https://doi.org/10.1109/CarpathianCC.2012.6228606

[11] Xianbo Xiang et al., "Survey on Fuzzy-Logic-Based Guidance and Control of Marine Surface Vehicles and Underwater Vehicles," *International Journal of Fuzzy Systems*, vol. 20, no. 2, pp. 572–586, 2018. *Crossref*, https://doi.org/10.1007/s40815-017-0401-3

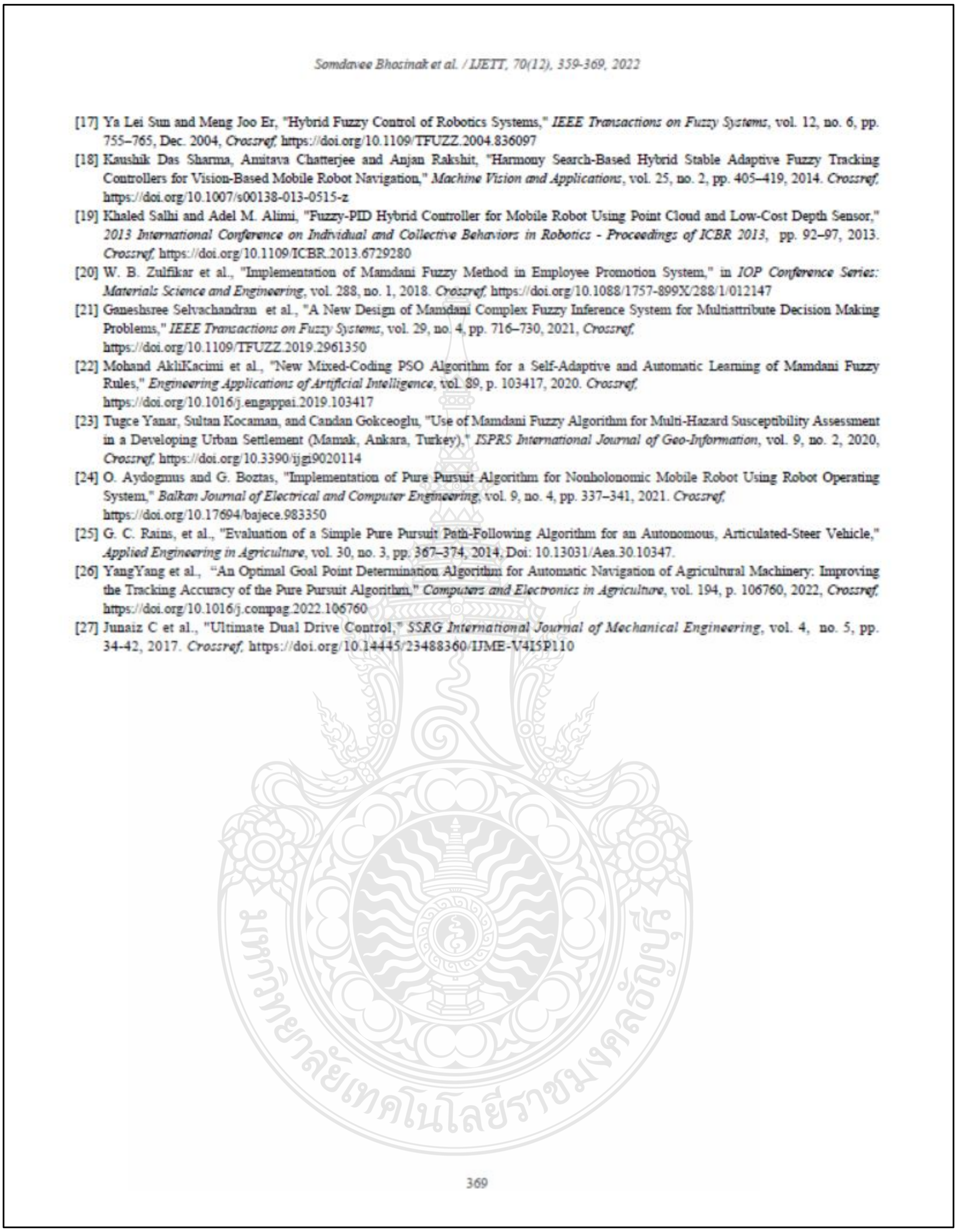
[12] Ngangbam HerojitSingh and KhelchandraThongam, "Mobile Robot Navigation Using Fuzzy Logic in Static Environments," *Procedia Computer Science*, vol. 125, pp. 11–17, 2018. *Crossref*, https://doi.org/10.1016/j.procs.2017.12.004

[13] Oscar Castillo and Patricia Melin, "A Review on Interval Type-2 Fuzzy Logic Applications in Intelligent Control," *Information Sciences*, vol. 279, pp. 615–631, 2014. *Crossref*, https://doi.org/10.1016/j.ins.2014.04.015

[14] Mohamed Esmail Karar, Ahmed Hamdy El-Garawany and Mohamed El-Brawany, "Optimal Adaptive Intuitionistic Fuzzy Logic Control of Anti-Cancer Drug Delivery Systems," *Biomedical Signal Processing and Control*, vol. 58, p. 101861, 2020. *Crossref*, https://doi.org/10.1016/j.bspc.2020.101861

[15] P. X. Thuy and N. T. Cuong, "Vision Based Autonomous Path/Line Following of a Mobile Robot Using a Hybrid Fuzzy PID Controller," *Collection of the 3rd National Science Project on Control & Automation of VCCA*, 2016. *Crossref*, https://doi.org/10.15625/vap.2015.0012

[16] H. Jiangqiang, L. Tieshan, and G. Chen, "Design of GA-Based Fuzzy Control for Ship Steering," *Proceedings of the World Congress on Intelligent Control and Automation (WCICA)*, vol. 1, pp. 3594–3598, 2006. *Crossref*, https://doi.org/10.1109/WCICA.2006.17130395



[17] Ya Lei Sun and Meng Joo Er, "Hybrid Fuzzy Control of Robotics Systems," *IEEE Transactions on Fuzzy Systems*, vol. 12, no. 6, pp. 755–765, Dec. 2004, *Crossref,* https://doi.org/10.1109/TFUZZ.2004.836097

[18] Kaushik Das Sharma, Amitava Chatterjee and Anjan Rakshit, "Harmony Search-Based Hybrid Stable Adaptive Fuzzy Tracking Controllers for Vision-Based Mobile Robot Navigation," *Machine Vision and Applications*, vol. 25, no. 2, pp. 405–419, 2014. *Crossref,* https://doi.org/10.1007/s00138-013-0515-z

[19] Khaled Salhi and Adel M. Alimi, "Fuzzy-PID Hybrid Controller for Mobile Robot Using Point Cloud and Low-Cost Depth Sensor," *2013 International Conference on Individual and Collective Behaviors in Robotics - Proceedings of ICBR 2013*, pp. 92–97, 2013. *Crossref,* https://doi.org/10.1109/ICBR.2013.6729280

[20] W. B. Zulfikar et al., "Implementation of Mamdani Fuzzy Method in Employee Promotion System," in *IOP Conference Series: Materials Science and Engineering*, vol. 288, no. 1, 2018. *Crossref,* https://doi.org/10.1088/1757-899X/288/1/012147

[21] Ganeshsree Selvachandran et al., "A New Design of Mamdani Complex Fuzzy Inference System for Multiattribute Decision Making Problems," *IEEE Transactions on Fuzzy Systems*, vol. 29, no. 4, pp. 716–730, 2021, *Crossref,* https://doi.org/10.1109/TFUZZ.2019.2961350

[22] Mohand AkliKacimi et al., "New Mixed-Coding PSO Algorithm for a Self-Adaptive and Automatic Learning of Mamdani Fuzzy Rules," *Engineering Applications of Artificial Intelligence*, vol. 89, p. 103417, 2020. *Crossref,* https://doi.org/10.1016/j.engappai.2019.103417

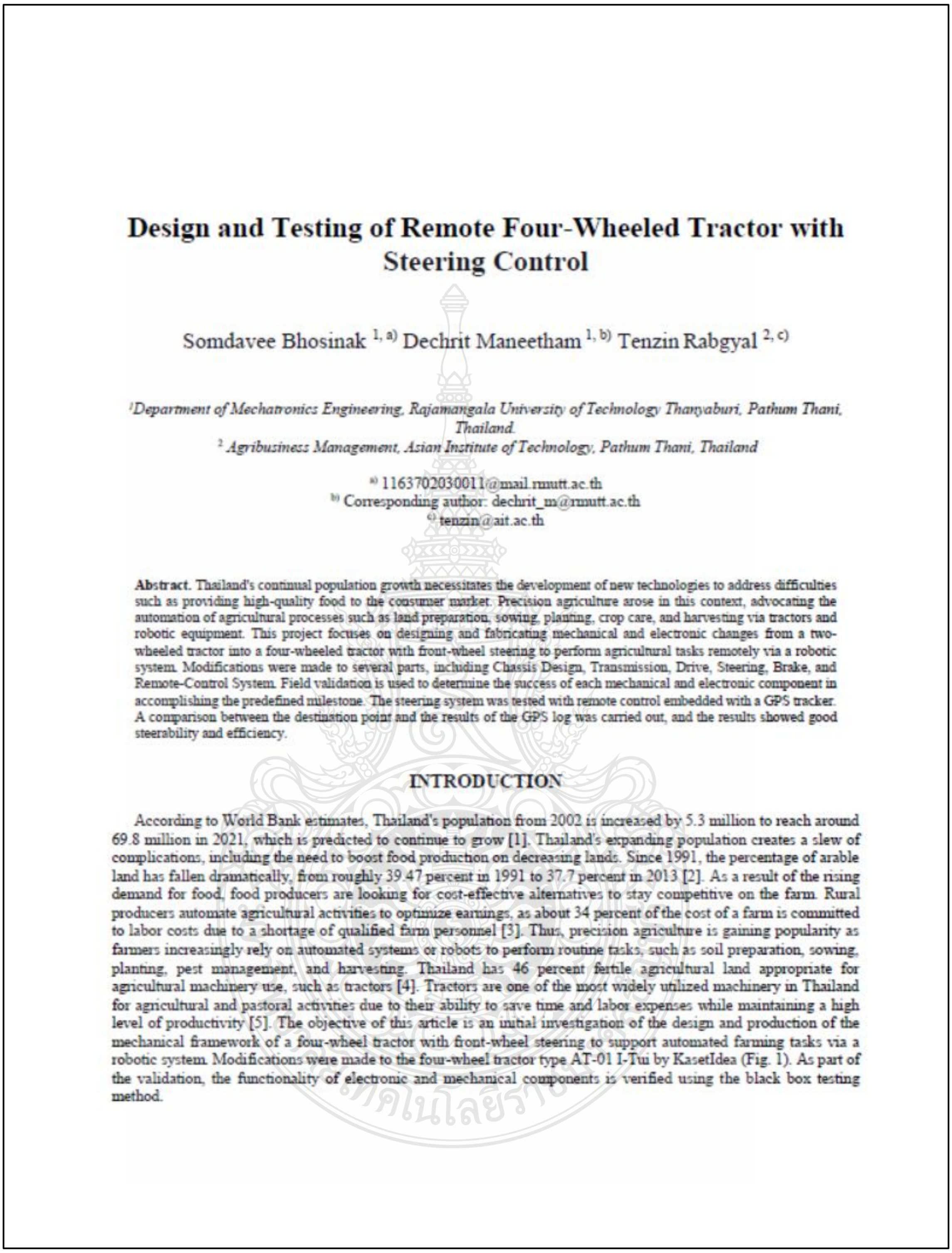
[23] Tugce Yanar, Sultan Kocaman, and Candan Gokceoglu, "Use of Mamdani Fuzzy Algorithm for Multi-Hazard Susceptibility Assessment in a Developing Urban Settlement (Mamak, Ankara, Turkey)," *ISPRS International Journal of Geo-Information*, vol. 9, no. 2, 2020, *Crossref,* https://doi.org/10.3390/ijgi9020114

[24] O. Aydogmus and G. Boztas, "Implementation of Pure Pursuit Algorithm for Nonholonomic Mobile Robot Using Robot Operating System," *Balkan Journal of Electrical and Computer Engineering*, vol. 9, no. 4, pp. 337–341, 2021. *Crossref,* https://doi.org/10.17694/bajece.983350

[25] G. C. Rains, et al., "Evaluation of a Simple Pure Pursuit Path-Following Algorithm for an Autonomous, Articulated-Steer Vehicle," *Applied Engineering in Agriculture*, vol. 30, no. 3, pp. 367–374, 2014, Doi: 10.13031/Aea.30.10347.

[26] YangYang et al., "An Optimal Goal Point Determination Algorithm for Automatic Navigation of Agricultural Machinery: Improving the Tracking Accuracy of the Pure Pursuit Algorithm," *Computers and Electronics in Agriculture*, vol. 194, p. 106760, 2022, *Crossref,* https://doi.org/10.1016/j.compag.2022.106760

[27] Junaiz C et al., "Ultimate Dual Drive Control," *SSRG International Journal of Mechanical Engineering*, vol. 4, no. 5, pp. 34-42, 2017. *Crossref,* https://doi.org/10.14445/23488360/IJME-V4I5P110



Design and Testing of Remote Four-Wheeled Tractor with Steering Control

Somdavee Bhosinak [1, a)] Dechrit Maneetham [1, b)] Tenzin Rabgyal [2, c)]

[1]*Department of Mechatronics Engineering, Rajamangala University of Technology Thanyaburi, Pathum Thani, Thailand.*
[2] *Agribusiness Management, Asian Institute of Technology, Pathum Thani, Thailand*

[a)] 1163702030011@mail.rmutt.ac.th
[b)] Corresponding author: dechrit_m@rmutt.ac.th
[c)] tenzin@ait.ac.th

Abstract. Thailand's continual population growth necessitates the development of new technologies to address difficulties such as providing high-quality food to the consumer market. Precision agriculture arose in this context, advocating the automation of agricultural processes such as land preparation, sowing, planting, crop care, and harvesting via tractors and robotic equipment. This project focuses on designing and fabricating mechanical and electronic changes from a two-wheeled tractor into a four-wheeled tractor with front-wheel steering to perform agricultural tasks remotely via a robotic system. Modifications were made to several parts, including Chassis Design, Transmission, Drive, Steering, Brake, and Remote-Control System. Field validation is used to determine the success of each mechanical and electronic component in accomplishing the predefined milestone. The steering system was tested with remote control embedded with a GPS tracker. A comparison between the destination point and the results of the GPS log was carried out, and the results showed good steerability and efficiency.

INTRODUCTION

According to World Bank estimates, Thailand's population from 2002 is increased by 5.3 million to reach around 69.8 million in 2021, which is predicted to continue to grow [1]. Thailand's expanding population creates a slew of complications, including the need to boost food production on decreasing lands. Since 1991, the percentage of arable land has fallen dramatically, from roughly 39.47 percent in 1991 to 37.7 percent in 2013 [2]. As a result of the rising demand for food, food producers are looking for cost-effective alternatives to stay competitive on the farm. Rural producers automate agricultural activities to optimize earnings, as about 34 percent of the cost of a farm is committed to labor costs due to a shortage of qualified farm personnel [3]. Thus, precision agriculture is gaining popularity as farmers increasingly rely on automated systems or robots to perform routine tasks, such as soil preparation, sowing, planting, pest management, and harvesting. Thailand has 46 percent fertile agricultural land appropriate for agricultural machinery use, such as tractors [4]. Tractors are one of the most widely utilized machinery in Thailand for agricultural and pastoral activities due to their ability to save time and labor expenses while maintaining a high level of productivity [5]. The objective of this article is an initial investigation of the design and production of the mechanical framework of a four-wheel tractor with front-wheel steering to support automated farming tasks via a robotic system. Modifications were made to the four-wheel tractor type AT-01 I-Tui by KasetIdea (Fig. 1). As part of the validation, the functionality of electronic and mechanical components is verified using the black box testing method.

FIGURE 1. I-Tui Tractor Type of AT-01 by KasetIdea (Front and Side View)

MATERIAL AND METHOD

Structure and Specifications

The tractor's structure is depicted in Fig. 1, including the engine, chassis, control system, and electronic equipment. The diesel engine (Kubota model RT 100) is 7.4 kW. The primary chassis comprises a gearbox, steering, drive, and braking system. DC motors, drivers, encoders, microcontrollers, and batteries are all examples of electronic equipment. The specifications of the tractor are presented in Table 1.

TABLE 1. Tractor Control Parameters

Function	Actuator	Voltage	RPM
Transmission	ZYTD80S-9F1-022-190404 DC MOTOR	24	2000
Brake	ZYTD80S-9F1-022-190404 DC MOTOR	24	2000
Steering	ZYTD80S-9F1-022-190404 DC MOTOR	24	2000

Chassis Design

The transmission is essential to the chassis, drive, steering, and braking systems (Fig. 2). The chassis was constructed and modified to convert the tractor from a two-wheel hand tractor to a four-wheel tractor. It was equipped with a steering system to be ridden and controlled from the tractor's top. Additionally, improvements were made to allow for electrical control of the tractor using a series of actuators and microcontrollers. The chassis is critical in keeping the engine safe [6].

FIGURE 2. Chassis Components. (1) Knuckle arm; (2) Tie Rod; (3) Drag Link; (4) Front Axle; (5) Longitudinal Tie; (6) Pitman Arm; (7) Steering Gear; (8) Steering Wheel; (9) Main Chassis; (10) Wheel Gear Block; (11) Brake.

Transmission System

The transmission system ties the gearbox and rear axle together. This engine has only one forward gear and one neutral gear. The tractor's rear was modified by adding an actuator, gear, and chain to enable shifting from neutral to drive gear and vice versa. (See Figure 3). The gear ratio is identical, even though the actuator (DC motor) must be operated in the low-efficiency zone with high current and torque for an extended period [7].

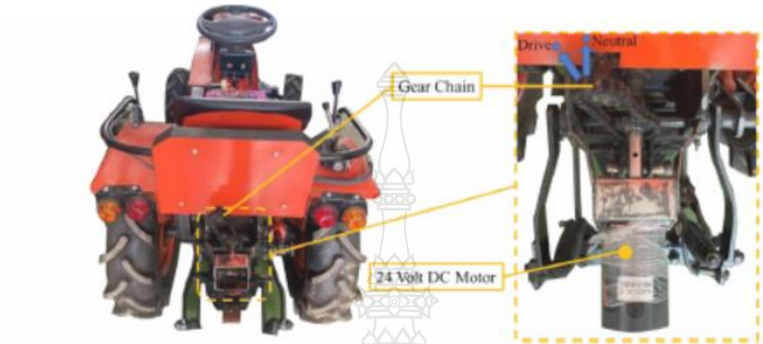


FIGURE 3. Transmission System.

Drive System

The two-wheel tractor drive system was changed by connecting the base chassis, wheel gear block, and Kubota RT100 engine (Fig. 4). A belt connects the wheel gear block to the engine. This study assumes the tractor speed is constantly based on the predetermined belt tension level. Testing costs are reduced by reusing outdated wheel gear blocks, which results in cheaper product prices and increased global competitiveness [8].

(a) (b)

FIGURE 4. Drive System. (a) Two-Wheel Tractor Gear Block Modification; (b) Kubota RT100 Engine.

Steering System

As illustrated in Fig. 5, by rotating the steering wheel, the gearbox converts the steering wheel's rotational motion to a straight-line movement, allowing the tractor's front wheel to be moved obliquely right or left [9]. The fundamental design was modified with the addition of an automatic steering system. A combination of large and small gears allows the steering wheel to be moved automatically. At the same time, a switch is fitted on the drag link and knuckle arm to limit the angle of wheel movement (Fig. 6).

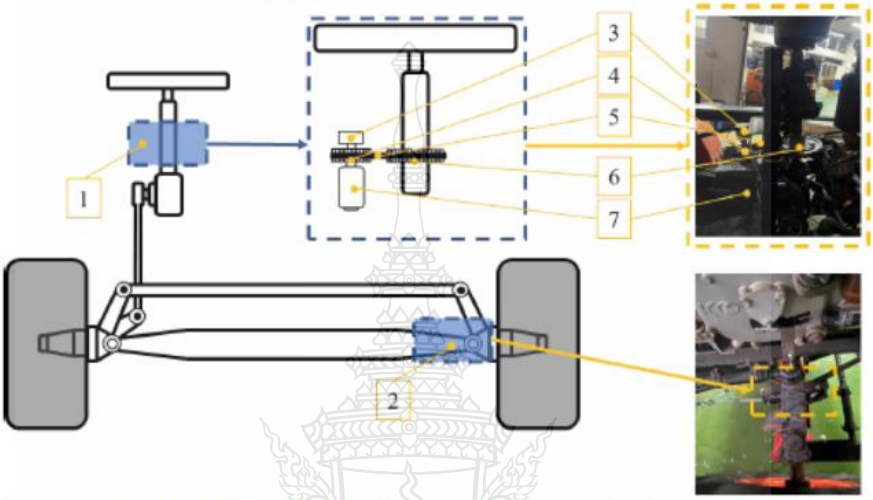


FIGURE 5. Steering System. (1) Actuator of the automatic steering system; (2) Front Wheel Limit Angle Switch; (3) Optical Rotary Encoder; (4) Actuator Gear; (5) Gear Chain; (6) Steering Axle Gear; (7) Actuator (DC Motor)

FIGURE 6. Limit Angle Switch Concept.

Brake System

Although foot pedals actuate the manual braking system, changes have been made to allow the pedals to be controlled automatically, as illustrated in Fig. 7. The top of the pedal is fitted with an actuator secured in place by the metal frame. The actuator is then connected via a shaft to the brake pedal pad. This design has both manual and automatic brakes for added safety. This system uses a rotary to linear motion concept [10].

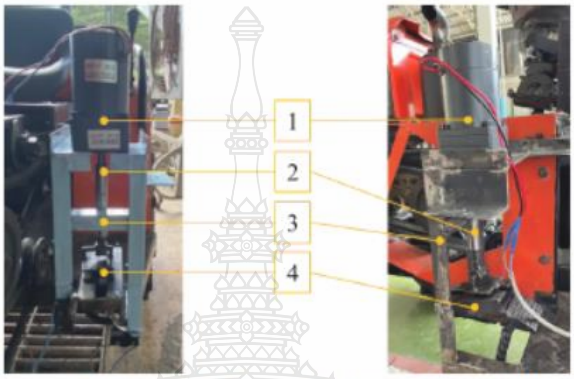


FIGURE 7. Brake System. (1) Actuator of the brake system; (2) Brake Shaft; (3) Actuator Holder; (4) Brake Pedal Pad.

RESULTS AND DISCUSSION

Control System

Fig.8 illustrates the electronic structure utilized to validate the mechanical and electronic functionality. The main control unit is an Arduino Mega connected to several actuators in the form of a DC motor and sensors (rotary encoder and switch). The tractor is operated via a Radio Frequency (RF) Remote Control equipped with a TX-2B transmitter and an RX-2B receiver. This tractor is also embedded with a GPS tracker to record the tractor's movement. Table 2 summarizes the situation and the results of preliminary tests conducted before field testing. As a result of the table, it is possible to conclude that the complete system can operate by the specified parameters.

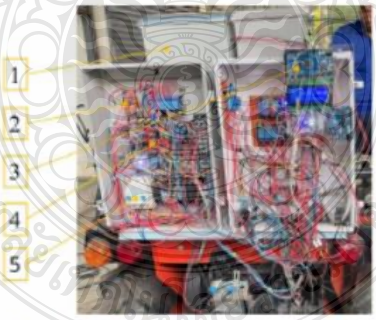


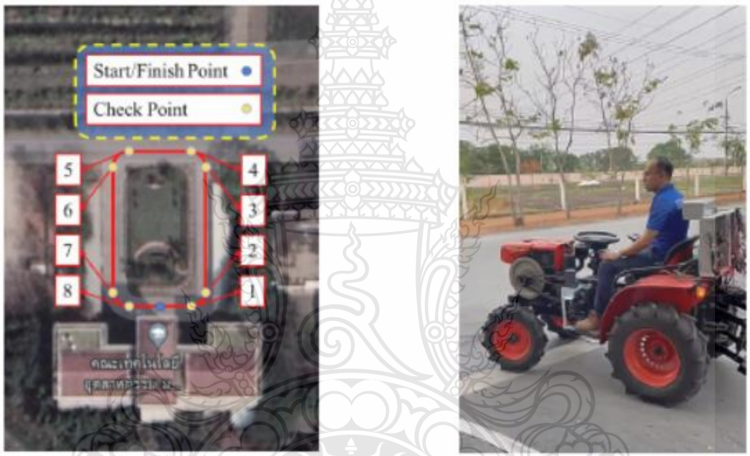
FIGURE 8. Remote Control and GSP Tracker Component. (1) GPS Box; (2) RX-2B; (3) Arduino Mega; (4) DC motor Drive; (5) Circuit Breakers.

TABLE 2. Testing Scenarios

Testing Scenario	Target	Result
RF Remote	The signal can be received	Success
Transmission	Switching from Drive and Neutral transmission (vice versa)	Success
Brake	Pressing and Loosen the Brake Pedal Pad	Success
	Go Straight, Turn Right, and Turn Left	Success
Steering	Encoder data reading	Success
	Limit angle switch (left and right)	Success

Field Test

This test was conducted in the vehicle park of the Industrial Technology Faculty, Valaya Alongkorn Rajabhat University. The field test scenario entails using an RF remote to guide the tractor along a specified course. Fig. 9a illustrates the path and checkpoints used to create the testing path. While Fig. 9b depicts the field conditions during the test, it also shows the location of humans on the tractor in case the tractor becomes uncontrollable. The tractor controlled by a remote successfully gained nine points during this field test, as given in Table 3.

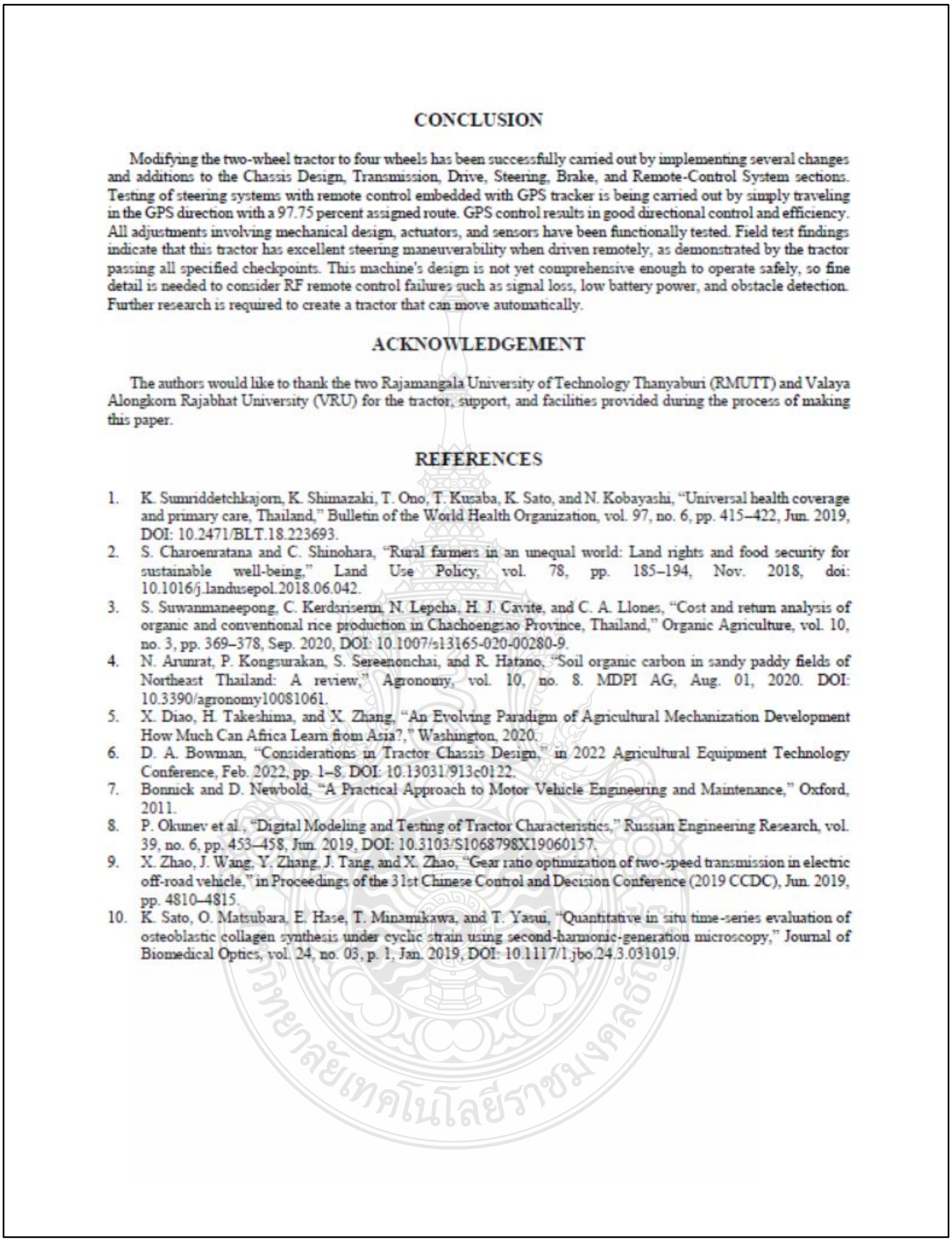


(a) (b)

FIGURE 9. Field Testing. (a) Scenario Path (b) Remote Tractor Test

TABLE 3. Field Testing Scenarios

Path Testing Scenario	Latitude Target	Longitude Target	Result
Start Point	14.134200	100.6097498	Success
First Check Point	14.134200	100.6098358	Success
Second Check Point	14.134231	100.6098758	Success
Third Check Point	14.134574	100.610410	Success
Fourth Check Point	14.134605	100.610364	Success
Fifth Check Point	14.134605	100.610235	Success
Sixth Check Point	14.134605	100.610181	Success
Seventh Check Point	14.134231	100.610186	Success
Eight Check Point	14.134200	100.610234	Success



CONCLUSION

Modifying the two-wheel tractor to four wheels has been successfully carried out by implementing several changes and additions to the Chassis Design, Transmission, Drive, Steering, Brake, and Remote-Control System sections. Testing of steering systems with remote control embedded with GPS tracker is being carried out by simply traveling in the GPS direction with a 97.75 percent assigned route. GPS control results in good directional control and efficiency. All adjustments involving mechanical design, actuators, and sensors have been functionally tested. Field test findings indicate that this tractor has excellent steering maneuverability when driven remotely, as demonstrated by the tractor passing all specified checkpoints. This machine's design is not yet comprehensive enough to operate safely, so fine detail is needed to consider RF remote control failures such as signal loss, low battery power, and obstacle detection. Further research is required to create a tractor that can move automatically.

ACKNOWLEDGEMENT

The authors would like to thank the two Rajamangala University of Technology Thanyaburi (RMUTT) and Valaya Alongkorn Rajabhat University (VRU) for the tractor, support, and facilities provided during the process of making this paper.

REFERENCES

1. K. Sumriddetchkajorn, K. Shimazaki, T. Ono, T. Kusaba, K. Sato, and N. Kobayashi, "Universal health coverage and primary care, Thailand," Bulletin of the World Health Organization, vol. 97, no. 6, pp. 415–422, Jun. 2019, DOI: 10.2471/BLT.18.223693.
2. S. Charoenratana and C. Shinohara, "Rural farmers in an unequal world: Land rights and food security for sustainable well-being," Land Use Policy, vol. 78, pp. 185–194, Nov. 2018, doi: 10.1016/j.landusepol.2018.06.042.
3. S. Suwanmaneepong, C. Kerdsriserm, N. Lepcha, H. J. Cavite, and C. A. Llones, "Cost and return analysis of organic and conventional rice production in Chachoengsao Province, Thailand," Organic Agriculture, vol. 10, no. 3, pp. 369–378, Sep. 2020, DOI: 10.1007/s13165-020-00280-9.
4. N. Arunrat, P. Kongsurakan, S. Sereenonchai, and R. Hatano, "Soil organic carbon in sandy paddy fields of Northeast Thailand: A review," Agronomy, vol. 10, no. 8. MDPI AG, Aug. 01, 2020. DOI: 10.3390/agronomy10081061.
5. X. Diao, H. Takeshima, and X. Zhang, "An Evolving Paradigm of Agricultural Mechanization Development How Much Can Africa Learn from Asia?," Washington, 2020.
6. D. A. Bowman, "Considerations in Tractor Chassis Design," in 2022 Agricultural Equipment Technology Conference, Feb. 2022, pp. 1–8. DOI: 10.13031/913c0122.
7. Bonnick and D. Newbold, "A Practical Approach to Motor Vehicle Engineering and Maintenance," Oxford, 2011.
8. P. Okunev et al., "Digital Modeling and Testing of Tractor Characteristics," Russian Engineering Research, vol. 39, no. 6, pp. 453–458, Jun. 2019, DOI: 10.3103/S1068798X19060157.
9. X. Zhao, J. Wang, Y. Zhang, J. Tang, and X. Zhao, "Gear ratio optimization of two-speed transmission in electric off-road vehicle," in Proceedings of the 31st Chinese Control and Decision Conference (2019 CCDC), Jun. 2019, pp. 4810–4815.
10. K. Sato, O. Matsubara, E. Hase, T. Minamikawa, and T. Yasui, "Quantitative in situ time-series evaluation of osteoblastic collagen synthesis under cyclic strain using second-harmonic-generation microscopy," Journal of Biomedical Optics, vol. 24, no. 03, p. 1, Jan. 2019, DOI: 10.1117/1.jbo.24.3.031019.

Biography

Name - Surename	Somdavee Bhosinak
Date of Birth	September 03, 1977
Address	235 Mooban Seri-Onnuch Praves Bangkok 10250
Education	Master Degree in Mechatronics Engineering – Rajamangala University of Technology Thanyaburi, from 2020- 2023. Bachelor Degree in Electrical Power Engineering – Mahanakorn University of Technology , from 1995 - 1999.
Experience Work	23 Years in Electrical Engineering Work Field as Present working at TEAM Consulting Engineering and Management Co., Ltd. Thailand.
Telephone Number	+66 8 4 6821292
Email Address	somdavee@gmail.com 1163702030011@mail.rmutt.ac.th