Design and Prototyping of Mini AGV with Arduino Microcontroller

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Abstract

This paper presents the design and prototype of a Mini Automated Guided Vehicle (AGV) using a microcontroller. The mini AGV system is based on an autonomous forklift. The purpose of the AGV prototype is to move objects from one place to another and continuously. To run, AGV uses the Line Follower method by using four obstacle detection sensors or infrared transmitters and receivers. Furthermore, when all sensors are active, AGV will stop when there are objects with RFID tags outside. The RFID reader which is placed in front of the AGV activates a stepper motor which will move the object's fork. Then AGV sends the object to a predetermined place. Most components use compatible Arduino modules, except for the chassis and some parts use components made of acrylic or printed in 3D.

Keyword: Automation, AGV, Forklift, Arduino.

Abstrak

Makalah ini menyajikan desain dan prototipe Mini Automated Guided Vehicle (AGV) dengan menggunakan mikrokontroler. Sistem mini AGV didasarkan pada forklift otonom. Tujuan dari prototipe AGV adalah untuk memindahkan objek dari satu tempat ke tempat lain dan terus menerus. Untuk menjalankan, AGV menggunakan metoda Line Follower dengan memakai empat sensor deteksi rintangan atau pemancar dan penerima inframerah. Selanjutnya, ketika semua sensor aktif, AGV akan berhenti ketika ada objek dengan tag RFID di luar. Pembaca RFID yang diletakkan di depan AGV mengaktifkan motor stepper yang akan menggerakkan garpu pengangkat objek. Kemudian AGV mengirim objek ke tempat tertentu yang telah ditentukan sebelumnya. Sebagian besar komponen menggunakan yang kompatibel dengan modul Arduino, kecuali untuk sasis dan beberapa bagian menggunakan komponen yang terbuat akrilik maupun dicetak 3D.

Kata kunci: Otomasi, AGV, Forklif, Arduino.

1. Introduction

Industrial development in Indonesia is currently increasing significantly and will be said to enter Industry 4.0 when automation and data exchange can be controlled and monitored via the internet including the Cyber-Physics System, the Internet of Things, big data and analytics, augmented reality, additive manufacturing, simulations and robots autonomous [1]. Autonomous Guided Vehicle (AGV) is an Industry 4.0 application and the ability to monitor, control and store data to the cloud increases the value and benefits for companies both in cost and time.

The next few years AGV will become a necessity in Indonesia. Currently the most popular autonomous vehicle is the line follower type, but no one has operated a Line follower mini AGV in the industry. In general, Line follower AGV is a self-operating machine that follows a line drawn on the floor, be it a black line or a white line. The basic operation of Line follower AGV is to use information from the sensor as input and motor position as output. This program can use discontinue (on-off) or continue using digital Derivative Integral Proportional (PID) programs.

Related to the same topic, some people have built mini-forklifts with their own methods, such as being controlled via Bluetooth. Bluetooth has a very minimum connection range and is not suitable for industrial scale [3]. Another method that has been carried out by others is load cell robot with line follower program and AVR Cortex-M microcontroller [4]. The author found that the robot or AGV load cell cannot import data to the database so that the user cannot monitor the data, while the AVR Cortex microcontroller is a microcontroller before Arduino existed

Based on the fact above, the author is interested in designing a mini AGV and building its prototype because there are a number of points that indicate AGV is suitable for Industry 4.0. First, the task for AGV is flexible, meaning AGV can be used to move objects, become smart cars, or direction guide. Furthermore, AGV is equipped with a computer system that allows companies to track every detail and can connect AGV to the internet to exchange data. Third, AGV can be operated in all conditions that may be dangerous, including extreme temperatures, chemicals, gases, biological contaminants, radiation. A damaged AGV can be replaced or repaired. The last is AGV productivity which can operate continuously all the time without a break..

2. Methodology

This section shows the steps how the author designs and constructs the AGV as shown in the flow diagram Figure 1. This AGV uses a Proportional-Integral-Derivative (PID) line follower program that is combined with a Radio Frequency Identification (RFID) device. The purpose of RFID is to identify the object whether it is the correct object and to adjust the height of the object. Recorded data can be seen in MySQL or php MyAdmin using the XAMPP or WAMP server. In addition, AGV is equipped with a WIFI module, ESP8266, which allows it to transmit data.

2.1 Problem Identification

Traditionally, human operators have many disadvantages compared to automatic guided vehicles. In the warehouse storage system, this problem arises because humans work with emotions which means that their work depends on emotions. This causes problems, for example in warehouses operators usually take or leave objects to the nearest storage. While they may not take or leave the furthest storage and cause the furthest object to dust because it was never taken. Another example, human operators might forget to record data storage. However, this problem can be solved by automated guided vehicles. AGV removes some of the potential for inaccurate workflows, reduces non-productive time and increases output, making operations more accurate and productive. When operators have limited time, to increase production usually companies need 3 shift operators while AGV is able to operate 24 hours a day and 7 days a week. In addition, AGV is able to simplify warehouse management systems.

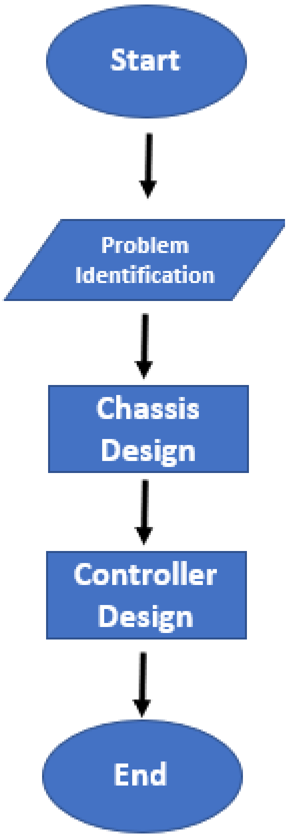


Figure 1. Workflow Diagram

2.2 Chassis Design

After the problem was identified, the authors designed the AGV chassis using CATIA V5 software. Figure 2 shows how the chassis is designed. To get a suitable chassis, the author included several electronic components to determine the position and dimensions needed from my chassis. Next, the author makes the components and assembles them. The author uses PLA material to print 3D some parts and some other parts use acrylic.

To ensure that the product that is designed to work properly, it is necessary to do some analysis of several product alternatives. Therefore, the author makes several designs to analyze the mechanism and choose the best. There are 3 models as shown if the picture below. each has advantages and disadvantages.

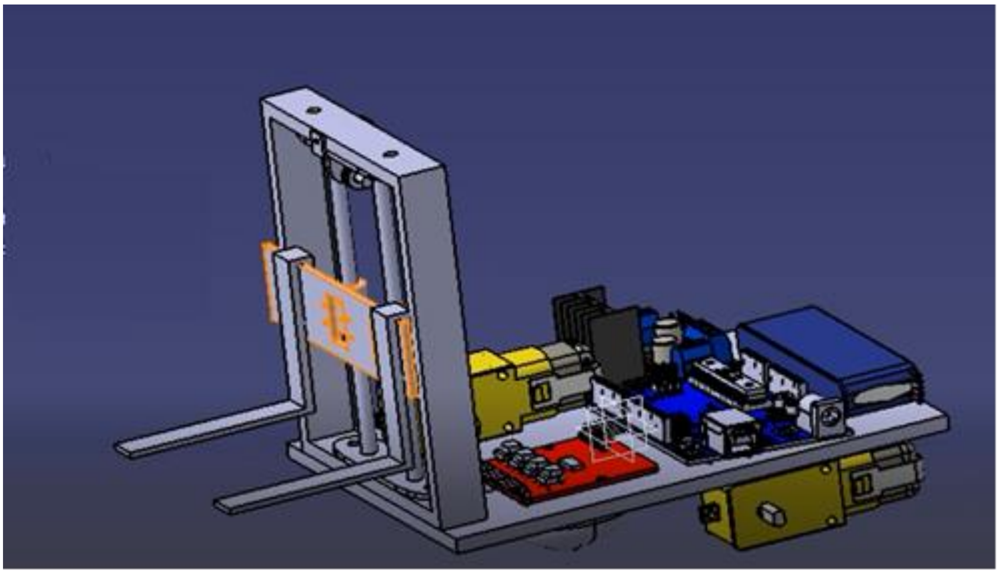


Figure 2. Alternative model 1

In alternative model 1, the authors found weaknesses in the lifting system. Especially the rectangular shape on the front is too heavy and difficult to make because the material is limited. In other words when the front side is too heavy, the center of mass may not be on the back side which might forklift fall to the front side.

In alternative model 2, the authors replace the rectangular bars in model 1 and print the parts on the 3D printer. When all components are assembled, the lifters and rods are barely able to move due to friction even though the author has used lubricating oil for the rods. Another problem occurs because the pulleys are separated as shown in Figure 3.

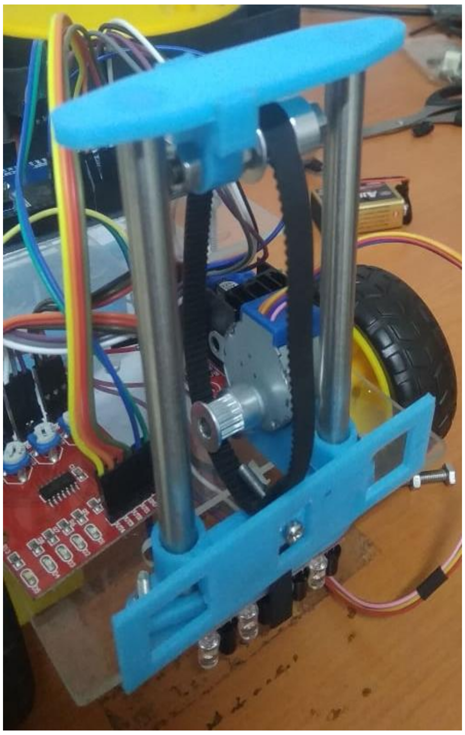


Figure 3. Alternative model 2

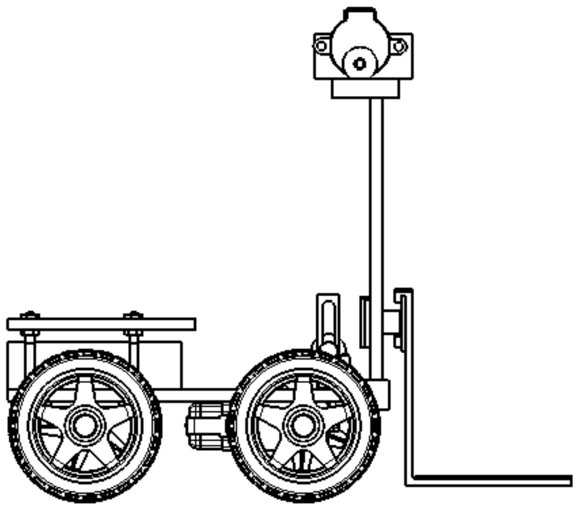


Figure 4. Alternative model 3

The author tried to connect them with screws but did not fit. The belt is not taut so the teeth cannot move. Second, the movers and gears above are not aligned. This creates different movement results. For example, when moving clockwise the belts can strain each other, and when moving counter-clockwise, the pulley becomes tense so the belt becomes loose and does not move.

In alternative model 3, the authors designed the adjuster so that the belt has tension can be maintained. Other pulleys are assembled with bolts and nuts that can be adjusted upside down which causes the belt to strain. Not only the adjuster, the author also replaced the stainless steel rod with a sliding track and the bolts connecting the separate belts were replaced with connectors. Sliding track has a very minimum friction coefficient. Means sliding track is a solution to the problem of friction in design models 2. Sliding track needs to be implanted with a minimum of 1 centimeter on the bottom and top so as not to fall. Next, the two sides of the belt are stretched taut. After that, the two sides are connected with the other side placed on the other side and pressed and locked using bolts and nuts. While other connectors have a rectangular shape with a height of 6 mm. This connector presses the belt to correct problems with model 2 above.

On the top side, the author also made a place for stepper motors. The main reason why stepper motors are not on the lower side is due to lack of space. Before analyzing the maximum load of the forklift, another problem arises. When looking back to model 3 (Figure 4), the upper and lower pulleys are not parallel. It has a small angle between them which might cause the same problem with model 2 but it is better.

2.3 Lift Calculation

According to the stepper motor 28BYJ-48 data sheet [5], the maximum torque is 300 gf.cm or 0.03 Nm. In ideal conditions the motor speed is 200 rpm. Based on the data sheet, motor power is 0.628 Watt. While the planned power in the AGV is calculated based on the rotation speed of 150 rpm is as follows:

$$P = T\,w$$

$$P = (0.03\ \text{Nm}) \times (150)\ 2\ (3.14)\ /\ 60$$

$$P = 0.471\ \text{Watt}$$

Thus, the weight of the load that can be lifted can be calculated as follows:

$$T = F\,r$$

$$0.03\ \text{Nm} = F \times 0.015\text{m}$$

$$F = 2\ \text{N}$$

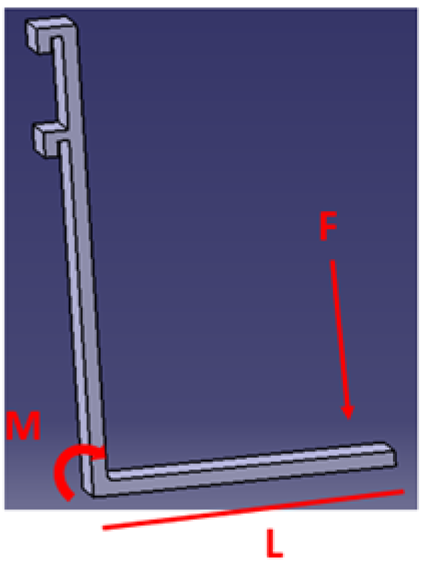
$$F = m\,g$$

$$2\ \text{N} = m \times 9.81\text{m}$$

$$m = 200\ \text{gram}$$

2.4 Calculation of Fork Bending Stress

The maximum load that can be lifted by AGV is 200 grams or approximately equal to 2 N. The position of the heaviest load is assumed to be at the end of the lifting fork, so the calculation of the bending stress is as follows:



$$M = F \times L$$

$$M = (2\ \text{N}) \times (75\ \text{mm})$$

$$M = 0.15\ \text{Nm}$$

$$\sigma_{max} = M \times y \times I^{-1}$$

$$\sigma_{max} = (0.15\ \text{Nm}) \times (1.5\ \text{mm}) \times (2.25 \times 10^{-11})^{-1}$$

$$\sigma_{max} = 10\ \text{MPa}$$

M: Moment
F: Load
L: Fork length
σ_{max} : Max Bending moment

From the PLA material specification data it is known that the flexural resistance is 97 MPa [6], if the safety factor is 4, the permit voltage is 97: 4 or equal to 24.25 MPa. Thus it can be said that this fork is safe.

2.5 Controller Design

The controller for this AGV is based on a flowchart as shown in Figure 5. There are two controllers created, namely the PID and RFID follower lines on the forklift lifters. Using the PID line follower means AGV uses Pulse Width Modulation (PWM) for motor speed which affects how the motor behaves. This is a continuous program, meaning that the PWM value will change over time and situations. In contrast to non-continuous programs that use ON and OFF statements. The advantage is that the movement of AGV is smoother than non-continuous programs. The PID controller is used to control the movement of the AGV in following the line, while the RFID controller is used by the AGV to recognize the object to be raised.

2.6 PID controller

Proportional-Integral-Derivative (PID) is a control algorithm that is widely used in industry to control robots or other [7]. PID consists of 3 main things namely Set Point (SP), Error and Present Value (PV).

SP = Set Point, is the parameter value that we have set before.
PV = Current Value, the variable measured by the sensor that will provide signal feedback.
Error = Deviation between the measured variables with the parameter values

The ideal condition of the sensor is when PV = 0 or two sensors in the middle are active. If the PV is not equal to 0 means AGV is not in ideal condition or error. When an error occurs, the PID will count the signal to the motor driver and convert it to a Pulse Width Module (PWM). Also if 4 sensors are used that means there are 16 probability of reactions between sensors.

Figure 5 shows the controller workflow diagram, the AGV will move to the picking destination and it will stop in front of the goods to identify its code using RFID. If the code is valid then the AGV will lift the goods and move to destination place and drop the goods to its place. After completed, the AGV will move backward and start moving the next destination.

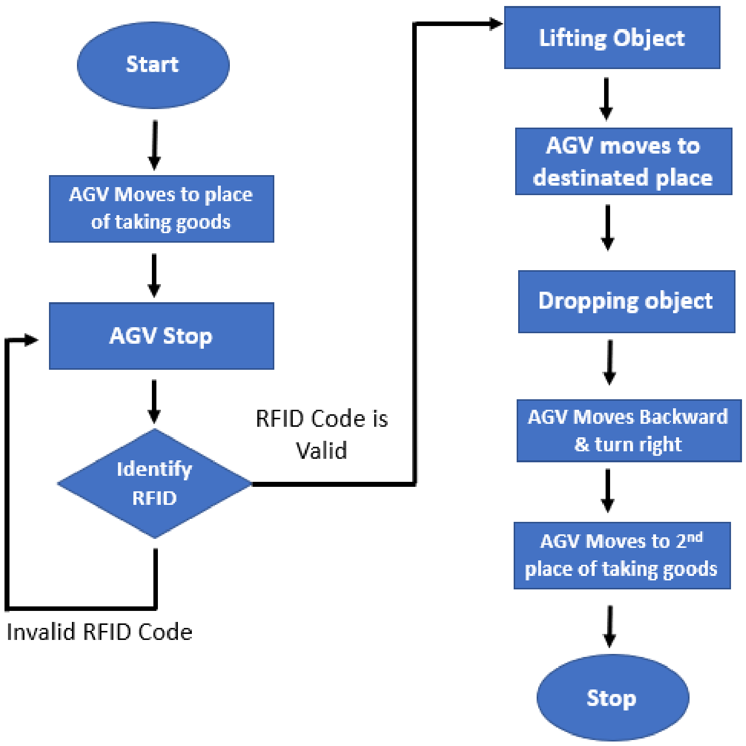


Figure 5. Controller workflow diagram.

2.7 RFID

Radio Frequency Identification (RFID) is a common technology that uses radio waves as its communication to read or exchange data between electronic tags and readers. RFID uses an automatic data retrieval system that improves performance. Codes stored in RFID tags are attached to physical objects. For example, RFID is widely used for attendance systems or Smart Lock systems. Usually the SL030 RFID module reads and writes RFID tags using 13.56 Mhz [8]. RFID can also be combined with MySQL to read objects and send data to databases via the internet.

2.8 Send Data to the Internet

The purpose of sending data to the internet is to help operators monitor movements and AGV systems on web pages. As a microcontroller, Arduino Mega is not equipped with an internet module, however AGV requires ESP8266 NodeMCU as a WiFi Module [2]. Because NodeMCU and Arduino Mega are different devices, their serial communication needs to be defined in the Arduino sketch. So, NodeMCU will receive data from Arduino Mega and the data received will be sent to MySQL. To achieve this goal, other programs need to be uploaded to NodeMCU.

3. Results and Discussion

After assembly is complete, testing is then carried out to ensure this AGV can work properly. There are five tests that will be carried out, namely PID program tuning, load weight test, combined load weight test with line follower, overall test, and battery or endurance test.

3.1 Tuning Proportional Integral Derivative Program

To find the best for Proportional Coefficient (Kp), Derivation Coefficient (Kd), Intergral Coefficient (Ki) the author uses the tial-error method by changing the values shown in Table 1 and uploading them to the Arduino program with PWM motor speed 40. In the experiment to -10 obtained satisfactory results, namely Kp = 50, Ki = 0.0125, and Kd = 100.

Table 1. Tuning Proportional, Integral and Derivative coefficient values

NO	Kp	Ki	Kd	Result
1	0	0	0	AGV just moves straight
2	10	0	0	AGV starts to follow line but not stable
3	20	0	0	AGV starts to follow line but not stable
4	25	0	0	AGV starts to follow line but not stable
5	50	0	0	AGV follows the line but oscillate too much
6	50	0	25	AGV needs to decrease overshoot
7.	50	0	50	AGV needs to decrease overshoot
8	50	0	100	AGV needs to eliminate some errors
9	50	0.05	100	AGV move more smooth
10	50	0.0125	100	AGV is perfect

3.2 Load Weights Test

Referring to the maximum torque of the motor and the calculation of the ideal ideal load, the maximum AGV load is 200 grams. The 200 gram load is the ideal load for AGV after applying safety factors to the stepper motor and maintaining the AGV center of gravity in the stability triangle. At the time of testing, the fact was that AGV was able to lift loads three times greater than ideal conditions, but would have an effect on the AGV's movements or the position of its center of gravity.

3.3 Load and Line Follower Combination Test

This test shows the ability of AGV to move objects with different loads when the line follower program and stepper motor are combined. The different AGV behavior is shown by changing the load but with the same motor PWM. For example, at 40 PWM and 580gram AGV loads are able to lift objects but fail to move objects because the load is too heavy. To overcome this situation, the PWM speed motor needs to be increased to get more torque. But as a side effect, before the AGV finds and lifts the object, the AGV moves faster and is more unstable because the PID program setting is set to 40 PWM.

3.4 Battery Test

When four batteries are arranged in series, the total voltage is 14.4V but the millimeter ampere hour (mAh) remains the same. In this case the author uses four 3.7 Volt batteries with 500mAh with a serial connection. This test shows how many AGV cycles can survive with 500 mAh.

When PWM increases, power consumption also increases. However, this causes a high PWM to have a lower maximum cycle in 1 period. But, while PWM is too low, AGV also has a lower cycle because the low PWM cannot run when the battery drops at some point. For example, when PWM is low it cannot run when the battery is 3.0 VDC because it produces low power or torque on the DC motor. It will be different if a higher PWM is used. PWM 40 is suitable for this case, AGV can run smoothly and has the highest cycle in 1 period. Also, there are external factors that cause a lack of cycles which are a condition of the battery. Batteries used may not mix with new batteries or they will affect battery performance in series. Usually one battery will fall faster or the charger faster than the other. To note, that 1 cycle is when AGV moves from A and returns to A on the AGV circuit.

3.5 Overall Test Results

Overall tests mean tests for AGV starting from the line follower test, RFID test, moving objects and starting to repeat. As a result of Table 4.5, it can be concluded that from 60 experiments with various speeds the AGV PWM was successful at 63.3%. Most failures are caused when AGV moves backwards and PWM speeds. When the PWM speed is too high, AGV becomes unstable because the Proportional, Integral, Derivative Coefficients (Kp, Kd, Ki) are set with a low PWM speed.

Table 2. Overall Test Result

NO	Initial Speed (PWM 1-255)	Maximum Speed	Load (gram)	Success	Failed	Trial(s)
1	38	45	120	12	3	15
2	40	45	120	11	4	15
3	42	48	120	9	6	15
4	45	50	120	6	12	15

Success 63.3% and failed 36.7% from 60 trials.

3. Conclusion

This research aims to design and create an Arduino-based mini AGV prototype. The AGV prototype is an Arduino-based forklift combined with a line follower that helps move objects from one place to another that has been determined. From the trials that have been done, AGV errors occur when having to move back and look for another track after sending an object. This error occurs because the motor is dependent on the battery. Which means that when the battery is low, the motor loses torque to move backwards. Overall, the test results show that this AGV works well with the following notes:

1. Communication between the Arduino IDE, the Radio Frequency Identification Tool Module and the Derivative Integral Derivative (PID) program is proceeding smoothly as designed.
2. The AGV movement depends on the PID coefficient, otherwise the PID coefficient needs to be adjusted.
3. AGV can be repeated up to 17 times with four 3.7 V, 500 mAh Li-Ion batteries.
4. AGV can lift three times greater than the specified load.
5. AGV completed 63.3% of all tests where all failures occurred when the AGV withdrew.

From the results above, there are a number of points that can be suggested to improve AGV:

1. Utilizing AGV chassis especially in lifting systems.
2. AGV can be programmed by a GPS system.
3. Use the ultrasonic sensor to identify obstacles in front of the AGV.
4. Use more infrared sensors on the back of AGV to move backwards..

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