Digital Zone
Jurnal Teknologi Informasi dan Komunikasi
Vol: 15 No 02 2024 E-ISSN: 2477-3255
Accepted by the Editor: 06-09-2024 | Revision: 11-11-2024 | Published: 30-11-2024

System Control of Prototype Forklift Using Android and ESP32 Based on MQTT Communication

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Abstract

This research develops and tests a prototype forklift robot controlled via an Internet of Things (IoT)-based system using an ESP32 microcontroller and the MQTT protocol. Designed to overcome the limitations of traditional manual forklifts, the robot enhances warehouse operations by increasing efficiency and minimizing human error. The study presents the design, testing, and evaluation of the forklift robot's movement control, mechanical wheel performance, load capacity, and wireless connectivity across various Android devices and network providers. Testing was conducted over distances ranging from 1 km to 90 km with different Android devices (e.g., Samsung, Xiaomi, OPPO, Vivo) and providers (Indosat, Axis, Telkomsel, Smartfren). The robot successfully performed a variety of movements, including forward, backward, left, right, rotation, and lifting operations. It demonstrated stable load lifting capabilities up to 300 grams, with instability observed for heavier loads, and could operate smoothly across a range of network conditions. Connectivity tests showed consistent performance and stable communication, reinforcing the robot's practical use for remote control and real-time monitoring. This research emphasizes the potential of IoT-enabled forklift robots to optimize material handling processes in warehouses, contributing to safer and more efficient industrial environments.

Keywords: *Forklift Robot, Internet of Things (IoT), System Control, MQTT, Mecanum Wheel.*

1. Introduction

Forklift is a lifting device that has a function to distribute goods in the form of lifting and moving from one place to another, which can be operated indoors or outdoors[1]. Forklifts are widely used in industry, expeditions and ports, especially in logistics and warehousing units[2], [3], [4]. The use of forklifts lightens the burden on employees, especially in moving goods by lifting objects that are difficult or too heavy to be lifted by humans[5]. Forklifts commonly used by companies in general are general forklifts, which means that forklifts are still operated manually. In some companies, forklift operators are prohibited from entering certain areas because they endanger human health and safety[6]. In addition, forklifts have weaknesses that can cause work accidents if the objects being moved are higher than the operator's view[3], [7].

https://doi.org/10.31849/digitalzone.v15i2. 22724

Since these forklifts rely heavily on the manual labor of the operator, there is the possibility of human error. The development of more efficient forklifts requires the incorporation of the most up-to-date remote control and data communication systems, such as robot forklifts, to reduce human error and optimize the use of forklifts [8].

Robotic can have many advantages that humans cannot have, one of which is that they can produce the same quality if they perform the same task repeatedly, so they can serve for a variety of tasks. This is considered highly efficient in the industry, mainly due to its high accuracy, low cost, and fast production time[9]. These advantages are further strengthened by the presence of the Internet of Things (IoT), IoT is an effective wireless communication technology that can be used in any scenario [10]. This technology connects objects around us with the internet so that daily activities become easier and more efficient. The development of IoT helps users create control systems and devices and monitor tools connected to IoT in real-time. The purpose of this IoT method is to connect andorid smartphones with robots, which can then be used to control Forklift robots [11], [12]

A study titled "Rancang Bangun Robot Forklift Dengan Kendali Smartphone Android Berbasis Arduino Mega 2560" was published in December 2017. In this study, research and development were conducted on a forklift robot prototype using a DC motor as a drive, a Bluetooth module, and a microcontroller that could be controlled by Bluetooth on an Android smartphone. The research findings indicate that a robot may be controlled using an Android smartphone to weigh objects with an accuracy of 31.2 grams per second while weighing a maximum of 200 grams [13].

The next study titled "Rancang Bangun Robot Forklift dengan Roda Mecanum Berbasis Internet of Things" (2020) Robot Forklift uses the Mikrokontroler ESP32 to move and control the robot. It has three different mechanisms, including an ESP Cam for operator visibility and monitoring via an Android smartphone app and a proximity sensor for detecting objects. Robot navigation makes use of the distinct speed of each rod to move in any direction without having to make abrupt route changes. If the robot gets a command using the Blynk application on a smartphone, it will stop responding. According to study findings, this forklift robot can carry up to 2600 grams of weight at a maximum lift speed of 3,49 km/h, or 0.97 m/s. [2].

To increase productivity, the ESP32 microcontroller is used to link the Internet of Things with the forklift robot control process. The Android system may remotely or wirelessly control the forklift robot's movement in real time thanks to the Internet of Things connectivity[14].

The method used is the integration of the Internet of Things on the forklift robot prototype using the MQTT protocol. The MQTT protocol is a small Machine to Machine (M2M) network protocol with a publish-subscribe mechanism[15]. MQTT requires low-power machines and low data traffic to function with limited network bandwidth or machine specifications. The protocol enables machine-to-network interactions and vice versa[16]. At the user's will, MQTT allows sending and receiving messages through control or supervision based on predefined topics[17]. MQTT is a good choice for communication between devices and Internet of Things (IoT) applications because it requires lower bandwidth than other protocols by following commands from a predetermined android device, where this forklift robot can pick up and put items[18]. In general, the control of the robot has two input controllers. One is on the robot itself. The other is on the mast device (lifting pole) based on the Android operating system, which controls remotely using a wireless system with integrated Internet of Things[19][20].

Previous research on Internet of Things-enabled forklift robots has mostly relied on Blynk or Bluetooth for remote operation[5]. But although Blynk requires user registration and limits platform access, Bluetooth-based solutions are less flexible and have a smaller range, making them less suitable for a variety of control requirements. Otherwise, MQTT provides a more adaptable solution because it doesn't require registration or login and works with a variety of platforms, including web browsers, Android, and MQTT-specific apps. Furthermore, in contrast to Blynk's preset designs, MQTT offers more choices for user interface design modification[21]. By employing MQTT, this study overcomes these constraints, offering a more adaptable and scalable communication protocol for forklift robots and improving the entire control and usage experience[22].

2. Research Methods

This research uses a quantitative descriptive method which is divided into several stages, namely literature study, prototype design, data processing, and data analysis and conclusions. Research using a descriptive approach conveys facts by describing what is seen, obtained, and felt. In this study, what was tested included the results of the mecanum wheel test, the results of the forklift load weight test and the results of the connectivity test, as well as the results of the design of the robot controller user interface display on a smartphone. Figure 1 is a circuit scheme that will be used in the IoT-based forklift prototype.

2.1. System Analysis

In this research, the forklift robot prototype can be positioned by following commands from a predetermined android device, where the forklift robot can pick up and place items. In general, the control of the robot has two input controllers. One is on the robot itself. The other is on the mast device (lifting pole) based on the Android operating system.

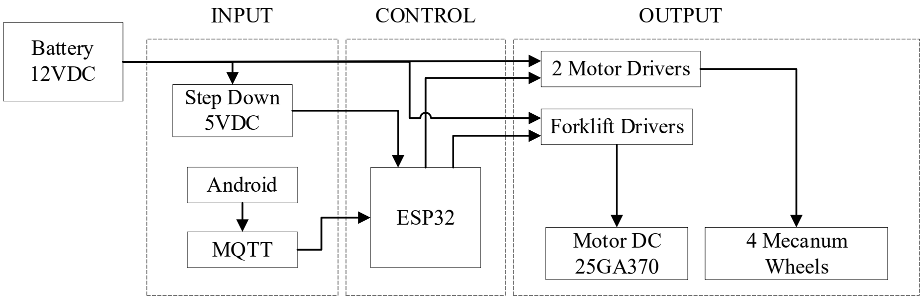

Figure 1. Block Diagram of Forklift Prototype

2.2. System design

The system design in the research of the Forklift Prototype Control System Using Android and ESP32 Based on MQTT Communication has the following work process: The prototype will be controlled wirelessly through the Android application. With ESP32 which functions as a microcontroller (brain) of the forklift prototype which will have two input controllers, motor control input, and elevator (mast) control input.

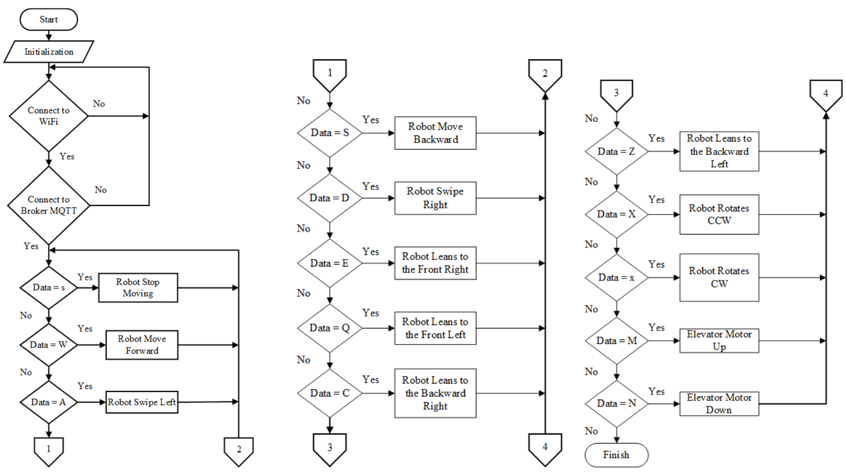

Figure 2. Flowchart Prototype Forklift

https://doi.org/10.31849/digitalzone.v15i2. 22724

2.3. Place of Implementation

The experiment was conducted at the Electrical Laboratory, Jl. Raya Gelam No.250, Pagerwaja, Gelam, Kec. Candi, Sidoarjo Regency as a place for the robot to be controlled remotely.

Figure 3. IoT-based Forklift Prototype Experiment Location

3. Results and Discussion

The research results obtained from the Forklift Prototype Control System Using Android and ESP32 Based on MQTT Communication here include a forklift robot prototype, mechanical wheel test results, forklift load weight test results, and connectivity test results, as well as the results of the robot controller UI design for smartphones [2].

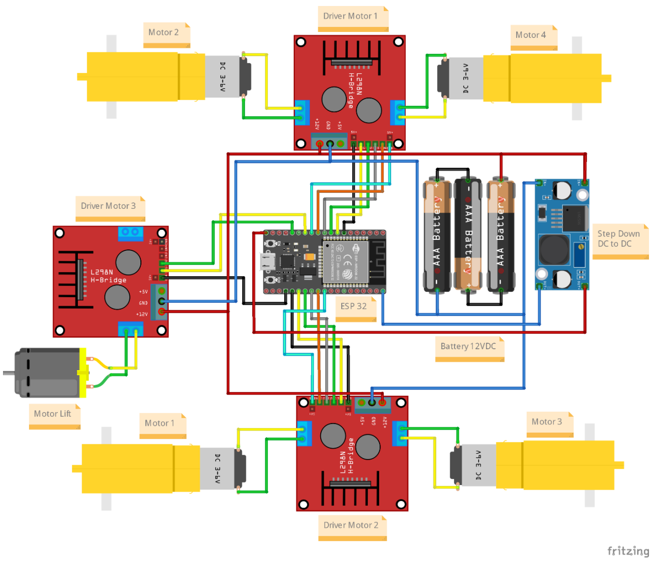

Figure 4. Forklift Prototype Circuit Schematic

3.1. Forklift Robot Prototype Results

The results of this research consist of two parts: software, which includes a control interface for smartphones, and hardware, which includes a prototype forklift robot with mechanical wheels that can be controlled remotely with a smartphone. The overall design result can be seen in Figure 5.

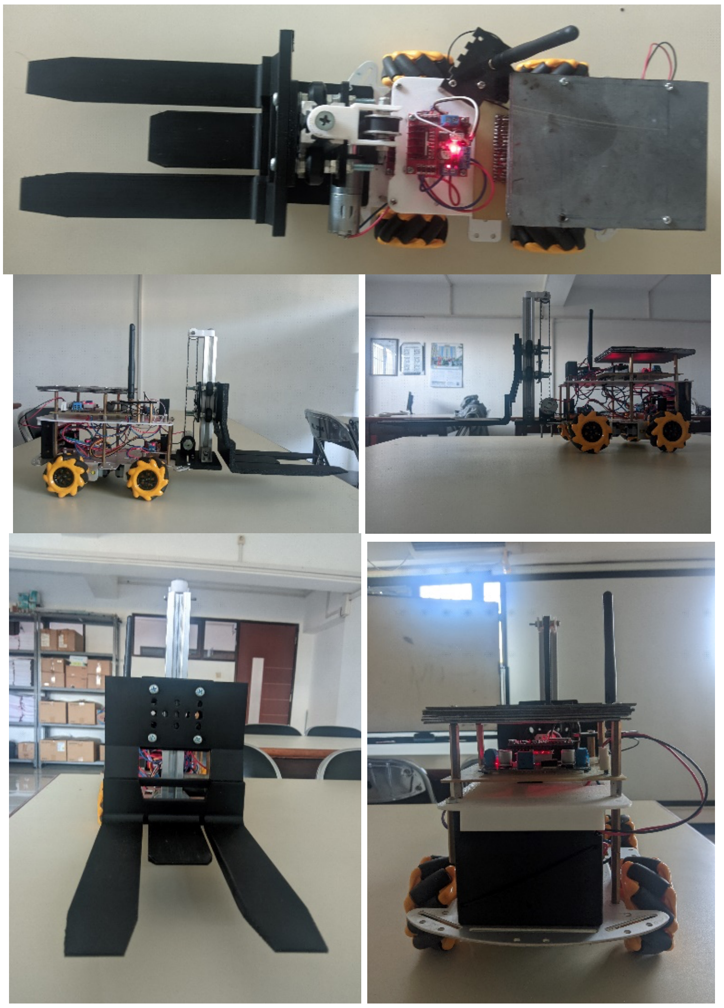

Figure 5. Forklift Prototype Results

The robot has a lifting fork that is driven by a 25GA 370 type DC motor that has a voltage of 12 volts DC, a speed of 12 rpm, and a torque of 9 kg/cm.

3.2. User Interface Display Results

The MIT App Inventor application is used to build a UI that functions as a forklift robot controller for smartphones with the result of the mit app inventor is forklift IoT.apk. The resulting UI form is shown in Figure 6.

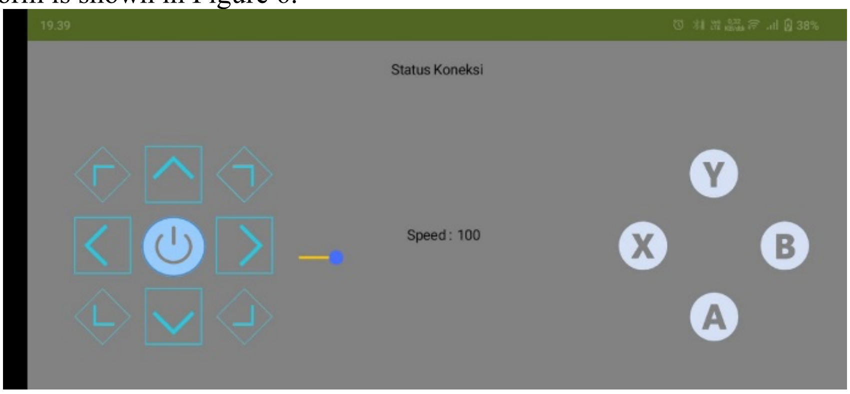

Figure 6. Results of Forklift Control User Interface

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Description:

Symbol		Keyword	Description
	=	-	Button Power is used as an MIT App application connected with MQTT
	=	W	Button Forward is used as a robot command to move forward
	=	A	Button Left is used as a robot command to move to the left
	=	S	Reverse button is used as a robot command to move backward
	=	D	Button Right is used as a robot command to move to the right
	=	E	Button Right Forward is used as a robot command to move sideways to the front right
	=	Q	Button Left Forward is used as a robot command to move sideways to the front left
	=	C	Right Reverse button is used as a robot command to move sideways to the back right
	=	Z	Left Reverse button is used as a robot command to move sideways to the back left
	=	X	Button B is used as a robot command to rotate clockwise
	=	x	Button X is used as a robot command to move counterclockwise
	=	M	Button Y is used as an elevator command to go up
	=	N	Button A is used as an elevator command to go down

This test starts by pressing the Power Button, the forklift control cannot be used if the user interface fails to connect with the MTT broker by sending a notification on the screen in the form of "MQTT broker not connected" until the connection status changes to Online. To move the forklift, press the button according to the command above and release the button to stop the movement of the robot, and add a speed slider to adjust the speed of the robot.

3.3. Mecanum Wheel Testing Results

Table 1. Mechanical Wheel Movement Test Results

No	Movement	Motor 1	Motor 2	Motor 3	Motor 4
1	Forward	Forward	Forward	Forward	Forward
2	Backward	Backward	Backward	Backward	Backward
3	Left	Backward	Forward	Forward	Backward
4	Right	Forward	Backward	Backward	Forward

No	Movement	Motor 1	Motor 2	Motor 3	Motor 4
5	Front Right	Forward	-	-	Forward
6	Front Left	-	Forward	Forward	-
7	Rear Right	-	Backward	Backward	-
8	Rear Left	Backward	-	-	Backward
9	CW rotation	Forward	Backward	Forward	Backward
10	CCW rotation	Backward	Forward	Backward	Forward

The data in table 1 tests the motors for the mechanical wheel. Motors 1, 2, 3, and 4 must move forward with the same PWM speed to make the robot move forward. If you want to move backward, all four motors must move backward. To move left, motors 1 and 4 must move backward, while motors 2 and 3 must move forward. To move to the right, motors 1 and 4 must move forward, while motors 2 and 3 must move backward. Each motor can move diagonally by combining forward and backward movements. Motors 1 and 3 move forward, while motors 2 and 4 move backward. Conversely, motors 1 and 3 move backward, while motors 2 and 4 move forward. The testing process is done to ensure that the robot can move as planned.

3.4. Forklift System Testing Results

Forklift system testing is carried out to determine the load capacity that can be lifted by the forklift prototype.

Table 2: Lifting Load Capacity Test Results

No	Weight of load (gr)	Lift time (s)	Down time (s)	Description
1	120	14	14	Stable
2	200	14.5	15	Stable
3	300	14.6	15.8	Stable
4	450	16	14	Unstable
5	520	16.3	14	Unstable
6	800	0	0	Cannot be lifted
7	1000	0	0	Cannot be lifted

The results of testing the forklift system obtained the maximum load that can be lifted by the 300 gram forklift prototype. Testing on loads of 450-520 grams can be lifted but the robot is not balanced so that the load is unstable. Testing at a load of 800-1000 grams cannot be lifted.

https://doi.org/10.31849/digitalzone.v15i2. 22724

3.5. Connectivity Testing Results

Connectivity testing is done to determine the performance of the android control system. Testing is done by connecting the android device to the internet and connecting to the MQTT broker.

Table 3. Testing Results of ESP32 as an IoT Module Based on MQTT Communication Against Different Devices and Providers

No	Android Type	Range Distance (km)	Provider	Test To					Connection Status	Description
				1	2	3	4	5		
1	Samsung	1	Axis	✓	✓	✓	✓	✓	✓	from Campus to Candi-Sidoarjo
2	Xiaomi	2	Indosat	✓	✓	✓	✓	✓	✓	from Campus to Tanggulangin
3	OPPO A53	8	Indosat	✓	✓	✓	✓	✓	✓	from Campus to Jenggolo
4	Infinix	12	Indihome	✓	✓	✓	✓	✓	✓	from Campus to Gedangan
5	Oppo Reno 3	16	Smartfren	✓	✓	✓	✓	✓	✓	from Campus to Ngoro
6	Vivo Y20	20	Telkomsel	✓	✓	✓	✓	✓	✓	from Campus to Bangil
7	Vivo S One Pro	34	Orbit Telkomsel	✓	✓	✓	✓	✓	✓	from Campus to Tarik-Sidoarjo
8	samsung A22	45	Indosat	✓	✓	✓	✓	✓	✓	from Campus to Gresik
9	Realmi C7	90	Indosat	✓	✓	✓	✓	✓	✓	from Campus to Paceng-Gresik

The results of testing ESP32 as an IoT module based on MQTT communication with various types of Android and providers show consistent performance in maintaining connections at various distances and different providers. Tests were conducted in various locations with distances ranging from one kilometer to ninety kilometers from campus. Every provider used, including Indosat, Axis, Indihome, Smartfren, Telkomsel, and Orbit Telkomsel showed a successful and stable connection status.

Android devices such as Samsung, Xiaomi, OPPO A53, and Vivo S One Pro successfully connected from short to very long distances, with positive results for each distance tested. For example, campus connections to various locations, ranging from Candi to Paceng-Gresik, remained stable without any issues.

Table 4. Overall Testing Results of Robot Part 1

No	Robot Condition	Range Distance (km)	Robot Movement			
			Forward	Backward	Left	Right
1	Connected	1	✓	✓	✓	✓

No	Robot Condition	Range Distance (km)	Robot Movement			
			Forward	Backward	Left	Right
2	Connected	2	√	√	√	√
3	Connected	8	√	√	√	√
4	Connected	12	√	√	√	√
5	Connected	16	√	√	√	√
6	Connected	20	√	√	√	√
7	Connected	34	√	√	√	√
8	Connected	45	√	√	√	√
9	Connected	90	√	√	√	√

The overall test results of the robot in part 1 show that the robot can perform four basic movements such as forward, backward, left, and right successfully at various distances as long as the MQTT broker is connected.

Table 5. Overall Testing Results of Robot Part 2

No	Robot Condition	Range Distance (km)	Robot Movement			
			Front Right	Front Left	Rear Right	Rear Left
1	Connected	1	√	√	√	√
2	Connected	2	√	√	√	√
3	Connected	8	√	√	√	√
4	Connected	12	√	√	√	√
5	Connected	16	√	√	√	√
6	Connected	20	√	√	√	√
7	Connected	34	√	√	√	√
8	Connected	45	√	√	√	√
9	Connected	90	√	√	√	√

The overall test results of the robot in section 2 show that the robot can perform all tested movements such as front right, front left, back right, and back left successfully at various distances as long as the MQTT broker is connected.

https://doi.org/10.31849/digitalzone.v15i2. 22724

Table 6. Overall Testing Results of Robot Part 3

No	Robot Condition	Range Distance (km)	Robot movement		Lift Movement	
			CW rotation	CCW rotation	Up	Down
1	Connected	1	√	√	√	√
2	Connected	2	√	√	√	√
3	Connected	8	√	√	√	√
4	Connected	12	√	√	√	√
5	Connected	16	√	√	√	√
6	Connected	20	√	√	√	√
7	Connected	34	√	√	√	√
8	Connected	45	√	√	√	√
9	Connected	90	√	√	√	√

The forklift robot can effectively execute a variety of actions, including clockwise (CW) and counter-clockwise (CCW) rotation, as well as up and down elevator operations over diverse distances, according to the robot's overall test findings in section 3. As long as the MQTT broker was connected, these movements—which are essential to the robot's operation—were successfully completed. During the test trials, there was no discernible lag or failure, and the MQTT protocol enabled smooth communication at distances ranging from 1 km to 90 km. This characteristic aligns with the anticipated results of IoT-enabled systems, where operational performance is largely dependent on connectivity.

The prototype's performance in this investigation is in good agreement with earlier findings when compared to the baseline study, a noteworthy improvement in this research is the stability and control accuracy over these distances showed IoT-based forklift robot[2], controlled via an Android app and MQTT protocol, achieved robust control capabilities at a range of distances from 1 km to 90 km, with similar successful movement types like forward, backward, and rotation. A solid communication infrastructure is shown by the robot's smooth operation over longer distances—up to 90 km—which was not as clear in the baseline research. otherwise, this study presents the forklift prototype's lifting capacity, achieving steady lifts of up to 300 grams, comparable to the baseline's load-carrying testing, where load stability became problematic when the weight exceeded 2600 grams[2].

This study has concentrated more on increasing the operational distances without sacrificing movement performance, using the MQTT protocol as a lightweight communication medium, even if both experiments employ the ESP32 microcontroller for the IoT framework. MQTT provides an effective, low-bandwidth solution for remote control systems. However, this study broadens its use by investigating its capacity to sustain stability over noticeably greater distances.

This study's comparison of lifting capacity confirms the baseline study's conclusions that robotic forklifts exhibited instability or failure when carrying large weights. This study finds that a load of 300 grams is the maximum for steady operation, after which the system becomes unstable. Future developments in robotic forklift design should take this into account, especially when looking into stronger lift motors and improved balancing systems[2], [13].

The results are further strengthened by the dependability of MQTT communication across several Android devices and network providers (Axis, Telkomsel, Indosat, and Smartfren). In keeping with the baseline findings, this study demonstrates that MQTT is a successful communication protocol for remote forklift management, as demonstrated by its successful operation from a variety of locations, including up to 90 km away. These results demonstrate how IoT-based forklift systems may improve warehouse operations by providing accurate, reliable control over a range of distances and increasing material handling efficiency.

4. Conclusion

The results of this study provide a deeper investigation into the real-world applications of IoT technology in warehouse automation while also confirming the forklift robot's operational reliability, particularly with regard to movement control and communication stability. Significant improvements in control range, load stability, and system integration are shown when comparing this research to earlier studies, which makes this forklift robot a more versatile option for real-world applications.

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