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ORIGINAL ARTICLE

A Study on Obstacle Detection For IoT Based Automated Guided Vehicle (AGV)

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ABSTRACT – In modern manufacturing industry context, Automated Guided Vehicles (AGVs) are mobile robots used in aiding the process of material handling from one point to a desired location in the workplace. Development on AGVs is a trending discussion among researchers due to its wide usage and the implementation of the Industrial 4.0. The performance of the AGVs is one of the spotlight issues in order to compete with the rising technologies and demanding workload in the industry. Current concern on obstacle detection in AGVs has become more subjective due to the uprising issue on the congested environment in the workplace. Therefore, an IoT system is developed to allow a flexible wireless communication among mobile robots in an indoor industrial environment. An AGV prototype is designed for obstacle detection and the performance is analyzed. In order to improve obstacle detection in the AGV prototype, Kalman Filtering (KF) algorithm is used in the signal filtering for the HC-SR04 Ultrasonic Sensor data acquisition. Furthermore, the communication verification is diagnosed for the Wi-Fi connection broadcast traffic and network latency. The study produced several significant results related to obstacle detection of AGV with IoT based technology. Experiment results show the vehicle movement reaction in dealing with obstacles. Next, the KF programming algorithm managed to diminish the measurement noise including the Main bang and flaw echo of the ultrasonic sensor. Moreover, the IoT system allows ease of accessibility and user-friendly GUI. Results proved that Wi-Fi is a reliable communication medium in obstacle detection and is comparable to ZigBee and Bluetooth connection. The communication delay for wireless connectivity on the AGV prototype surpassed the requirements of latency test, which is less than 20 ms. The research concludes that the IoT-based AGV prototype is competent and reliable in handling the obstacle detection in fixed route with indoor environment workplace

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INTRODUCTION

The influence of industrial 4.0 has led to transform in the conventional approaches for the manufacturing industry. Promptly, a material handling system reputes as a significant part in modern manufacturing process [1]. The smart material-handling system becomes a current trending in the manufacturing sector where custom-built system implements in every domain of material handling such as material flow control, machine control, product routings, and distribution.

Industrial 4.0 is a signature of inculcating IoT and automation system into every sector in the industry, also known as Cyber-physical systems (CPS). CPS is the integration of computation with physical processes [2]. In the manufacturing context, embedded computers and networks monitoring systems are applied to control physical processes such as material handling [3]. Therefore, automated guided vehicles (AGVs) is introduced into the manufacturing industry.

Current trends of AGV equip with different types of microprocessor and sensors in order to achieve multi-function in the workplace. Global technological varies the functionality of AGV, which includes multiple vehicles, navigation aids, communication hardware and safety devices [4]. On top of that, automated guided vehicles increase efficiency and reduce labor cost by automating the facility, warehouse, and shop floor [5].

In this technologically developed era, physical devices (robots, AGVs, workpieces, etc) in the manufacturing system are able to connect and communicate with each other through the development of embedded algorithms, which, autonomous-cooperative manufacturing environment [6]. IoT technology implements in AGVs system for task-oriented collaborative as it enhances flexibility in term of communication between mobile intelligence [7]. Mobile intelligence synchronous with each other and they are able to track and monitor by manufacturers in order to visualize their performance [8]. Furthermore, decentralized intelligence stimulates intelligent networks and optimize autonomous processes, with the interaction of the real and virtual worlds representing a revolutionary milestone in industry development.

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METHODOLOGY

In this study, a prototype robot vehicle is purchased through the online market, which includes a standard aluminum body structure, dc motors, and wheels. The specifications of the robot vehicle are listed below in table 1.

Table 1: List of robot vehicle's specification

Components	Dimension	Specification
Body structure	18.8cm x 18.2cm x 3.4cm	Material: Aluminum Thickness: 0.1cm Weight: 350g
DC motors	1cm x 2.6cm x 1.2cm	Gear ratio: 150:1 Free-run speed: 85rpm Stall torque: 1.1kg·cm
Wheels	-	Diameter: 4.6cm Width of tire: 1cm

AGV Prototype Design

The prototype robot vehicle is equipped with an Arduino UNO as the controller of the prototype AGV. This controller is able to receive multiple signals in a single command. Therefore, it is a multi-purpose micro-controller with high flexibility in term of functionality compared to other controllers. Ultrasonic sensor HC-SR04 is installed on the AGV for obstacle detection. A LiPo power shield is attached with a LiPo rechargeable battery, which acts as a power supply for the AGV. Besides that, the auto-calibrating line sensor will be used for path guiding purpose as it has high accuracy and auto-calibrating function, which is compatible with this research.

Figure 1: Arduino UNO

Figure 2: HC-SR04 Ultrasonic Sensor

Figure 3: Auto Calibrating Line Sensor

Figure 4: ESP8266 Wi-Fi Module

A LiPo rechargeable battery is installed on the AGV as a power source. It is rated at 3.7V and 1300mAh. It is handy and rechargeable using the USB 2.0 port.

Figure 5: LiPo Battery

The AGV is assembled and the complete AGV prototype is shown in figure 6.

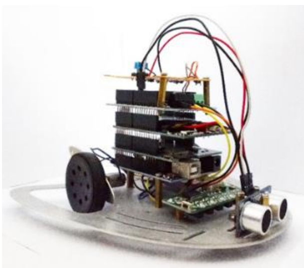

Figure 6: AGV Prototype Assembly

Flowchart of Experiment Framework

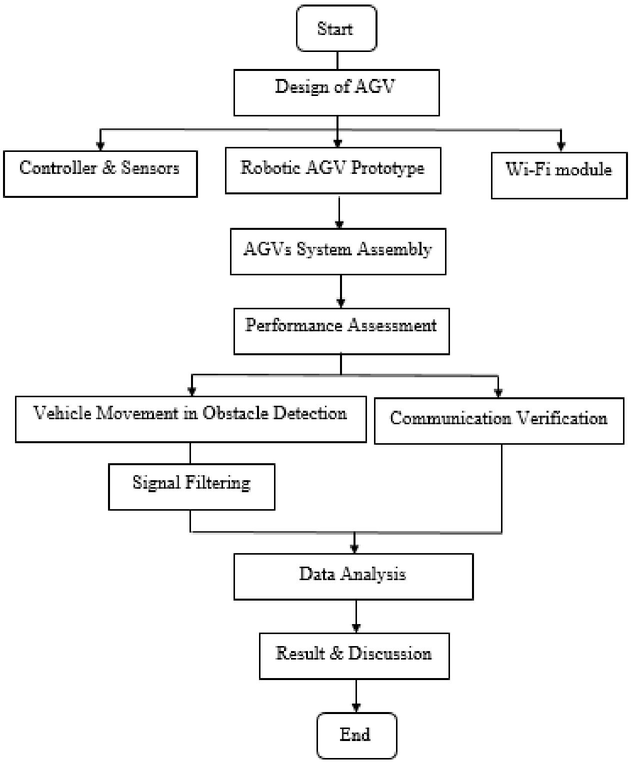

Figure 7: Experiment Framework Flowchart

Performance Assessment

The main objective of obstacle detection is the vehicle movement of AGV. The speed of AGV is controlled based on the specific distance of the obstacles. The ultrasonic sensor operates along with the movement of the AGV. At the same time, AGV will follow the path with tape on the floor using the auto-calibrating line sensor. The specific distance of obstacle will be classified in two different stages where obstacle range is set to a safe range (>0.2m), and critical range (< 0.2m).

The performance of AGV is determined through the vehicle movement of the AGV prototype in obstacle detection. The AGV decelerates when an obstacle is identified while it accelerates once the obstacle is removed. The AGV will completely stop if an obstacle is detected within the 'critical-range' as proposed. In addition, the emergency STOP button is added to the GUI in order to execute emergency breaking to the AGV.

Routes are designed for the AGV prototype in this experiment. Every route is designed with the same layout and equal total length. The obstacles are placed randomly on every route. Each route will conduct twice, where raw data and filtered data are collected simultaneously. Raw data is the distance measurement of obstacles by ultrasonic sensor without any signal filtering process. Next, filtered data is the distance measurement for obstacle detection with signal filtering. The signal filtering is executed in order to filter out noises and disturbances in the surrounding. Experiments will involve both raw data and filtered data, where therefore comparison will be performed in term of multiple graphs.

Results for every obstacle range in different routes will be tabulated and the distance-time graph is plotted using the Matlab application. The summary of the mechanism flowchart in obstacle detection is shown in figure 7.

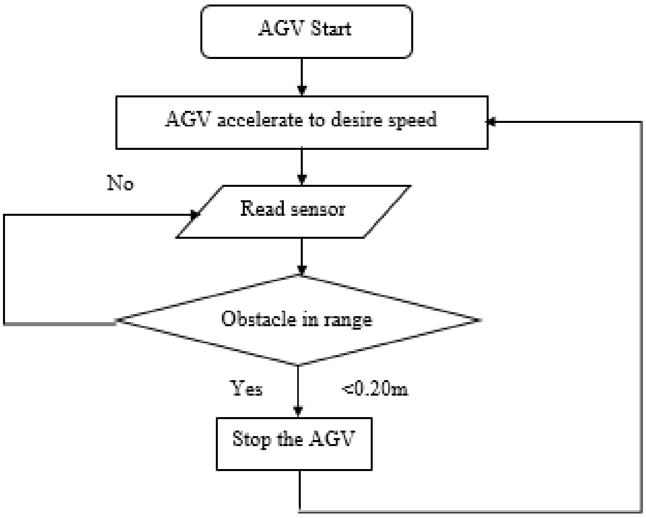

Figure 8: Mechanism Flowchart of obstacle detection in AGV

Kalman Filter is a popular algorithm in signal filtering, especially for ultrasonic sensor HC-SR04. Studies on the application of the KF algorithm of ultrasonic sensors have been widely carried out. The KF algorithm works by estimating the state measurable recursively [9]. Pseudo Code for Kalman Filter is utilized in obstacle detection as illustrated in (1). This algorithm is applied in this research for signal filtering on obstacle detection application. The pseudo code is reconstructed in C-Languages for programming algorithm purposes. Programming algorithm is implemented and comparison will be executed between raw data and filtered data.

$$x_k = x_{k-1}(1 - T_F) + \partial(T_F) \quad (1)$$

The equation is derived from the pseudo code of the KF algorithm [10]. x_k is the current distance while x_{k-1} is the previous distance. T_F, represents the Trust Factor where it is tuned for the best outcome based on repeated experiments. ∂ indicates the measured data.

Communication Verification

In the AGVs system, the Wi-Fi network is used to allow wireless communication between the coordinator and the AGV prototype. An ESP8266 Wi-Fi shield is installed on the AGV and connects with the Arduino UNO controller. The wireless communication allows data transfer and command transmit between the coordinator and the controller on the AGV. An IoT system interface will be introduced for ease of operation for the user. The display GUI will update the latest data acquired from the ultrasonic sensor based on the distance measurement from any obstacle detected. Figure 3.5.4.1 shows the overall communication between the AGV and the coordinator.

This experiment will perform a sequence of testing to compute the communication delay between the coordinator and controller on the AGV. For instance, the distance measurement recorded by the ultrasonic sensor is synchronized and updated every 10 seconds interval as the dynamic data display on the GUI. Communication delay occurred as the existence of latency in a wireless connection. The experiment is tested using windows command prompt for a series of information such as latency, minimum and maximum ping, and packet loss. Figure 9 shows an example of network testing using the windows command prompt.

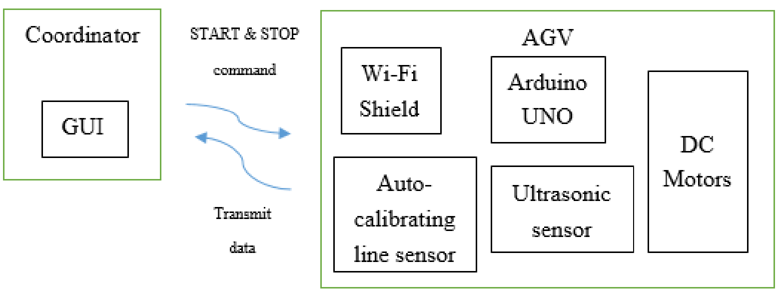

Figure 9: Programme Flowchart

RESULT AND DISCUSSION

Technical Specification of AGV Prototype

Table 2: List of AGV Prototype's technical specifications

No.	Condition	Value
1	Wheel's diameter	46mm
2	Wheel's circumference	144.51mm
3	AGV reduction gear	30:1
4	AGV initial velocity	0.09m/s
5	AGV deceleration	0.39m/s

The initial velocity of the AGV is calculated from the total time taken on the specific distance covered by the robot vehicle. The AGV travelled through linear motion guided by the auto-calibrating sensor. As for deceleration of the AGV, the result is acquired by measuring the change of velocity over time taken required on the route.

AGV Prototype Performance Analysis

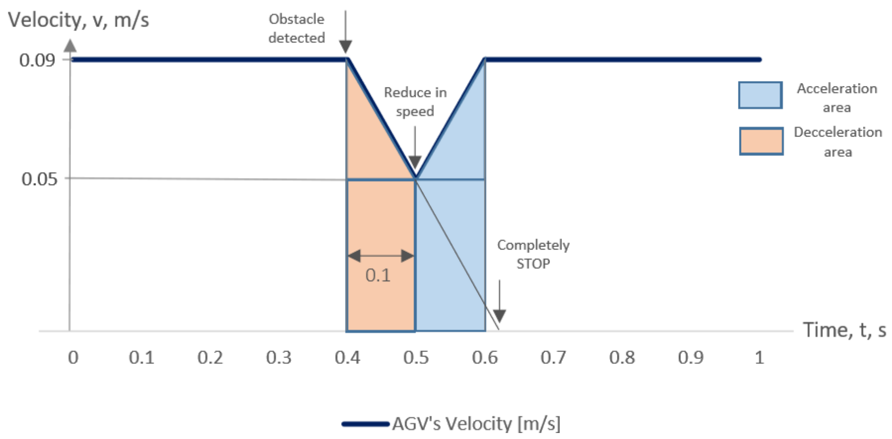

Figure 10: Time Variation for the AGV Prototype

The initial velocity of the AGV is traveling 0.09 m/s on the designed route. The AGV reduced its speed once the controller received a response from the ultrasonic sensor. For t=0.1, the AGV prototype is competent in reduced its speed from 0.09 m/s to 0.05 m/s. The acceleration area indicates the response of the AGV if the obstacle is removed from the critical range from the ultrasonic sensor, set as 0.2m originally. On the other hand, the AGV will continue in reducing its speed to a complete stop if the obstacle remains in the critical region from the ultrasonic sensor. According to the kinematic equation and graph interpolation, the AGV required 0.225 seconds to completely stop in standstill. Besides, the AGV traveled 0.01m after applying braking from the initial velocity until a complete stop. Hence, the AGV compromised a rigid movement response from the ultrasonic sensor to the gear motor. The precise response of the AGV is indispensable in cooperative driving operation, as it is able to perform anti-collision and obstacle detection in the workplace. Therefore, dominant response and a substantial performance are crucial, as safety factor is the priority in the workplace.

In obstacle detection application, raw data of distance measured are collected based on the HC-SR04 Ultrasonic Sensor. The distance measured between the AGV and obstacles on the designed route is recorded using Processing application. Every experiment is organized in a fixed route and the AGV runs through two times. The experiments assigned several set points for different obstacles on every route. The route lining is covered with black tape while the remaining background is done in white. The AGV is traveling in desired speed in every route and physical factors are retained constant such as surface roughness, route length, and indoor surrounding. The actual route is shown in figure 11. In addition, the 2D outlook of all routes is illustrated in figure 12.

Figure 11: Actual Route 2D Layout

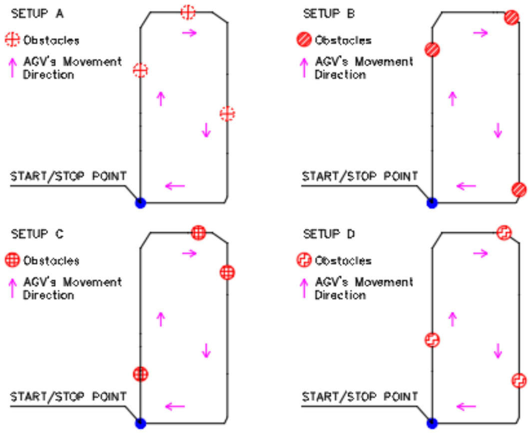

Figure 12: 2D Route Setups for Experiment

Kalman Filtering Analysis

Kalman Filter (KF) algorithm is designed to process the data acquisition system for the ultrasonic sensor. The experiment involved the investigation on the performance of the filtering process resulted in noise eviction. The experiment involved two quadrants. The first trial is executed with raw data collection while the second trial is performed with signal filtering data collection. Both of the results are collected in Processing application and plotted in Matlab application. The 4 different setups designed routes are executed in this research. Results are shown in figure 13, 14, 15, and 16 respectively.

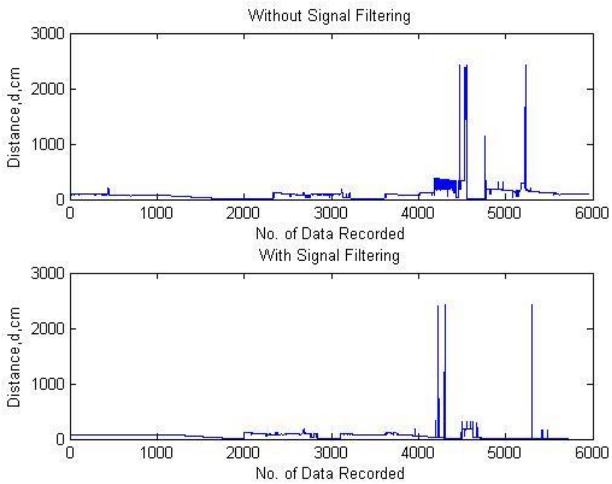

Figure 13: Experiment result for setup A

In figure 13, a consistent trend of data collected is observed with signal filtering from range 0-2000 data recorded. Besides, it has steady fluctuation compared to the AGV system without signal filtering from range 2000-4000. Furthermore, there is an unstable frequency, which is also known as ‘Main Bang’ effect in the range from 4000-5500. However, graphs with signal filtering have a minor deviation in overall, which enhances the accuracy of the data collected during the experiment.

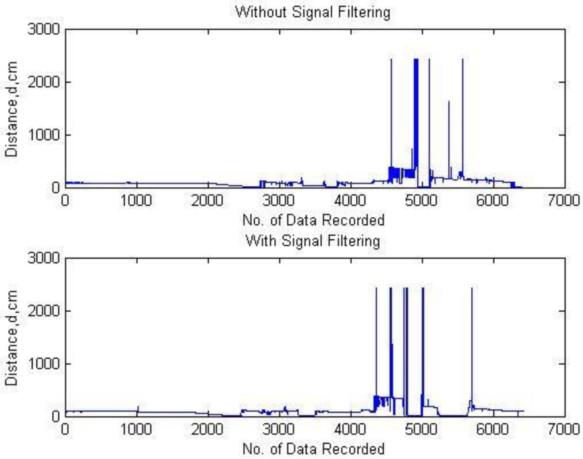

Figure 14: Experiment result for setup B

In figure 14, the line had a plunge as the AGV moving closer towards an obstacle in the ranged from 0-2500 in the data recorded on the AGV with signal filtering. Both systems performed steadily as no significant dissimilarity. Yet, small fluctuation began from range 2500-4500 and preferable unvarying data recorded with signal filtering. In addition, erratic 'main bang' effect occurred several peaks, which recorded from range 4500-6000 and the fluctuation is subdued with the signal filtering process.

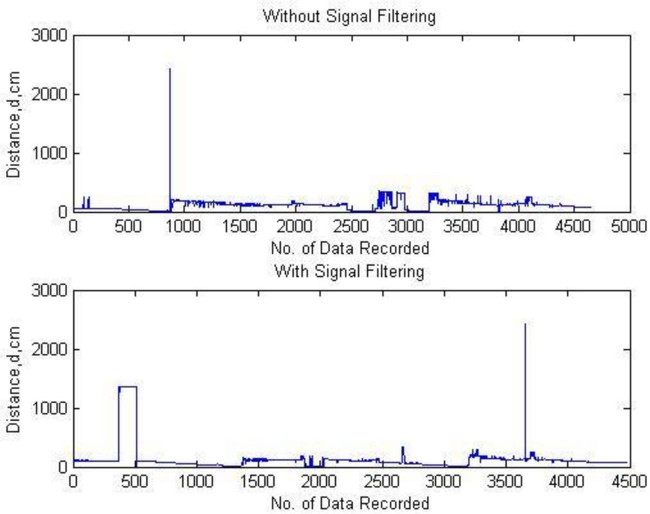

Figure 15: Experiment result for setup C

In figure 15, there is a peak arise at the beginning of the experiments and significant data fluctuation captured without signal filtering throughout the remaining route. A gap of flaws occurred in data collected from range 300-500 for signal filtering, as a probability in errors during collections of data by external interference. The stability of data recorded increased with signal filtering from the range of 1000-4500.

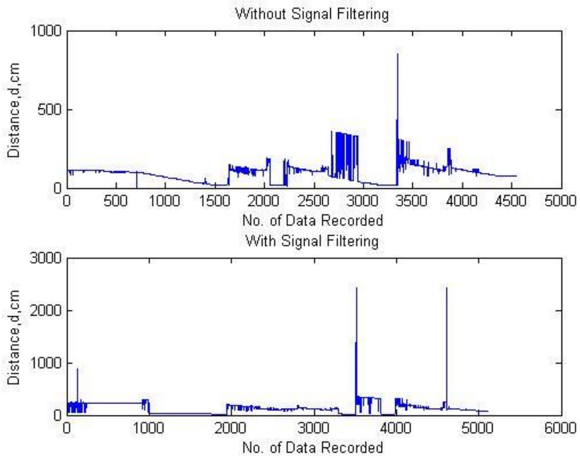

Figure 16: Experiment result for setup D

In figure 16, a stable decrement of distance recorded from range 0-1600 by the ultrasonic sensor without signal filtering. However, the results of signal filtering are having a vary of uncertainty in distance collected as there is a sudden drop in the records. The remaining data achieved a remarkable dwindle in fluctuation as noises and disturbances are filtered by Kalman Filter (KF) algorithm in the system.

Every graph indicates a different setup on the location and gaps between obstacles. Patchy peaks can be noticed in every graph where it indicates the low specification, complexity of measured state, external noises and disturbances available in the surrounding. The ultrasonic noise signals from grain boundaries and other microstructural in homogeneities place a fundamental limit on the detection of small cracks, flaws, or other metallurgical defects [11]. Undoubtedly, results indicating a better consistency and accuracy with KF algorithm. It is capable of reducing the measurement noise of the ultrasonic sensor. Main bang and flaw echo are significantly reduced as the KF algorithm act as a filter bank with a self-adjusting window structure that can display the temporal variation of the signals spectral components with varying resolutions.

IoT System Interface

The mobile robot is controlled through wireless communication between the controller of AGV and coordinator. An IoT system is constructed through an HTML webpage. The HTML webpage is functioned as a Graphical User Interface (GUI). It displayed the distance recorded by the ultrasonic sensor on the AGV prototype in two color tone. The purple color tone defines as if the obstacle lies within a safety region of the ultrasonic sensor, which is >0.2m. On the other hand, the red color tone indicates if any obstacle appeared in the critical zone (≤0.2m) of the ultrasonic sensor. In addition, there is an additional emergency button added on the GUI for emergency cases, where the power supply will be discontinued for the gear motor and the AGV will stop after the button is triggered. Furthermore, a shortcut link is included in the HTML webpage for page refreshing. The webpage is set for auto-refreshing every 10 seconds interval, where the latest data acquired from the ultrasonic sensor will be updated to the HTML webpage. As for dynamic data monitoring system, 10 seconds of data update indicated a good communication with the coordinator [12]. The IoT system is designed for its convenient unified management, monitoring, and efficient dynamic data. The IoT system interface is shown in figure 17 and 18 respectively.

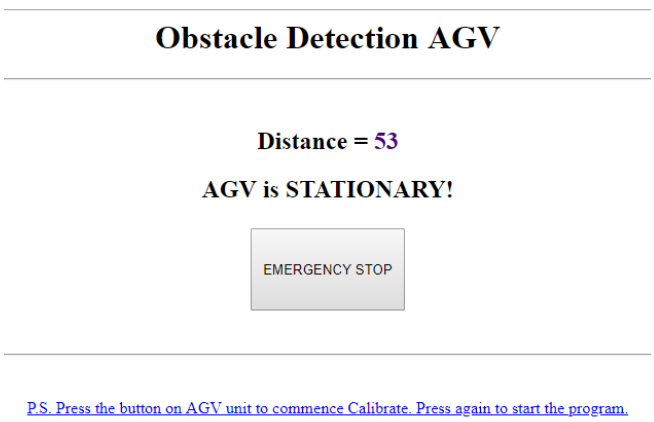

Figure 17: IoT system Interface display when AGV in the safety distance range

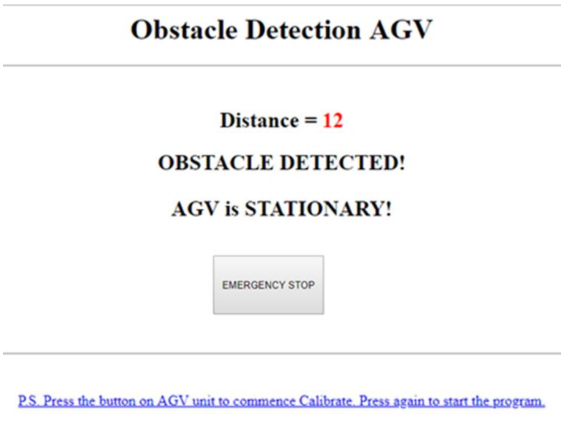

Figure 18: IoT system Interface display when AGV in the critical distance range

Communication Time Delay

Communication delay refers to the efficiency of the connection between the AGV and the coordinator. Wireless connectivity is enabled for the conveyance of information between mobile robots and the user. In real-time monitoring device and server communication, the device must be capable of sending online information to the server every 5 seconds, stipulating an efficient communication with the server. In this research, the development of the IoT system is set to renew the data on the GUI every 10 seconds interval. This is to ensure the consistency of communication and rigid connectivity between the controller and the coordinator. Hence, dynamic data monitoring is developed instead of real-time data display for obstacle detection. The communication delay duration between the data transferred from the ultrasonic sensor to the coordinator is illustrated in table 3.

Table 3: Time taken for HTML webpage to refresh completely

Num.	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
1	2.61	2.53	2.93	2.67	5.32	2.35
2	2.65	2.66	2.78	2.83	2.61	2.68
3	3.47	2.77	2.67	2.77	2.73	5.50
4	3.04	5.10	2.90	2.71	2.81	2.84
5	4.32	2.86	2.84	2.94	2.95	2.73
6	2.27	6.78	4.57	2.72	2.74	4.68
7	2.10	2.78	2.55	2.50	2.70	2.77
8	2.95	2.39	2.53	2.68	2.56	2.72
9	2.73	2.17	2.77	2.45	2.84	2.83
10	3.00	2.94	2.91	3.23	3.05	2.84

The results summaries the time taken needed for the HTML webpage to refresh completely and display the information regarding the distance between the AGV and obstacles on the GUI. The experiments are conducted in an indoor environment and the connectivity range tested within 10 meters. The unit for the results time taken is in seconds. The experiment is accumulated 10 readings per test and repeated 6 times in total. Based on the experimental results, the average time taken for communication delay is 2.8 seconds on the Wi-Fi connection. The performance is less favorable compared with ZigBee technology, which recorded 2.5 seconds on average [13]. In addition, there is a unusual peak in the communication traffic in every 10 readings obtained, which alternate within the range of 4-7 seconds. There are also wireless communication jamming occurred during the experiments due to the data broadcast on the AGV frequently. The results of the wireless communication delay are acceptable as the AGV itself is able to react instantly even if any errors occurred on the wireless broadcast traffic. It is because the controller of the AGV is competent in multiple tasking for a single command, where vehicle movement of the AGV and wireless communication is running individually. The obstacle detection program is designed in prioritize the safety level of the AGV prototype in all emergency. Therefore, the AGV reacts accordingly based on the programming sequences without the interference on the wireless communication errors.

Network Latency Test

In the latency test, 20 readings are obtained for every trial. The results are shown in figure 19, 20 and 21 respectively. In this research, the GUI proposed is displayed through IP address 192.168.4.1. The latency test is executed in three different scenarios, which is STANDSTILL mode, RUNNING mode and STOP mode of the AGV prototype in obstacle detection. The data collected are tabulated accordingly and the comparison is determined through graphs illustrated in figure 22.

```
Pinging 192.168.4.1 with 32 bytes of data:
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=3ms TTL=255
Reply from 192.168.4.1: bytes=32 time=8ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=7ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=3ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=2ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=2ms TTL=255
Reply from 192.168.4.1: bytes=32 time=2ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=2ms TTL=255

Ping statistics for 192.168.4.1:
    Packets: Sent = 20, Received = 20, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 1ms, Maximum = 8ms, Average = 2ms
```

Figure 19: Network Latency Test for STANDSTILL Mode

In STANDSTILL mode, the minimum network latency recorded is 1 ms. In addition, the highest network latency during the broadcast traffic in wireless communication is 8 ms. Overall, the average on network latency is 2 ms.

```
Pinging 192.168.4.1 with 32 bytes of data:
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=7ms TTL=255
Reply from 192.168.4.1: bytes=32 time=16ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=3ms TTL=255
Reply from 192.168.4.1: bytes=32 time=2ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255

Ping statistics for 192.168.4.1:
    Packets: Sent = 20, Received = 20, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 1ms, Maximum = 16ms, Average = 2ms
```

Figure 20: Network Latency Test for RUNNING Mode

In RUNNING mode, the minimum network latency recorded evenly with STANDSTILL mode, which is 1 ms. However, the highest network latency recorded 16 ms in RUNNING mode. The unusual peak in network latency is due to the heavy broadcast traffic in the networking as the program command progressing simultaneously by the controller of the AGV. In general, the average latency result in both STANDSTILL and RUNNING mode are equally matched with 2 ms over 20 trials.

```
Pinging 192.168.4.1 with 32 bytes of data:
Reply from 192.168.4.1: bytes=32 time<1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=2ms TTL=255
Reply from 192.168.4.1: bytes=32 time=2ms TTL=255
Reply from 192.168.4.1: bytes=32 time=11ms TTL=255
Reply from 192.168.4.1: bytes=32 time=3ms TTL=255
Reply from 192.168.4.1: bytes=32 time=9ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=2ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=5ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255
Reply from 192.168.4.1: bytes=32 time=1ms TTL=255

Ping statistics for 192.168.4.1:
    Packets: Sent = 20, Received = 20, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 11ms, Average = 2ms
```

Figure 21: Network Latency Test for STOP Mode

In STOP mode, the minimum network latency recorded in 1 ms. Besides, 11 ms is the peak latency acquired during the tests. Generally, all three modes have equal performance on the average network latency of 2 ms.

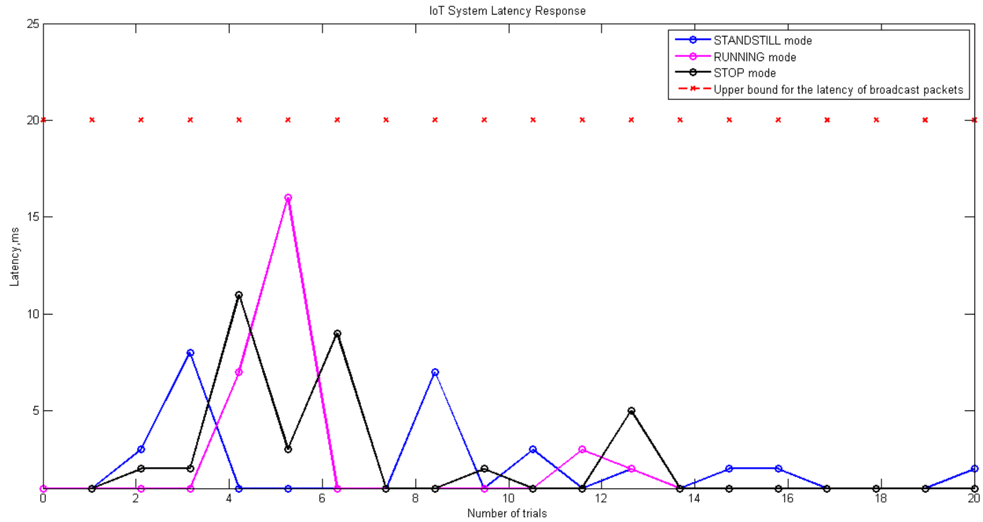

Figure 22: Comparison Network Latency Test for All Modes

In figure 22, the result shown the comparison of the strength of network latency for all three modes in obstacle detection. The lower the overall network latency, the stronger the strength of wireless communication between the AGV and the coordinator. The IoT based AGV prototype in obstacle detection commenced in phase 1, STANDSTILL mode. The AGV system is powered up while the controller and sensors are standing by to receive command from the user. The STANDSTILL mode is represented with the blue color solid line. Next, AGV starts moving on the designed route while all the sensors and controller are functioning accordingly in phase 2, RUNNING mode. It is plotted in magenta solid line. Moreover, AGV stop its vehicle movement by applying braking force to the gear motor and cutting off power supply in phase 3, STOP mode. It is represented in the black solid line. The red dotted line delineated as the upper bound for the latency of broadcast packets in a flexible wireless communication for mobile robots in an indoor environment. It is designated as the benchmark of qualify wireless communication for the AGV prototype in obstacle detection.

Substantially, the overall network latency is the 2 ms and the maximum latency of every trial is beneath the 20 ms mark. The tested results scored above the benchmark for flexible Wi-Fi communication among mobile robot in indoor industrial environments [14]. In modular production systems, the requirement for communication technology is delicate and demanding. Machine control is targeted at the network latency range from 1-10 ms while 10-50 ms marked for the cooperative driving [15]. The AGV prototype is eligible for efficient wireless communication between the controller and the coordinator as the results surpassed the network latency requirements (<20 ms) for obstacle detection. Hence, the designed IoT system for this research is practicable in real-time workplace implementation for obstacle detection.

CONCLUSION

In conclusions, an AGV prototype is designed and constructed based on obstacle detection for an indoor workplace. The technical specification of the AGV performed competently in vehicle movement for obstacle detection. Kalman Filtering (KF) algorithm successfully processed noise disturbance, surrounding interference and minimizing fluctuation on the raw data acquired. This increased the accuracy of data acquisition on the sensor output and magnified the stability in obstacle detection. Besides, IoT system developed with ease of operation as the user are able to surveillance the status of the AGV and the latest distance measurement by the ultrasonic sensor. In addition, the IoT system surpassed the minimum requirement for a flexible indoor wireless communication in obstacle detection based AGV. Hence, the development of this AGV prototype accomplished all the objectives in this research and the results are sustainable.

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