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Smart automated guided vehicles for manufacturing in the context of Industry 4.0

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Abstract

Industry 4.0 is the next step for the manufacturing industry by adding internet technologies to optimized automation system. This paper demonstrates automated guided vehicles (AGVs) in a real factory scenario which utilized radio frequency identification (RFID) tags for identification and motion control purposes. The AGVs were tested in a real factory scenario, focusing mainly on two types of AGVs, Karl and Jimmy. They were equipped with RFID readers to detect tags placed on the ground or inside objects. The internal logistics of a smart factory's manufacturing environment were demonstrated using the two types of AGVs. It highlighted three aspects which are seldom talked about in order to effectively implement a smart AGV system: reconfigurability, flexibility, and customizability.

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Keywords: AGV; RFID; Smart Factory; Industry 4.0.

1. Introduction

Advances in technology and increasing population has put more demand on the manufacturing industry. Customers expect both higher productivity and greater variety [1-3]. To achieve this, current systems must be more efficient and manageable. Industry 4.0 is the next step for the manufacturing industry. With the addition of internet technologies to optimized automation systems, manufacturing processes can be made more seamless, relying less on human intervention, and allowing systems to perform self-decision-making [4]. The goal is to make factory environments more intelligent where the products themselves will be used to determine their next required process.

One of the core components in the manufacturing industry are the logistic systems. Automated Guided Vehicles (AGV) are widely used to transport goods and materials to different parts of a factory, and are considered to be one of the most efficient and suitable

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options [5]. AGV systems must be able to handle different situations, such as a change in layout, and operate in a dynamic environment. These challenges require smart decision-making inside a factory environment. Therefore, this paper looks at the use of Radio Frequency Identification (RFID) technology for creating a smart AGV system that is flexible and reconfigurable in such an environment.

A factory scenario was setup to demonstrate the RFID-enabled smart AGV system. RFID technology was used for guidance or motion control of the AGVs, and for creating objects known as smart products. There were two different AGVs termed as Karl and Jimmy in this paper:

- Karl - This was an AGV robot with an arm and attached gripper. It could be used for carrying objects. It used RFID for motion control and object identification.
- Jimmy – This robot followed a fixed laid-out path and used RFID for motion control. It replicated the roles of an AGV used for transporting goods.

Based on these two types of AGVs, tracks were designed to showcase the individual abilities, interactions, and to demonstrate the flexibility of RFID technology in creating a much simpler guidance and control method.

This paper is organized as follows: Section 2 is a literature review of relevant topics from current research. Section 3 introduced the equipment and design of different components using 3D printing. Section 4 presents the AGV setup and section 5 describes the factory scenario with multiple AGVs. Section 6 talks about the limitations of the research and the discussion. Section 7 summarizes the conclusions and includes suggestions for future work.

2. Literature Review

2.1. Industry 4.0 and Smart Factories

Industry 4.0 is the term used to describe the fourth industrial revolution. It merges different technologies to further improve the organization and management of manufacturing environments [4, 6]. Its concepts can be applied to current manufacturing factories with the addition of internet technologies [7]. These technologies aim to enhance the communication between systems and better manage facilities inside factories [8, 9]. This can be done by using sensor data from real world systems to create a virtual counter-part. This allows for improved monitoring and control of systems. This concept is known as a cyber-physical system (CPS) [4, 10]. Data may need to be collected from manufactured products, so some form of connectivity must be added to the products to exchange data. This concept is known as the Internet of Things (IoT) [11].

An implementation of Industry 4.0 is referred to as a smart factory. Inside smart factories are smart devices and products which demonstrate IoT and CPS concepts. Smart devices have onboard processing, data storage, communication technology, sensors and actuators. Smart products can identify themselves, describe their status, history, and upcoming processes [8, 12]. Manufacturing is thus more flexible and intelligent in smart factories, which results in more individualized products and allow for a modular structure to factories [13].

2.2. Automated Guided Vehicles (AGV)

These vehicles are used for processing and transporting goods inside of a factory environment. They are unmanned and navigate using guidance and control methods. Their shape, size, and operation depend on their use within a factory.

AGVs are smart devices which can use onboard processing to perform decentralized decision-making, such as path planning and collision avoidance. Path planning has been found to be computationally expensive with multiple running AGVs. This operation may need to be off-loaded to a more powerful central processor [14]. In a real factory environment, localization and routing of AGVs can present difficulties. Correct equipment must be setup in the factory, which is time consuming and costly, and inefficiencies can occur due to the AGVs not understanding the dynamic environment [15].

AGV guidance technology can be separated into two groups: fixed and free route guidance methods [16]. Fixed route methods rely on a laid-out path that the AGV will sense and follow. Such examples include magnetic and optical tape. Free route methods store coordinates which the AGV uses to identify its current location. Such examples include GPS and vision guidance. Fixed route methods, such as magnetic tape, are not flexible as any changes would require re-taping which has a high maintenance cost, although the material cost is low [17]. They provide accurate positioning of AGVs and some decision-making capabilities, but other methods are required to monitor the exact location of an AGV. Free route methods are expensive and can be disturbed by the environment. They require less maintenance once installed and are able to locate the AGV, but are less reliable and accurate [16, 17]. Free route methods such as GPS offer flexibility and easy customization of AGV routes.

Factories will generally require multiple AGVs. To manage such a fleet different models can be applied to the AGV system [18]. A flow path design model increases the flexibility of the paths for each AGVs but adds complexity and there is a higher chance of collisions. A tandem regional model divides the factory floor into non-overlapping regions. Each region has one operating AGV with exchange stations in between. However, exchange stations can introduce delays which would slow down productivity [19].

2.3. Radio Frequency Identification (RFID)

This technology transmits information via radio waves of a specific frequency. The circuitry can be encapsulated inside tags, where the information can be extracted by readers. There are two types of tags: passive and active. Passive tags do not require a power source, while active tags do. The information found in the tags are unique identification keys. These keys are useful when linked to a database.

In a manufacturing environment, these tags can be attached to manufactured products to create smart products. It is then possible to track these products and use the tags for decision making [9, 20]. RFID can be used for accurate positioning of AGVs [5]. This can be achieved by analyzing the magnetic fields produced by RFID readers to determine where a tag is most likely to be detected, and tags can be rearranged into patterns to ensure reliable detection [5]. Error suppression methods can then be used to determine accurate positions [21].

2.4. Smart Design

One of the essential framework of Industry 4.0 is smart design [4]. The framework made use of rapid prototyping, such as 3D printing, which enables fast and easy manufacturing of products for testing.

With 3D printed components, AGVs can be easily customized to suit their application [22], spare parts can be manufactured in-house, which will improve efficiency and decrease costs.

2.5. Manufacturing Systems

AGVs are the future for manufacturing systems, however an effective way to implement them with respect to Industry 4.0 is still lacking. There are three types of manufacturing systems [23]:

- Dedicated Manufacturing System (DMS): A system that can cope with a specific product or product range and is especially designed for a high throughput. However, its capacity is fixed and cannot be modified to cater volatile customer demands.
- Flexible Manufacturing System (FMS): A system which is functionally flexible. The extent of its flexibility however is pre-defined. Hence, substantial financial and time expenditure are required if the adaptations exceed the limit of the system.
- Reconfigurable Manufacturing System (RMS): The main feature of a RMS is that it consists of a relatively inexpensive manufacturing line or equipment that can be set up to manufacture a particular product in a dedicated manner much like a DMS, but that can later be reconfigured, over a relatively short changeover period, to manufacture a different product [24].

Table 1 - Key characteristics of RMS

Key characteristic	Description
Convertibility	Short conversion times between different manufacturing statuses
Customization	Customized flexibility and control for certain products and product families
Diagnozability	Traceability of product quality during ramp-up and operating phases
Extensibility and reducibility	Degrees of freedom of system objects in terms of their expansion, growth or shrinkage
Function and utilization neutrality	Dimensioning of tasks or functions to fulfil various requirements and applications
Interconnectivity	Allows various connections inside and outside of a system

Integrability	Quick integration of new components and technologies, e.g. with the help of standardized interfaces
Mobility	Local, unrestricted mobility of objects within a system
Modularity	Modular structure of components and controls

From Table 1, RMS is the best manufacturing system to date as it considers more factors. With that in mind, this paper attempts to design a smart logistic system with RMS and Industry 4.0 technology as its backbone.

3. Equipment and Designed Components

3.1. RFID

RFID came in the form of tags and was used for decision-making by the AGVs. Readers were attached to the AGVs to detect the tags. The devices used are shown in Fig. 1. There were two frequencies of RFID tags used: 13.56 MHz and 125 KHz. The 13.56 MHz tags were used for motion control and were either embedded into clear plastic or white paper. The 125 KHz tags were used for object identification and were embedded into black plastic.

Fig. 1. RFID tags and readers

The MFRC522 RFID reader detected 13.56 MHz RFID tags only. It had a reading distance of up to 50mm. It was attached to the base of both AGVs and was used for motion control. The ID-12LA RFID reader detected 125 KHz RFID tags only which had a reading distance of 120mm. It was attached onto the gripper of Karl and was used to identify objects.

3.2. 3D Printed Components

3D printed components allow easy customization of the AGVs. The main body of Jimmy and Karl themselves are easily customized to suit any factory scenarios. This brought adaptability and cost efficiency on to the table.

Any required custom components for the AGVs were designed in CAD and then 3D printed. There were three RFID reader mounts that were designed for the AGVs. They are shown in Fig. 2. Two were used for Karl and one was used for Jimmy. The first mount housed the ID-12LA RFID reader and was attached onto Karl's gripper. The next two mounts housed the MFRC522 RFID reader, attached to the base of both Karl and Jimmy.

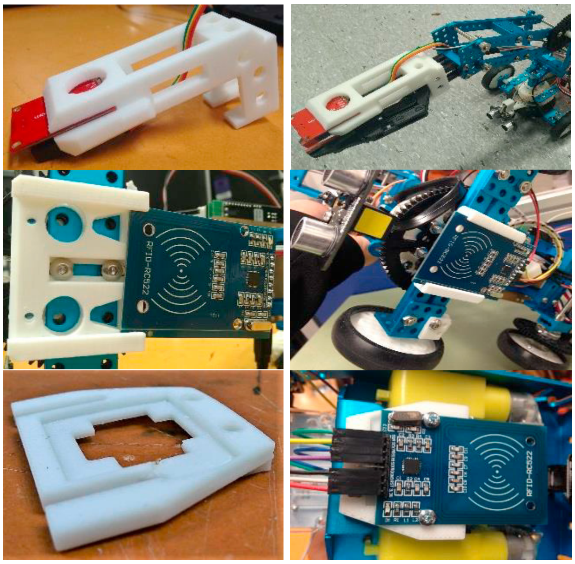

Fig. 2. RFID reader mounts for AGVs

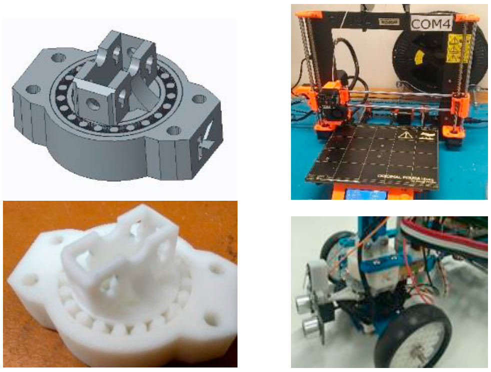

Fig. 3. 3D printed bearing used for Karl

Karl required a bearing for the rotation of the front wheels, so it could turn. A 3D bearing model was designed in this paper for the rotation of the wheels. The bearing shown Fig. 3 allowed the arm and the front wheel to share the same axis of rotation, while holding them firmly in place. This unique design enabled one motor to rotate the front wheel and the arm at the same time, instead of having separate motors for each.

Karl used two limit switches for calibration and limiting the rotation of its wheel and arm. Mounts were made to hold the limit switches for Karl to press.

4. AGV Setup

4.1. Jimmy Setup

The final setup of Jimmy is shown in Fig. 4. Its main microprocessor board was the mCore. The following features were present:

- Line following module to follow a laid-out path
- Front sonar for avoiding collisions
- Platform for carrying objects
- RFID reader attached to the base for motion control
- Mega 2560 microprocessor board used specifically for the reader
- Me RJ25 adapter to connect the Mega 2560 to the mCore

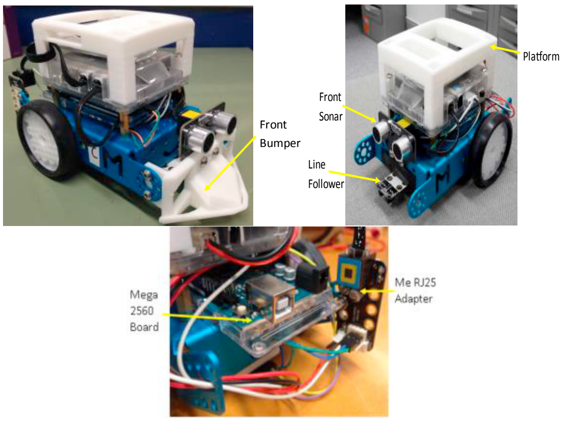

Fig. 4. Final setup of Jimmy

4.2. Karl Setup

The final setup for Karl is shown in Fig. 5. Its main microprocessor board was the MegaPi. The following features were present:

- Front and back sonar for avoiding collisions
- RFID reader attached to the arm for identifying the smart products
- RFID reader attached to the base for motion control
- Limit switches to limit rotation of arm and body

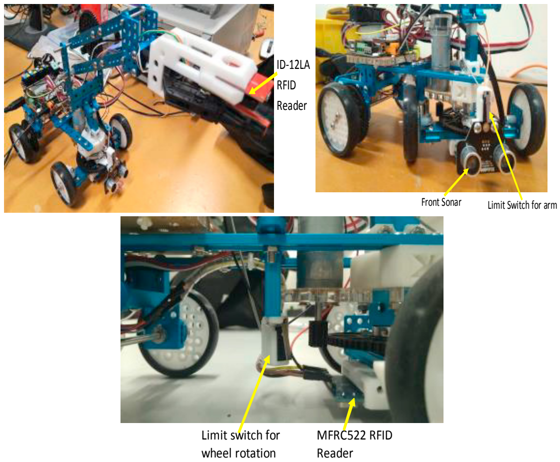

Fig. 5. Final setup of Karl

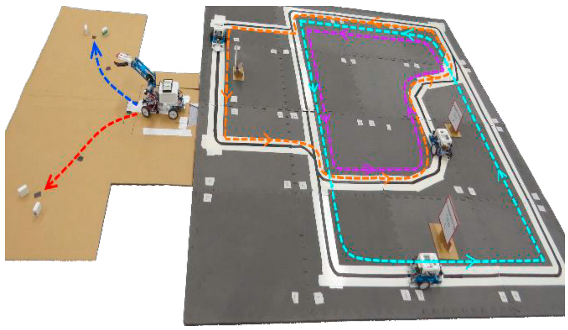

Fig. 6. Full factory scenario of both AGVs

5. Factory Scenario

A smart factory environment was established to provide insights in determining the practicality of the proposed solutions and how it will fit in the advent of Industry 4.0. In most real-world cases, a fleet of AGVs would be used in a factory. In the current scenario, one Karl and three Jimmy AGVs were conducted on separate tracks. Each Jimmy AGV had a fixed path to travel in its track. The factory scenario is shown in Fig. 6.

5.1. Track Design

The optical line-following module, used on Jimmy, replicated the roles of magnetic tape, which is typically used as a guidance system in real factories. It required a thin black reflective path, with a white reflective background as shown Fig. 7. Multiple paths were created onto the track.

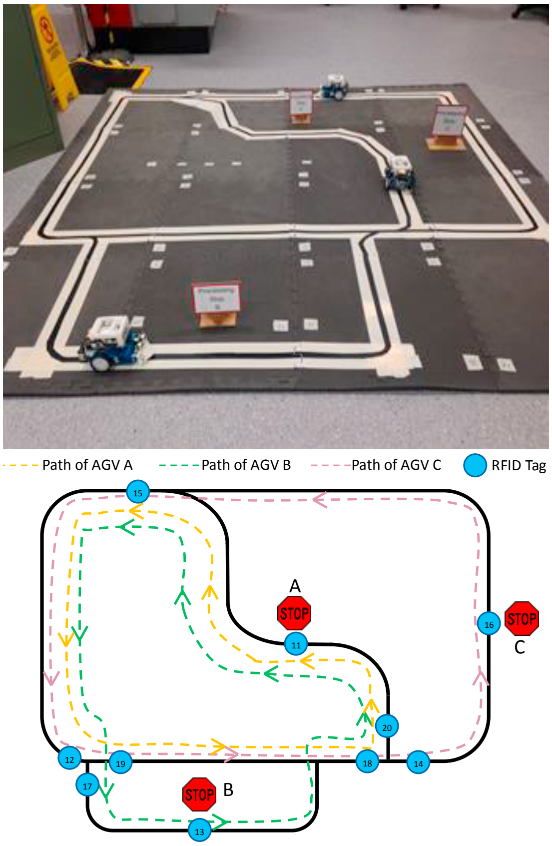

Fig. 7. Multi-path rubber mat track for Jimmy

Karl only used RFID tags for guidance, so the track was made by taping RFID tags onto a large piece of cardboard. The tags were taped on such that a split-path track could be implemented, where Karl had an option of two paths.

5.2. RFID Implementation

The white paper 13.56 MHz RFID tags were taped onto the multi-path track to create stops for Jimmy as shown in Fig. 8. Tags were than used for changing the direction of Jimmy as it moved. This was demonstrated on the test track. This was implemented onto the multi-path track alongside the stopping ability.

A smart product was created by putting a black 125 KHz RFID tag inside of a 3D printed box with sliding lid. The smart products were handled by Karl. To use the RFID tags, the code of each tag had to be recorded in a database. The 125 KHz tags were made up of a sequence of six hexadecimal numbers, while the 13.56 MHz tags were made up of eight. When a tag was read, the bytes would be sent to a microprocessor board. The database of recorded tags was stored onto each microprocessor board such that motion control and object identification could be carried out by an AGV.

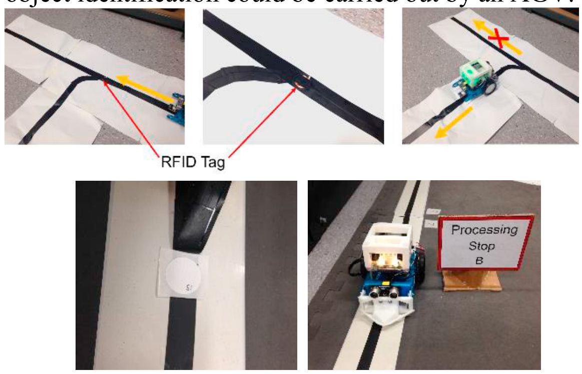

Fig. 8. Path changing and stopping of Jimmy using RFID tags on test track

5.3. Multi-AGV Scenario

5.3.1. Jimmy

There were three Jimmys that were setup (A, B and C) to run on the multi-path rubber mat track. RFID tags were used for stopping and for changing paths; as previously described. The speed of each Jimmy was approximately 0.3m/s which was assumed to be fixed. There were three different paths for each of the three AGVs. The RFID tags were used to carry out specific motion changes for each AGV, such as stopping or changing paths. The tags were also used to check if an AGV was travelling on the correct path. Each AGV had exactly one stop.

Table 2. Commands for Transporter AGV

Tag Command	Description
0	No tag read
1	Stop motion
2	Turn left
3	Turn right
4	Slight left
5	Slight right
6	Wrong path
7	On correct path

On each Jimmy, commands were sent from the Mega 2560 board, which is connected to the RFID reader, to the mCore, which controls the AGV's motion. A command took the form of an integer number. A single tag could result in different commands depending on the AGV which passed over it. Commands 2 and 3 were used to change the path of an AGV. Commands 4 and 5 were used to make sure the AGV did not change paths by ensuring it travelled away from the path change. Commands 6 and 7 were used if any Jimmy travelled on the wrong path. If this occurred, it would signal a flashing red light until it returned to its correct path.

To implement the multi-path running of the three Jimmys (A, B and C), each tag had to correspond to a tag command for each AGV. This decision-making was programmed into each AGV, to carry out the necessary command, when it passes over the RFID tags.

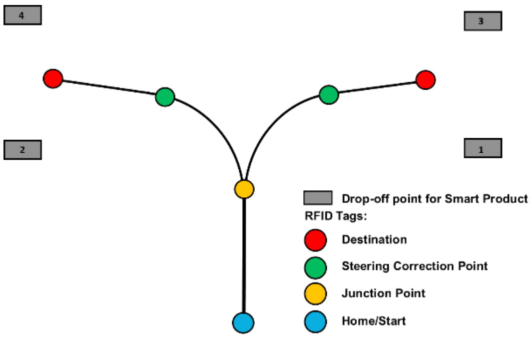

Fig. 9. Layout of autonomous product delivery

5.3.2. Karl

Karl was able to deliver the smart products to different locations on the split-path track. The smart products themselves determined the destination of Karl, when their RFID tag was read. Tags on the ground were used as a guidance system to the desired drop-off points. Karl travelled at a fixed speed of 0.1m/s.

The autonomous product delivery is shown in Fig. 9. The split-path was implemented using RFID tags. It would start at the home position, and once successfully delivering a smart product, would return to it. At the junction point, Karl had an option of going left or right. The steering correction point ensured the wheels were correctly angled to reach the next tag.

The autonomous functionality was performed using a Moore-type Finite State Machine (FSM). There were 22 states as shown in Table 3.

Table 3. Name and Description of States

State	State Name	Description
0	RESET_TO_HOME_SW	Used for calibration. Rotates front wheels until limit switch is pressed
1	ARM_DOWN	Move arm down
2	OPEN_GRIP	Open gripper
3	PICK_UP	Scan smart product
4	CLOSE_GRIPPER	Close gripper. Grab smart product
5	ARM_UP	Move arm up
6	ROTATE_CCW	Rotate front wheels clockwise to center
7	FIND_JUNCTION_POINT	Move forward until the junction point is found
8	CHOOSE_CURVING_FWD	Pick direction of motion (left or right)
9	FIND_STEER_POINT	Move forward until the steering correction point is found
10	STRAIGHTEN_WHEEL	Rotate wheels to center
11	FIND_DESTINATION	Find the drop-off point
12	ROTATE_2_DROP	Rotate wheels to drop-off zone (left or right)
13	ARM_DOWN1	Move arm down
14	DROP_OBJECT	Open gripper. Release smart product
15	ARM_UP1	Move arm up
16	BACK_TO_MIDDLE	Rotate wheels back to center
17	BACK_2_STEER_POINT	Reverse until the steering correction point is found
18	ROTATE_WHEEL	Rotate wheels to return to junction point
19	BACK_JUNCTION_POINT	Reverse until the junction point is found
20	ROTATE_TO_MIDDLE	Rotate wheels to center
21	FIND_HOME	Reverse to home and reset

The RFID readers, encoders, and switches were used to transition to next states. The states can be separated into four key processes:

- Resetting – In home position ready to grab smart product
- Acquiring Object – Smart product is retrieved ready for delivery
- Delivery – Actual delivery to drop-off zone
- Returning – Movement back to home and resetting for next run

6. Discussions

6.1. Limitations

The research aimed at demonstrating, so majority of the limitations related to the performance of the hardware, specifically the robots used as AGVs.

- For both Jimmy and Karl, the speed was fixed programmatically, but it was not possible to measure and control the speed of both. Karl's speed was set at the maximum and could not be increased any further due to its mechanical setup. Jimmy's speed was kept relatively low to avoid erratic motion.
- Battery life affected both AGVs but was more visible with Jimmy. Demonstrations of Jimmys were kept below five minutes as the speed of all three would significantly slow down. This resulted in greater interference between Jimmys, as they travelled at different speeds.
- Limited processing power from microprocessor boards on both AGVs. On Jimmy there were two microprocessor boards, where one was solely used for RFID. Earlier setups of Karl showed issues with travelling in a straight line, partly due to how the microprocessor board controlled the motors.
- The Jimmys were able to recognize movement on the wrong path, but could not carry out any operation to return to the correct path. The current design of Karl is unable to return to its intended path if it misses the tags as the setup is only to show a proof of concept. Possible solutions to solve this problem will be discussed in the next section.

6.2. Further Discussions

The robots used for this paper were setup to be representations of real AGVs. It must be noted that real AGVs are much more sophisticated and robust. Karl and Jimmy were successfully demonstrated in a factory scenario which mimicked the tasks of real AGVs. Jimmy used an optical line-following module and RFID for guidance, while Karl used RFID alone. The addition of RFID tags not only simplified decision-making but made the AGVs more intelligent. An example of such was when the Jimmys were able to determine when they went off-track using the RFID tags. The laid-out optical tape used for the guidance system of Jimmys, was not a flexible option as any changes would require re-taping or building of new track. In a real factory, where much longer and complicated paths may be present, any changes would be time consuming, costly, and would require downtime of operations. The added RFID tags were much more flexible, they could be easily removed or shifted to new locations or could be reprogrammed to carry out different maneuvers when AGVs detected the tags. Thus, re-taping the optical tape was not necessary. It could be possible to reprogram the tags in real-time with the addition of networking.

For the multi-AGV scenario, each of the three Jimmys were able to traverse their paths and stop at their designated stops. Higher speeds did result in more misses of RFID tags, but this was solely due to more erratic movements of Jimmy, where the reader was not aligned correctly to detect RFID tags. This would not occur with real AGVs that have more improved motion control. Generally over time there more misses in RFID tags due to lower battery power. These issues meant that the AGVs would not be able to carry out appropriate decision-making, which resulted in ignoring designated stops and traveling down wrong paths. The speed of the AGVs would also significantly slow down over time, meaning that the AGVs could not run for longer than five minutes. These results are not acceptable for real factory environments, where AGVs must reliably run for continuous hours every day. This was a demonstration, so the performance of the AGVs can be overlooked, but it reveals potential issues that real AGVs could face. Testing of RFID with real AGVs should be conducted to determine the performance of such a system.

With the setup shown in Fig. 9, it was possible for Karl to miss the steering correction point. An adjustment procedure was not included in the programming. To prevent the issue, the two curves before the straight line heading towards the destination point should be evenly populated with more steering correction points. Each correction points correspond to the correct angle that Karl should be facing at that moment. Otherwise, Karl will rotate accordingly until the designated angle is met. Karl will behave in similar way as it reverses towards its home position. Karl's current design allows it to travel perfectly on a straight line. The only possible error comes from the curve region of the track.

In the autonomous product delivery, Karl was able to deliver the smart products using RFID guidance only. It must be noted that Karl originally was a tracked robot, rather than the wheeled iteration shown. The issue with the tracks was a deviation when Karl was programmed to move straight. This deviation would have resulted in Karl missing the RFID tags when running. The wheeled iteration ensured Karl travelled straight but made turning more difficult. Setting up the path using only RFID tags were much easier and efficient compared to using tapes. As it was manually setup, it still can be time consuming to ensure the straightness of tags alignment. This was more apparent when designing the curved path.

7. Conclusion

This paper introduces an AGV system for a smart factory which uses RFID technology to create an intelligent and flexible environment. Several interesting findings have been observed:

- RFID technology enabled Jimmy and Karl to realize RMS
- RFID technology enables smart decision-making for AGVs
- RFID improves fixed form guidance methods such as optical line

Some future work will be carried out as follows:

- Networking capabilities to allow the AGVs to communicate and enhance interactions. This will allow for real-time changes to the paths of the AGVs using RFID tags
- A graphical user interface (GUI) which features a map of the smart factory in real-time. The user can interact with the GUI to design the desired path for an AGV
- Setup and test RFID with real AGVs to determine likely performance in real factories
- A more efficient method to setup RFID tags on a shop floor

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