Research Article

Microcontroller-based Forklift Path Following Robot Prototype

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Abstract: The development of science in the field of robotics has made many heavy jobs that cannot be done by humans replaced by robots, especially in the factory industry. In modern factories, most of them have a warehouse or similar facility that contains heavy equipment for use in a factory, for example, forklift heavy equipment. Based on an interview with one of the forklift operators, the problem of using forklifts is usually when there are items that must be moved that cannot be lifted by humans which must be done immediately according to the route where the item is stored. To answer the existing problems, a robot prototype was made which is useful to help facilitate the work of factory workers. This robot prototype was built using the User Centered Design (UCD) method. This robot prototype uses the main components of Arduino UNO, L293D Motor Driver, and PWM Servo Motor Driver. Based on the overall testing that has been done, it can be said that the robot prototype can follow the route according to the program and can lift and remove objects in front of it with a score of 80%. So that workers can be helped to facilitate their work.

Keywords: Line Follower Robot; Microcontroller; Factory Industry; Otomation; forklift

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1. Introduction

The textile factory is a building in an industry in which there are production activities of goods, or products produced where workers are tasked with processing and supervising the processing of machines from one product to another to get added value for a product. Most modern factories have a warehouse or similar facility that contains heavy equipment for use in a factory, for example, forklift heavy equipment.

Based on observations of several factories in which there is heavy forklift equipment and interviews with one of the forklift operators. The problem of using forklifts is usually when there are items that must be moved that cannot be lifted by humans which must be done immediately according to the route where the item is stored. Forklift drivers usually have to be experts and have K3 (Occupational Safety and Health) certificates. So new forklift operators can officially operate if they already have the Ministry of Manpower's Forklift Operator K3 certification better known as the Forklift Operator SIO. But in reality, from the average factory that has been observed, there are problems where forklift operators have made mistakes that can have fatal consequences.

Based on observations, the problems that occur in a factory are caused by a forklift operator who does not understand the route situation and what obstacles he will pass through when operating the forklift. Such as passing through narrow areas, areas with many pedestrians, and areas with many piles of pallets. This lack of understanding can lead to fatal accidents for operators and other workers such as the risk of collisions and forklifts rolling over (15-20). Then another mistake when operating a forklift is an operator who does not understand the maximum height of the goods being moved so that the forklift operator's vision area is reduced and makes fatal accidents such as crashing into whatever is in front of him even though the times are increasingly sophisticated, factories should keep up with the times with technology that can minimize work accidents.

The development of science and technology has been very rapid lately, one of which is in the field of robotics. Robots are not inanimate objects that are only silent and do a job according to the program that has been determined by the maker. The role of robots in human life is getting more and more benefits from robots created, for example in the industrial field where the field of robotics is no longer underestimated as a science that develops only in the context of technology in the form of physical only, but more and more problems related to the human environment that need attention. So that it can reduce the risk of fatal accidents that will have an impact on the workplace, for example, a factory. After finding the existing problems, this research aims to produce a robot that is useful for assisting factory workers in removing objects beyond human limitations that will automatically remove the object.

2. Theory

2.1 Prototype

The initial model that is made to conduct trials related to the concept that has been made can be the definition of a prototype. Concepts that have been made are usually made prototypes to be implemented and marketed. In the market or business world, prototypes are included in the second stage before production.

One of the initial examples or models built to test a concept or process to act as something that must be replicated or learned is by making a prototype. In this way, the teaching and learning process becomes more interactive because it is directly practiced on the prototype. Prototype is the final picture of a product that will be made but the form is not final and can be changed, developed, or refined to become a final product. To develop a final product that is ready to circulate to the public or end users, the product will undergo three stages, namely prototype, Minimum Viable Product (MVP), and Proof of Concept (PoC) (Ibnu, 2021).

2.2 Type

According to (Sanjaya, 2021) there are two types of prototypes, namely physical prototypes and analytical prototypes. The following is the discussion:

1. Physical prototype which is a real object and is made to take into account the desired product with a real model made into an object and used for testing purposes by the developer. Needed to anticipate things that were not following the initial design and function properly according to the final product.
2. Analytical prototypes tend to be dynamic from physical prototypes because they are non-tangible such as sketches, simulations, and mathematics. From the 2 examples above related to physical prototypes and analytical prototypes, it can be concluded that there are differences in the media and the way they are made. What is now widely used is physical prototypes because they can be effective learning materials to be realized to the general public. However, it does not rule out the possibility of many analytical prototypes using it.

2.3 MVP

Minimum Viable Product abbreviated as MVP is a product with various basic features that can attract the attention of every user are also able to meet the needs of end users, and have a very high functional value even though the form itself is not too sophisticated. The term MVP was first introduced by Eric Ries, an American entrepreneur and startup consultant in his book entitled "Lean Startup". The book explains that MVP is a version of the product that allows entrepreneurs to be able to collect responses to consumer satisfaction levels with low effort and cost. The purpose of MVP is to speed up product launches, product testing can be done on real users and get real feedback and users save on spending funds and less risk of failure. The main characteristic of MVP is that there is enough value to attract users and can show future benefits (Ibnu, 2021).

2.4 PoC

Proof of Concept (PoC) is a phrase often used to describe early-stage research and is also a buzzword used to indicate that research has the potential to be scaled up. According to the Merriam-Webster Dictionary, PoC is defined as "Something that demonstrates the feasibility of a concept such as a product, idea, or business plan". Broadly speaking, proof in PoC means the likelihood of something happening in an experiment, while concept refers to an idea (whatever it is). Another definition given by the National Science Foundation is "The realization of a method or idea to confirm its scientific or technological parameters. PoCs should be sufficiently understood so that potential application areas can be identified and follow-on prototypes can be designed." Simply put, PoC is an initial launch of a program, process, method, principle, model, or idea to demonstrate or prove its feasibility. For example, PoC can be used to test whether a new technology works before it is rolled out to the wider community, whether a new curriculum can be widely implemented in the next school year, or whether a new product to be launched can be accepted by a wide audience. The steps to conduct PoC on technology adoption in the agricultural sector are (i) pre-planning, (ii) program planning, (iii) pre-implementation, (iv) program implementation, and (v) evaluation (Ulkhaq, Pertiwi, Wijayanto & Ningsih, 2021).

2.5 Line Follower Robot

Robots that can follow a line or route that has been made before automatically supported by circuits and electronic components equipped with wheels are also driven by motors that depend on the rotation limit between the base that is passed by the robot wheel and are called line followers robots. A simple design, the cost of making this robot is relatively cheap and the design of this robot can be realized using a large-scale robot prototype in the industry is the advantage of this line follower robot. A line follower robot is a device that can run automatically following a line of both black and white. The result of the color change causes the value on the photodiode to change, causing the value that enters the ADC port on the microcontroller to change and the ADC value that we will process into an input (K. Alisher, K. Alexander, and B. Alexandr, 2015).

2.6 Forklift

Material handling equipment such as heavy equipment that has the function of lifting, tilting, and moving heavy materials that humans are unable to do is called a forklift also called a fork truck intended for manufacturing and warehouses [20-25]. A forklift also called a forklift truck is a device consisting of a body (body) and work equipment (work equipment) that is used to load goods (loading) and unload (unloading) its main function is as a means of transporting goods that can be used in industry to move goods to the goods storage room with 4-DOF, namely forward and backward motion, right turn and left turn, and Fork motion to carry or lift goods, while Mast motion functions for Lifting and Tilting (Poniman, Yulis). Forklifts are divided into several types that are tailored to their respective needs and functions to facilitate human work, especially workers who work in manufacturing or warehouses.

3. Method

3.1 Flowchart and Block Diagram System

After observing a warehouse in which there is a forklift, the author analyzes how a forklift works with its pilot to move one object to another place. From the process of using the forklift, the author argues that it is not easy to use heavy forklift equipment because one must have a skill in using it so that not just anyone can drive a forklift. The prototype of the forklift line follower robot is designed to help the company, especially workers who work using heavy forklift equipment, in facilitating a job of moving objects that workers are unable to lift. Designing this prototype requires several stages, preparing the components to be used, making prototypes, programming prototypes, and the final stage, namely testing prototypes so that prototype results are obtained with accurate performance. Furthermore, the author studies research from the results of observations in one warehouse by analyzing the running system by analyzing the objects needed for the system to be designed which is intended to focus on the functions of the running system without focusing on the flow of system processes.

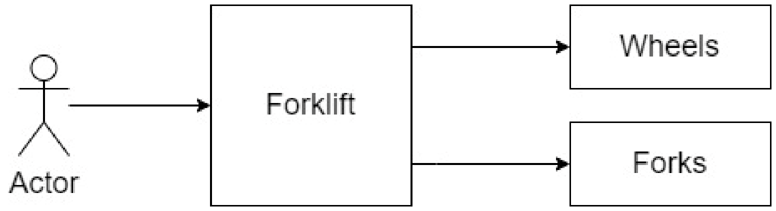


Figure 1. Simple block diagram and user relationship

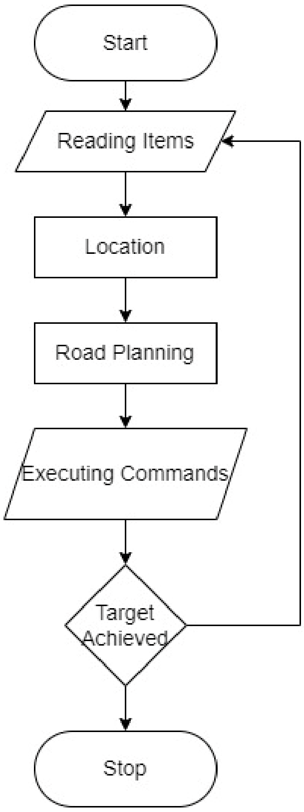


Figure 2. Flowchart of object reading and Robot Walking

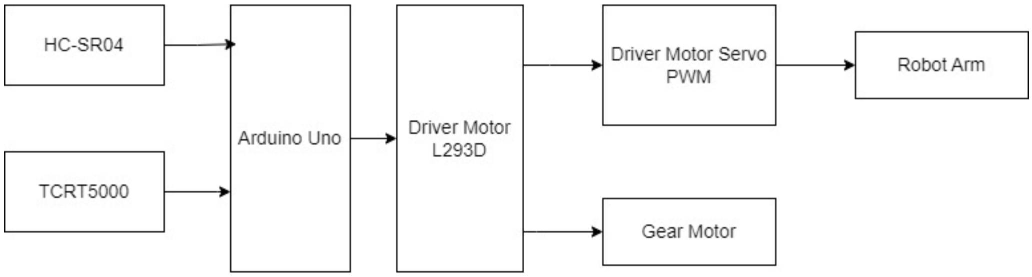


Figure 3. Block Diagram Hardware system in detail

The flowchart shows how objects can be detected by the Robot, starting from color detection, the path used as a path, and finally being able to move the actuator or motor to lift and lower the load according to its place.

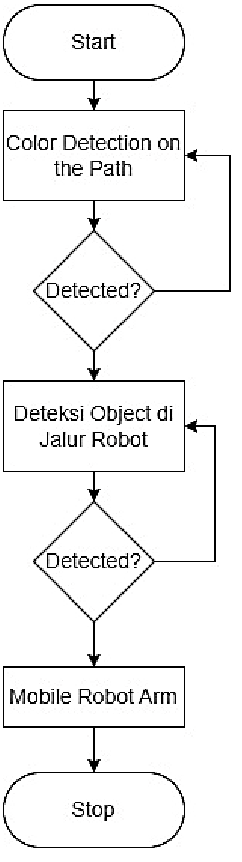


Figure 4. Object detection flowchart

3.2 System Design

The following is the design scheme of the "Microcontroller-Based Forklift Line Follower Robot Prototype, shown in Figure 5.

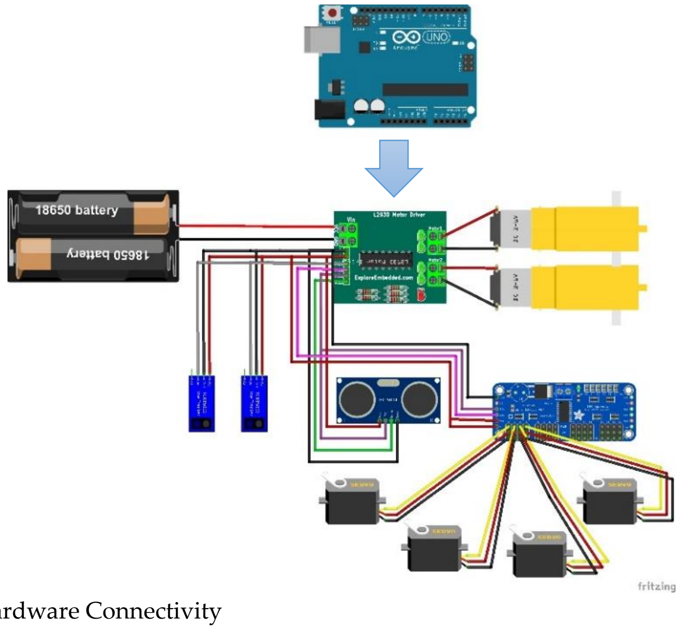


Figure 5. Hardware Connectivity

The first thing that is done is to detect whether there is a black line path that has been made in the form of a TCRT5000 sensor, the data obtained by the sensor will be directly informed to the Arduino UNO microcontroller which plus the L293D motor driver functions as the system control center, then the microcontroller processes the data then the gear motor moves and the robot follows the black line path. Then the ultrasonic sensor will inform the control system if there is an object that blocks the robot's path, it will be immediately executed by the robot arm by moving it to an airy place and the robot can walk again.

4. Result and Discussion

4.1 Prototype Assembly

In the implementation section, the author will describe the implementation steps which consist of 2 (two) stages, namely device assembling and device programming. For the TCRT500 sensor component, connect the ground pin as the negative pin on the L293D Motor Driver connected to the ground foot on the TCRT5000 then the VCC pin is connected to the 5 V pin. And pins A3 and A2 are connected to the DO pin on the TCRT5000. (Figure 6). For the HC-SR04 sensor component, connect the ground pin as a negative pin on the L293D Motor Driver connected to the ground foot on the HC-SR04 sensor then the VCC pin is connected to the 5 V pin. Pin A1 is connected to the Trig pin on the HC-SR04 and pin A0 is connected to the Echo pin on the HC-SR04 sensor. (Figure 7).

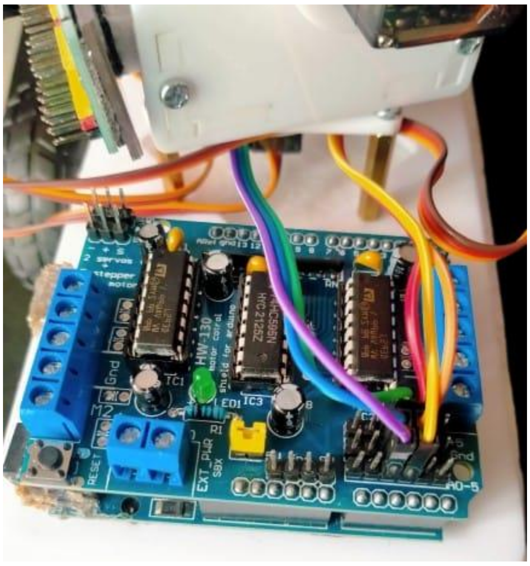


Figure 6. TCRT5000 Sensor Assembly

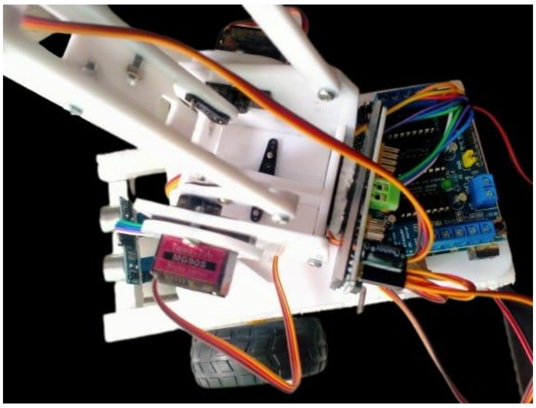


Figure 7. HC-SR04 Sensor Assembly

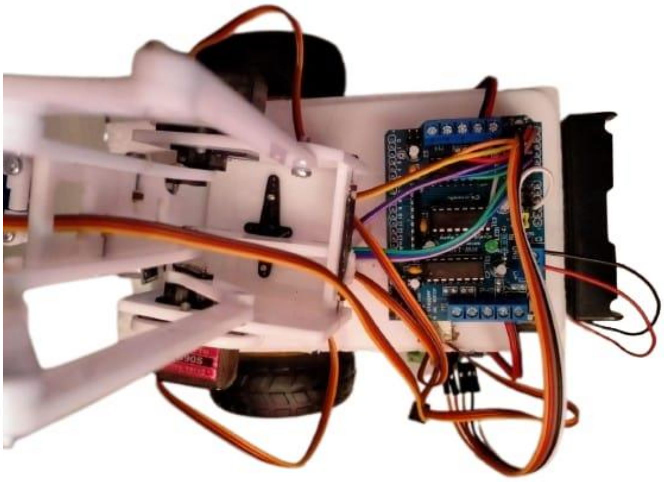
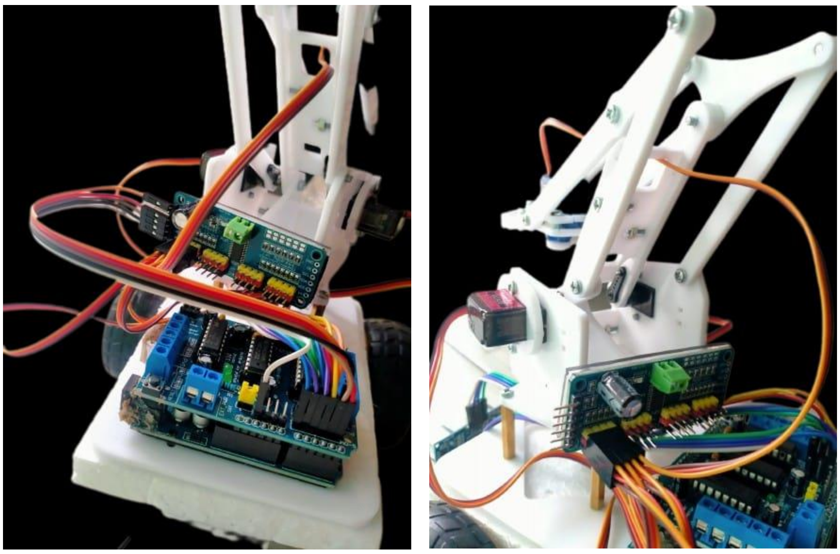


Figure 8. Gear Motor Assembly

For the Gear Motor component, connect pin M2 and pin M3 on the L293D Motor Driver with its positive and negative wires. (Figure 8). For the PWM Servo Motor Driver component, connect the ground pin on the L293D Motor Driver to the PWM Servo Motor Driver pin. The VCC, SCL, and V+ pins on the PWM Motor Driver are connected to the 5 V pin on the L293D Motor Driver. The SDA pin on the PWM Servo Motor Driver is connected to pin A4 in the L293D Motor Driver. (Figure 9a). For the Servo Motor component, connect pin lineup 0 on the PWM Servo Motor Driver to pin lineup 1 of the Servo Motor according to the color of the cable. Pin lineup 1 on the PWM Servo Motor Driver is connected to pin lineup 2 of the Servo Motor according to the color of the cable. Pin lineup 2 in the PWM Servo Motor Driver is connected to pin lineup 3 of the Servo Motor according to the color of the cable. Pin lineup 3 in the PWM Servo Motor Driver is connected to pin lineup 4 of the Servo Motor according to the color of the cable. (Figure 9b).



(a) (b)

Figure 9. (a, b) PWM Servo Motor Driver Assembly and Servo Motor Assembly

Moreover, if using a Python programming language to drive a forklift car to an object can be seen in Figure 10.

```
import pygame
import sys

# Inisialisasi pygame
pygame.init()

# Konstanta
WIDTH, HEIGHT = 800, 600
WHITE = (255, 255, 255)
BLACK = (0, 0, 0)
RED = (255, 0, 0)
GREEN = (0, 255, 0)

# Atur layar
screen = pygame.display.set_mode((WIDTH, HEIGHT))
pygame.display.set_caption('Forklift Robot Game')

# Kelas Forklift
class Forklift:
    def __init__(self):
        self.x = WIDTH // 2
        self.y = HEIGHT // 2
        self.width = 60
        self.height = 40
        self.speed = 5
        self.image = pygame.Surface((self.width, self.height))
        self.image.fill(RED)
        self.rect = self.image.get_rect(topleft=(self.x, self.y))

    def draw(self, surface):
        surface.blit(self.image, self.rect)

    def move(self, dx, dy):
        self.x += dx
        self.y += dy
        # Cegah forklift bergerak keluar dari batas layar
        self.x = max(0, min(WIDTH - self.width, self.x))
        self.y = max(0, min(HEIGHT - self.height, self.y))
        self.rect.topleft = (self.x, self.y)

# Kelas Tujuan
class Target:
    def __init__(self):
        self.x = WIDTH // 4
        self.y = HEIGHT // 4
        self.size = 30
        self.color = GREEN
        self.rect = pygame.Rect(self.x, self.y, self.size, self.size)

    def draw(self, surface):
        pygame.draw.rect(surface, self.color, self.rect)

# Inisialisasi forklift dan target
forklift = Forklift()
target = Target()
```

```
# Loop utama
clock = pygame.time.Clock()
running = True

while running:
    for event in pygame.event.get():
        if event.type == pygame.QUIT:
            pygame.quit()
            sys.exit()

    keys = pygame.key.get_pressed()
    dx = dy = 0

    if keys[pygame.K_LEFT]:
        dx = -forklift.speed
    if keys[pygame.K_RIGHT]:
        dx = forklift.speed
    if keys[pygame.K_UP]:
        dy = -forklift.speed
    if keys[pygame.K_DOWN]:
        dy = forklift.speed

    forklift.move(dx, dy)

    # Cek jika forklift mencapai target
    if forklift.rect.colliderect(target.rect):
        print("Target reached!")
        # Pindahkan target ke posisi baru
        target.rect.x = WIDTH * 3 // 4
        target.rect.y = HEIGHT * 3 // 4

    screen.fill(WHITE)
    forklift.draw(screen)
    target.draw(screen)
    pygame.display.flip()
    clock.tick(30)
```

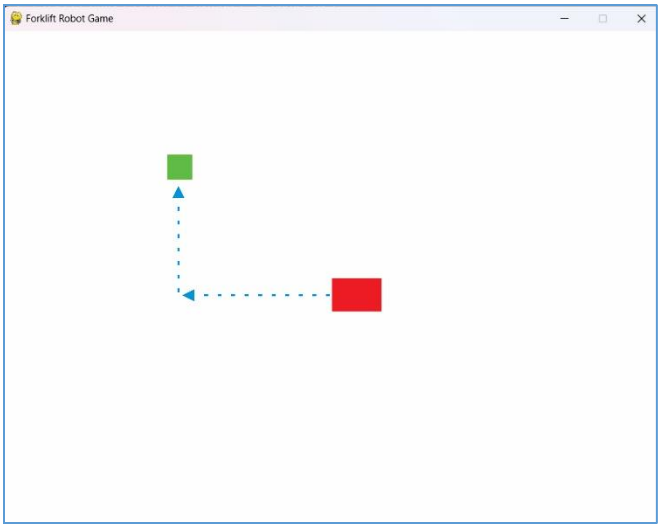


Figure 10. Movement from forklift car to object

4.2 Test Results

Test Results on the Tool The purpose of testing the tool is: 1. Ensuring that the tool is properly interconnected between the control center and the sensors used. 2. Ensuring the sensor function is running properly. 3. Ensuring the overall tool is running properly. Tests carried out on TCRT500 sensor components, HC-SR04 sensors, Gear Motors, and Servo Motors are carried out by configuring each pin on the component to the Arduino microcontroller while testing the connection between components and overall tool performance is done by uploading the final Source Code to the Arduino microcontroller. Then the test results are obtained as follows (Table 1).

Table 1. Component Test Results with Microcontroller

No	Component Name	Test Scenario	Test Results
1.	Sensor TCRT5000	The sensor can detect black color and white color.	Success
2.	Sensor HC-SR04	The sensor can emit and receive signals when it detects an obstructing object.	Success
3.	Gear Motor	Gear Motor can move according to the system that has been made	Success
4.	Motor Servo	Servo motor can move according to the system that has been made	Success

The component test results cover the TCRT5000 sensor and Gear Motor. This test is carried out to determine whether the input from the TCRT5000 sensor and the output from the Gear Box can work according to the functions and programs that have been made. This test is done by assembling the TCRT5000 sensor and Gear Box with the Arduino microcontroller and uploading the Source Code scenario that has been determined to be uploaded on the Arduino board. Then the test results are obtained as follows (Table 2).

Table 2. Microcontroller Test Results with TCRT5000 Sensor and Gear Motor

No	Component Name	Test Scenario	Test Results
1.	Sensor TCRT5000	Sensors can detect the robot path that has been created	Success
2.	Gear Motor	Gear Motor can move according to the system that has been made	Success

Moreover, Testing of other components includes the HC-SR04 sensor and Servo Motor. This test is carried out to determine whether the input of the HC-SR04 sensor and the output of the Servo Motor can work according to the functions and programs that have been made. This test is carried out by assembling the HC-SR04 sensor and Servo Motor with the Arduino microcontroller and uploading the Source Code scenario that has been determined to be uploaded to the Arduino board. Then the test results are obtained as follows (Table 3).

Table 3. Microcontroller Test Results with HC-SR04 Sensor and Servo Motor

No	Component Name	Test Scenario	Test Results
1.	Sensor HC-SR04	The sensor can detect any obstructing objects in front of the robot.	Success
2.	Motor Servo	Servo motors can move according to the program that has been made so that the robot arm can move.	Success

The purpose of software testing is to ensure that the source code in the Arduino IDE has been uploaded without any errors on the Arduino UNO board as shown in. Moreover, Figure 4 shows the Functional Test Results Tool Testing is said to be successful if the tool can detect objects that block the path of the robot and detect the path that has been made for the robot to move. However, the tool is said to be unsuccessful if it contradicts by not being able to detect objects that block or robot paths that have been made. The test scenario is carried out when the robot has been given a power supply and then placed in a field where there is a robot path to move, the first test and so on are attached to the test results in the table below (Table 4).

Table 4. Overall Tool Testing Results

Testing To-	**Testing Results**
1	The robot can follow the line and can remove objects that are in the way.
2	The robot can follow a line and can remove obstructing objects but is a little rough.
3	The robot has errors when searching for lines and can remove objects that are in the way.
4	The robot can follow the line and the robot arm cannot remove the obstructing object due to system delay.
5	The robot can follow a line and can remove obstructing objects but is a little rough.
6	The robot had an error while searching for the line and the robot arm was unable to remove the obstructing object due to system delay.
7	The robot had errors when searching for lines and was able to remove obstructing objects but was rough.
8	The robot can follow the line and the robot arm cannot remove the obstructing object due to system delay.
9	The robot can follow the line and the robot arm cannot remove the obstructing object due to system delay.
10	The robot can follow a line and can remove obstructing but rough objects.

Overall, the test results of 2 types of tests on the system or tool can run well even though there are several system errors from the scenario made. This is indicated by the data from the component test results, 80% of which can function according to the function of each component. Then the software test results show that 80% of the robot moves according to the program that has been designed and the results of the robot functionality test can detect, lift, and move objects that block the robot's path.

5. Conclusion

The conclusions that can be drawn after the author has tested this microcontroller-based forklift line follower robot prototype include: 1. The forklift line follower robot prototype has been successfully designed by assembling component devices according to the design scheme and programming the tool by uploading the program that has been designed using the Arduino IDE software version 1.8.19. The robot is designed based on the results of a literacy study conducted by the author in making the proposed tool. 2. The prototype of the forklift line follower robot has been successfully built properly by putting together each component neatly and according to their respective functions so that a microcontroller-based forklift line follower robot prototype is formed. 3. The test results of the device of each component indicate that the device functions properly in detecting the path made and objects that block it, and the software used functions properly with the source code that was successfully created without any errors in the compile process. 3. The results of testing functions and features on the robot with 10 trials around the path that has been made there are 3 times the robot experienced errors on the line follower and 4 times errors on the robot arm. So it can be concluded that 80% of the robot can run well because it only experiences a few errors and has achieved the purpose of making this robot.

6. Suggestion

The design of the tool made by this author is far from perfect. Therefore, the author suggests that readers develop this tool to be even better. This robot can be developed into a robot that can deliver objects to the place where the object must be placed. Arriving at the place where the object is placed, the robot will release the object which will then return to the starting place. 2. The robot can be developed with a camera that can detect the shape of objects according to the needs needed so that computer vision is formed which can be implemented in industry and other fields.

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