Final Report

AMPC
AUSTRALIAN MEAT PROCESSOR CORPORATION

AGVs

AGVs (with optional integrated collaborative robots) - Stage 2

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1.0 Executive Summary

Autonomous Guided Vehicles (AGVs) are vehicle systems that follow the desired path and move around the operating areas autonomously. They are designed and implemented with advanced perceptive sensors and mechanical parts for functions with minimal human coordination. With the advancement in their sensing and perceptive technologies, they are broadly used in manufacturing or warehousing facilities and are feasible to be used under any dynamic environment conditions.

In this project, AMPC partnered with the University of Adelaide (UoA) to investigate potential application scenarios in which AGVs can be used to support the Australian red meat processing industry. This report introduces all constraints that will limit the function and performance AGVs in the meat processing facility. The report also provides examples of how can AGVs be used in the meat processing sites and potential implementations. Based on the knowledge introduced and the project findings, UoA suggests using existing conventional development/systems of

1. Using forklift AGVs for loading and stacking pallets, and
2. Self-guided AGVs for handling material in existing facilities;

Investigating AGVs implemented with tools for additional functions, including

1. Collaborative robot integrated AGVs, and
2. Fully/semi-autonomous facility cleaning AGVs; and

UoA also introduced a human-AGV collaborative system with its main characteristics. It introduces the design of an AGV system while remaining humans in their roles. A high-level system design is introduced in this report.

Based on these suggestions, UoA proposed three research and development projects for developing and demonstrating the single unit proof of concept in meat processing scenarios for the suggested tasks in the meat processing environment, which will be tested in meat processing facilities.

2.0 Introduction

With the rapid development of automation technologies, AGVs are replacing manually operated goods and objects transportation systems. They are safe semi-/full-automated solutions for warehouses, manufacturers, distribution centres and many other industries. However, the meat processing industry has not broadly adapted with such innovative technology and benefit from their advantages in safety, flexibility, efficiency and productivity for transporting materials, maintenance and many other tasks. More specifically, implementing AGV systems in meat processing facilities will help the industry in reducing labour costs and effects by workforce shortage, eliminating high-risk and heavy load manual processes, handling dynamic situations and tasks, reducing human errors, etc.

The Australian red meat processing industry has deployed, by Scott Technology Ltd, the industry's first successful AGV system with Kilcoy Global Foods. This example system controls 14-16 AGVs that operate fully autonomously for transporting packed meat products within the packing and distribution zone. This system is specifically designed for and limited to the application within an indoor chilled environment, not freezing or outdoor environment. These AGVs are usually referred to unit loaded fixed wheel platforms, and they are usually guided based on magnetic strips installed in the ground. All AGVs operate with the same closed-loop procedures, from loading palletised items to wrapping and barcode scanning and then delivering to the distribution zone.

Some typical types of AGVs and their characteristics are introduced in the Appendix.

3.0 Project Objectives

Through on plant studies, develop an industry AGV narrative specific to the Australian red meat processing sector, including:

- 'Educate': AMPC, processors and providers of possible use-cases.
- Ascertain industry readiness level (ability and mindset) to adopt and leverage AGVs beyond the current single deployment example at Kilcoy Pastoral Company.
- Document possible use cases now and in the future (the latter require further developments or third party value-adds).
- Develop Stage 3 pilot programs (technology, software and training)

4.0 Methodology

In this project, we investigated all different types of AGVs and suggested new upgrades or implementations of using AGVs in the Australian red meat processing industry. We have,

- Undertake visitation process with AMPC at mutually agreed red meat (bovine, ovine and caprine) processing facilities.
- Analysis on each processing plant visited for
    - Opportunities of deploying AGVs with no/minor modification of the processing plants.
    - Opportunities of deploying AGVs with major upgrades of the processing plants.
    - Potential modifications and improvements of AGVs.
- Provide high-level design for a multi-AGV collaborative system based on finds in item 3.
- Design tasks for system evaluation in stage 3.

5.0 Project Outcomes

This project aims to find and suggest using AGVs within the Australian red meat processing industry to improve processing efficiency and safety. We find that there are several constraints that limit the use of AGVs in meat processing facilities. We also suggest some scenarios in which AGVs can be used through our investigation.

5.1 Constraints and limitations

Through our investigation, we found many barriers limiting AGVs from being used in meat processing facilities.

5.1.1 Dynamic operational environment

Humans in the workspace

Many meat processing operations rely on human operations, which means humans can move freely in the processing facility. It will affect AGVs' real-time mapping and navigation abilities. In order to move safely in the facility, AGVs are implemented with advanced sensing functions to detect any dynamic obstacles blocking or will block their moving directions. Even with the most advanced obstacle avoidance functions, AGVs will still need to stop frequently to avoid collisions with humans and other moving obstacles, which will significantly affect the operational efficiency of AGVs.

Environment conditions

The operational environment of the meat processing facilities varies in different parts. The environmental disturbances will affect the performance of sensing and motion functions of AGVs. For example, steam and blood-spatter on the cameras will affect the vision-based object detection and infrared distance detection, and a fragment of meat/bone may jam the motor of RPLIDAR. These will affect the dynamic obstacle avoidance and localisation functions of AGVs, and it mostly requires manual cleaning. The slippery floor (water or meat on the floor) is another constraint, which can affect the encoder feedback and, eventually, affect measurements of the actual motor speed and counting of rotatory steps. In addition, the changing temperature will also affect the performance and lifespan of the batteries. Conventional AGVs are not built to handle these external effects. Therefore, we will need to design and use robust and reliable platforms for all perceptive and motion functions. We can modify outdoor AGV platforms to be feasible for indoor applications. We can also design and install a global tracking system with beacons or laser tracking to provide global guidance.

Avoiding environmental disturbance

Many environmental disturbances are unavoidable in meat processing facilities. Other than improving the performance and robustness of AGVs, which will increase the cost, we can design feasible scenarios in which the AGVs will operate in the environment with minimal environmental disturbances. We can use AGVs in areas with limited human access, such as the packing and loading zone and the chillers, to avoid human intervention in the autonomous operations of AGVs. We can also use AGVs after/before daily processing operations, such as after-hour floor cleaning and disinfecting.

5.1.2 Limitations in AGV functions

Conventional functions

Conventional AGVs are used for unit delivery and material handling. However, in the meat processing facilities, conveyor belts and overhead rails run through the entire facility. Functions required for unit delivery and material handling are limited.

Payload and sizes

For conventional AGVs, the payload is proportional to the size of the AGV, which is limited by the operational space. In the meat processing facilities, the space is limited. Only small (300-600mm) or middle (600-1000mm) AGVs are feasible to be used in the meat processing facilities. With enough battery capability for 12 hours of operations, payloads are limited to 10-50kg, which is less than a goat carcase. Therefore, the payloads of AGVs are limited in the boning room of the existing processing facilities, yet we can consider planning for more spaces while building up new facilities. While using AGVs in other parts of the processing facilities, such as the palletising and loading zone, the space will not limit the payloads of AGVs.

Customised and integrated tools

AGVs can also be used with integrated tools such as robotic arms and disinfect lights. However, with additional integrated tools, the robustness of the AGV systems will be further reduced. For example, when using an AGV with a robotic arm, it is not only the AGV platform that needs to avoid crashing onto humans, machines and other entities, the robotic arm will also need to avoid any potential risk situations. Therefore, the number of constraints and limitations to the system will increase.

5.2 Material handling

Material handling is a critical challenge in the meat processing industry due to the nature of the items being handled. In existing processing facilities, the processing parts are carried by the overhead rails or the conveyer belt. Therefore, the only parts that require dynamic material handling arrangement are the packaging and distribution zone and the waste handling.

5.2.1 Forklift AGVs

The forklift AGVs can be used to handle packed and boxed products. At the end of the conveyer belt in the meat processing site, packed and boxed meat products are manually piled up on the pallets. Humans drive forklifts to lift these pallets and then deliver them to the storage room or load them directly into freight containers. Human operators are at potential risk from fallen pallets in this heavily loaded task. AGVs can be used to complete this function autonomously with a simple setup process, and they are able to work safely without human control yet still in the human-machine shared workspace.

Tasks set up

Usually, in large meat processing facilities, all processed products for the day will be delivered and stacked up at the same target location (storage rooms or freight loading bays), and the path is repetitive. While using forklift AGVs for stacking and loading up products requires a simple setup for a repetitive point-to-point path. Two methods can be used for finding the path from the loading zone to the stacking zone, and both options are based on implementing Forklift AGVs in existing processing facilities.

- **Manual teaching:** For setup, human operators can guide an AGV through a general path for the task and program motions for lifting and unloading pallets in different locations. Then, the AGV will be based on the taught general path, find its way each time, and complete the task autonomously. While implementing forklift AGVs into existing meat processing facilities, they will be working in a shared environment with humans or other entities blocking the moving directions. Therefore, the AGV will need surrounding sensors or multiple RPLIDARs to avoid clashing with obstacles. Due to the limitation of its path planning function, this type of AGV can not plan a new path to avoid obstacles in real-time, yet it will stop until the obstacles are cleared. Based on the overall production quantity and speed, multiple forklift AGVs can operate together with duplicated functions and assigned tasks, and no additional setup procedure is required.
- **Autonomous path planning**: Forklift AGVs with autonomous path planning algorithms (e.g. SLAM) can be used for this application. Trackers or markers (e.g. laser beacons, QR codes and RFIDs) can be attached to the areas where AGVs lift up and drop off pallets. AGVs will be able to scan the environment in real-time and find an optimised path between two locations. They will be able to predict and avoid dynamic obstacles in the operating zone. With this method, no unique setup is required, yet AGVs used for this task need to have more advanced functions of environment perception and real-time path planning. Global guidance and predefined map of the operating environment may also be required.

5.2.2 Tools and meat part delivery

Some items such as tools and trimmed waste can not be transported on the conveyor belts in meat processing sites. For tools, they require human operators to pick up by themselves from different locations, which human operators may need to walk through the entire processing facility and pick up some tools. The trimmed parts are usually contained by buckets on the side of the processing stations, and humans carry them out for disposal after the buckets are full.

Shapes and sizes are usually not unified and need to be stored in clean and low-temperature conditions. None of the current arrangements is efficient, and self-guided AGVs with carts can easily replace the tasks. These two example tasks are usually non-urgent low-payload tasks, and AGVs can easily deliver through the facility and stop and wait for any emergency.

For example, while an AGV is used for loading and transporting trimmed waste parts, it will park on the side of the trimming station (or the deboning station) and wait for human operators to drop all trimmed waste into the bucket attached to it. Until the bucket is full, operators can press a button to trigger autonomous actions. Another AGV with an empty bucket will come over autonomously and replace the position of the fully-loaded AGV. Then, the fully loaded AGV will drive autonomously to the disposal zone. A central command system will be used to coordinate all activities of AGVs and assign different tasks to different AGVs. Each station in the processing site is required to install a unique tracking or marking tag (e.g. laser beacons, QR codes and RFIDs). AGVs will be able to find and track the position of each tag and approach them based on required tasks.

5.3 Integrated tools

AGVs can also be used for advanced autonomous functions in meat processing facilities with additional integrated tools. Some example applications are,

5.3.1 Collaborative robots

A typical application is integrating a collaborative robotic arm on the AGV to achieve additional functions in meat processing scenarios. With robotic arms attached, AGVs will no longer require human support in tasks that require loading items to be transported. For example, while an AGV is used to deliver needed tools, it can autonomously drive to the loading areas or the storage rooms and pick up the required items by itself. The AGV can load up with different meat parts and deliver them to different stations. After the AGV reaches each target location, the robotic arm can pick up the needed tools from the cart of the AGV and leave them on the station even without human support. Then, the AGV will continue to deliver to the following target location. AGVs can also provide collaborative robots with extra operating range, such as autonomously moving along the conveyer belt to monitor the processing quality and push out carcasses on the overhead rails from the chiller.

AGVs can also provide extra motion range for the collaborative robotic arms. With their safety requirements, collaborative robots are usually limited in their sizes. Their functions and performances are limited to tasks that require long-range motions. For example, collaborative robots can be used to scan the carcases for any abnormalities, yet unable to reach both sides for scanning. AGVs can provide an extra range of motion and carry the robotic arm to scan around the carcases.

Consensus between the collaborative robot and the AGV is critical when integrating them. While the collaborative robot and the AGV system will be running independently, they must communicate in real-time and share their perceptive information and operating statuses. The platform will not only be required to avoid crashing onto obstacles blocking the AGV's moving directions but also need to prevent hitting anything within the operational radius of the robotic arm.

5.3.2 Cleaning AGVs

Cleaning AGVs are another example application used in meat processing facilities. For this application, AGVs are required to be integrated with brushes, water jets and other cleaning and disinfection tools. Based on human involvement, there are two ways to use the cleaning AGVs.

Additional floor cleaning and air disinfection

In addition to normal and standard manual cleaning operations, we can use an AGV to go through the non-operating areas of the processing facility and provide additional measures to ensure the clearness of the processing sites and provide extra sterilisation. By redesigning the cleaning procedures, we can shift some manual cleaning operations to the AGVs after/before manual cleaning and reduce the workload for humans. The operation can be done fully autonomously when the cleaning area is not used. The AGV will have rotary and vibrating brushes (attached under its chassis), a UV lights (attached on top) and top/button spray for dry sterilisation. It will navigate based on SLAM using an RPLIDAR. Medical grade AGV platforms have been successfully implemented in hospitals and public venues. They can be deployed to the processing site with minor modifications.

Human-machine collaborative cleaning procedures

In manual cleaning procedures, humans use hoses and water jets to spout high-pressure water on the floor and brush with brushes and scrapers. By designing human-machine collaborative cleaning procedures, humans will only need to wash the floor with water jets, and the AGV will follow the human motions and guidance and brush the floor with electrical wheeled brushes and scrap excessive water. The AGV can scan the entire operating area and plan an optimised path to cover the entire floor. The AGV can also be integrated with other tools, such as the spray for sanitiser and steam, based on different hygiene standards. However, the operational speed of the AGV is not fast enough to match human operations. Therefore, multiple AGVs are required to collaborate with a single human cleaner.

Fully autonomous cleaning AGVs

We can also use a fully autonomous solution for the cleaning task in which AGVs are integrated with all necessary tools and functions, including multi-directional high-pressure jets, suction excavation, heavy-duty brushes, steamers and monitoring and inspection modules. Due to the limitation of visibility during such heavy-duty operation, AGVs will require environment-guided navigation functions such as magnetic stripes installed on the floor or remote manual-driven functions. However, such high performance, robust and multi-functional platform is costly.

5.4 Human-AGV collaborative systems

AGV operations require human intervention for setup and programming for any new desired tasks. Once it is set to operate, a single AGV can repetitively complete the programmed tasks autonomously. As introduced in section 5.1.1, the meat processing facility has many environmental disturbances, and tasks are changing according to different production requirements. Therefore, the AGV platform requires considerable human efforts to establish harmonious human-AGV collaboration to optimise the performance of the AGV.

5.4.1 High-level system design

Figure 5.4.1.1 shows the high-level system design of the human-AGV collaborative system. This is a centralised system with a host computer coordinating functions and the task of the AGV. Humans must communicate with the host computer to assign tasks and monitor all aspects of the AGV. Humans need to physically interact with the AGVs to complete tasks collaboratively. The host computer can be facilitated in a central control room and operated by humans via a portable device in any processing station. This operational framework allows simple upgrades when multiple AGVs are required at different locations or for different tasks.

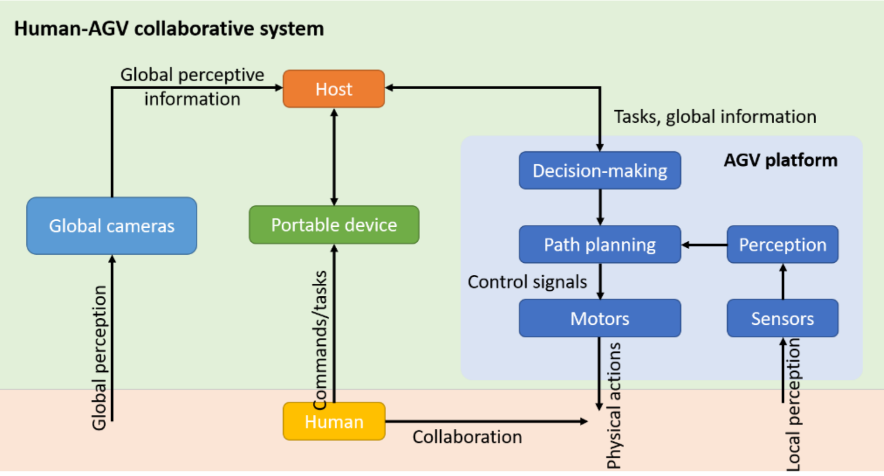

Figure 5.4.1.1 Human-AGV collaborative system

Task assignment: If assistance is needed, the human operator can use the portable device to assign the task to the AGV. The system will have preprogrammed tasks such as reaching a target location based on a predefined facility map or scanning through an area. For example, if a waste bin at a processing station is full, the human operator will "call for help" and request an AGV to deliver an empty bin to the station.

1. **Human-AGV collaboration:** In order to effectively use the AGV, some operations can be manually performed by humans. We will standardise the human operations and provide guidance and instructions on the portable devices for what needs to be done. In the bin changing example, after the AGV reaches the target location, the operator will be instructed to swap the bin and then confirm if the bin is replaced. In order to achieve harmonious human-vehicle collaboration, we will need to analyse all required tasks and their associated human operations and possibly develop feasible detection functions and AI decision-making processes to provide more practical guidance to human operators.
2. **Safety features in human-vehicle shared workspaces:** Many conventional AGVs are required to work in unmanned facilities or with restricted human access in their operational areas to avoid incidents caused by unpredictable human behaviours. However, humans can not be eliminated in most processing scenarios in the meat processing facility. While the AGV can provide support in tasks, such as material handling, safety features are the most important criteria. The AGV is designed to operate safely in workspaces shared with humans. It is implemented with a fusion of different sensors to detect current human involvement and predict

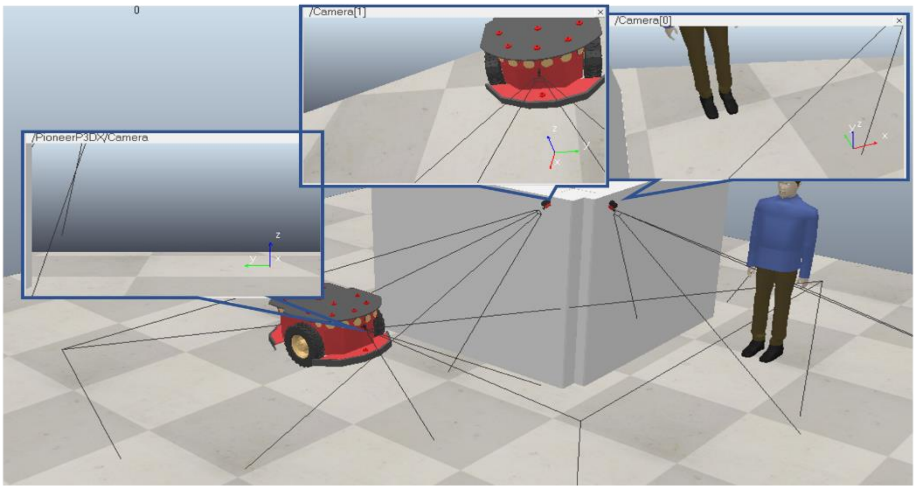

Figure 5.4.1.2 Shared perceptive information human-AGV collaborative system

human motions. This function allows the AGV to plan the approaching paths that avoid crashing onto humans. The AGV is also implemented with surround brakes to stop the AGVs in an emergency. The brakes are usually mechanically triggered switches. If the AGV crashes onto something, the brakes will be triggered simultaneously to cut-off supply power to the motors.

3. **Shared local-global perception:** Real-time perception of the AGV platform can be critical, and the performance of AGV's local perception will directly reflect its functionality, such as optimised path planning and safety, such as collision avoidance. For the AGV, the only method of improving its perception of the surrounding environment is to implement sensors with a better performance which is an additional cost on the platform. However, we can install overview cameras that provide additional global perceptive information to improve the AGV's understanding of environmental situations. For example (Figure 5.4.1.2), while an AGV is planned to pass through a cross pathway, it can not detect there will be a human walking out from the other side because a wall blocks the view. However, we can install cameras to view both sides of the wall and share the camera detection with the AGV coming into that corner.
4. **Possible future implementation on multi-vehicle systems:** In a multi-AGV collaborative system, AGVs can work individually or together to achieve advanced functions on group tasks. Assigning a group of AGVs for the tasks in some complex scenarios will be more efficient and practical. For example, while handling heavy items, such as pallets of packed meat products, AGVs with a high payload limit are required. These AGV platforms are usually large and difficult to convert for other tasks. Most meat processing sites have limited spaces to allow AGVs to move across the facilities. Therefore, using a group of medium/small size AGVs assembled will be a more feasible practice to increase the payload of AGVs in these tasks. While not handling heavy items, the same group of AGVs can be disassembled for some other tasks.

   Conventional multi-vehicle systems usually have the same AGV platforms that can only be used for similar tasks. Increasing the system capabilities requires improvement and advancement of each and all platforms in the system. Envisioning the complexity of many application scenarios in meat processing industry, it will be more efficient and flexible to have multiple different types of AGVs working collaboratively with each other and benefitting from the unique capabilities of different platforms. For example, AGVs with robotic arms can pick up boxes of packed meat parts and load them onto unit load AGVs or forklift AGVs with pallets, and the latter can then deliver directly to the freight containers. Both platforms will be under the coordination of the centralised system and assign sufficient numbers of platforms for different tasks. In the facility cleaning scenario, some AGVs can connect and carry a water hose for high pressure rising, which will have a limited moving range, and other AGVs can be attached with rolling brushes that move through the floor of the entire cleaning area. Using these AGV platforms with different functions can reduce the unit cost and risk of being affected by faulty individual platforms, and some of these AGVs can also be redirected or reassigned with other tasks, such as using the brushing AGVs for a quick area cleaning in the operating site or delivering some tools if needed.

6.0 Discussion

All suggested example applications of AGVs do not have any technical challenges yet need to be carefully considered with limitations and constraints introduced in section 5.1. However, they will need to be tailored and tested in meat processing scenarios. Several critical issues need to be assessed in the real environment, which includes,

1. **Perceptive robustness:** Perception capability is significant for AGVs to be flexible and adaptive enough to comply with the functionality demands. If the AGVs do not percept necessary, precise and correct information, they will not be able to perform as they are expected. The meat processing facility is a complex dynamic environment with many unpredictive disturbances, distractions and uncertainty. Therefore, it is critical for the AGVs to adapt to varying and dynamic conditions of the environment, and testing different perceptive methods and sensing technologies with different types of hardware is essential to any potential applications of AGVs in the meat processing facilities.
2. **Navigation:** Navigation of AGVs in meat processing facilities is another critical issue. How the AGVs can effectively reach the desired position is a critical challenge. There are two general navigation methods of AGVs: environment guided and self-guided, detailed in appendices 9.1. For the environment-guided navigation, AGVs are aware of their positions based on the pre-installed references/landmarks, such as magnetic tapes and painted lines/tags. However, it is not practical or cost-effective for existing facilities to re-install them in most processing sites. Therefore, self-guided navigation is a more practical approach for AGVs used in meat processing facilities. While most parts (machines and infrastructures) are fixed, the processing site is still a changing environment, such as humans, tools and equipment. It is necessary to assess different navigation methods that can be used for AGVs in the meat processing environment.
3. **Safety:** AGVs eliminate human errors, and they are, in general, safer than manually driven vehicles. While manually driven vehicles mostly rely on human alerts, AGVs are implemented with various sensors and designed with advanced collision avoidance algorithms to prevent crashing onto humans, infrastructures, machines and other vehicles. However, many different safety systems can be used on AGV, and there is no universal solution for all environments and scenarios. Therefore, based on the intention of using AGVs in the meat processing facilities, the safety systems of AGVs need to be evaluated to find the most feasible methods.
4. **Human collaboration/involvement:** While AGVs are used in other industries, such as car manufacturers, human workers are expected to possess some general knowledge about engineering and technologies, in which they will be able to understand the general concept of their operations associated/collaborated with AGVs. However, in the conventional meat processing industry, workers are from different backgrounds with different skills and knowledge. Therefore, in order to make humans work safely and effectively with the AGVs, we will need to develop unique training programs for meat processors while implementing AGVs in the existing processing facilities. These training programs will include standardised procedures for working with different AGVs, such as loading and unloading the AGVs or driving/guiding AGVs on a set/training paths, and a “do” and “don’t” list that prevent humans from high-risk or unsafe operations. We will also need to train onsite production managers/coordinators to set up AGVs with different functions and basic debug procedures.
5. **Communication and information sharing:** The functionalities of a networked AGV system is highly dependent on the information exchanged between the AGV and general system updates. Due to human involvement, environmental situations are changing in the meat processing sites. Therefore, setting up an

effective topology for communications within the system is critical. We can investigate how to assess locally obtained information and use it to improve the global system perception, providing better guidance to the AGV in local operations. In addition to that, we can also investigate how to use global perceptive information to improve the performance of the AGV on collision-free and obstacle avoidance functions.

6. **Network-security:** While the system performance largely relies on networked communication, cyber-security in the system is a significant import to ensure the safety of operations.
7. **Human-vehicle collaboration:** AGVs with single functions usually request human support in setting up multiple. In order to achieve more advanced functions, the same single functional AGVs can interact with humans and other entities in the facility and collaborate effectively through difficult tasks that are otherwise impossible for a single AGV to complete. The AGV operations and aspects are standardised, so in order to ensure a harmonious collaboration to enhance the AGV performance, we will need to develop a human operation standard to teach human operators how to interact with AGVs.

7.0 Conclusions / Recommendations

Based on the suggested example of further investigation and development, we propose three projects of building prototype systems for the next stage of development on the demonstration of using AGVs in the proposed example scenarios in meat processing facilities.

7.1 Forklift AGVs

This project aims to realise and demonstrate the use of forklift AGVs in the existing meat processing facility for loading pallets to the trucks autonomously. AGVs will load up pallets from the end of the conveyer belt and deliver them to the trucks. The operator can set up this operation easily based on the tasks and monitor and coordinate the operations based on the orders. The project will achieve the objectives of,

- Develop a working example of using forklift AGVs in the meat processing industry
- Demonstrate the feasibility of using forklift AGVs in the existing site
- Demonstrate human-guided AGV planning algorithm
- Assess the advancement in the aspects of operating cost, productivity and safety compared with manual-driven forklift

7.2 Delivery AGVs

This project will develop and demonstrate a human-AGV collaborative system in an example application that uses AGV to deliver a bin to a processing station when requested by humans. The project will focus on investigating constraints and disturbances that will affect the performance of AGV systems for collision-free and self-guided operations in the processing site for the example application. The project will achieve the objectives of,

- Design sensing and motion requirements based on the investigated constraints and disturbances in the example application
- Select a feasible commercial AGV (or a collection of commercial products to be integrated) that can be used in the dynamic environment of the meat processing facilities

- Develop a working example of an AGV system that can deliver required items to different target locations
- Demonstrate the feasibility of using AGVs for material handling in the existing meat processing site

7.3 Cleaning AGVs

This project aims to develop and demonstrate a cleaning AGV system that can be used for autonomously cleaning the chiller, and the AGV will plan a path and go through the entire area without human control. We will review the cleaning standards and procedures in the meat processing facilities to understand the functionality needs for cleaning. We will investigate all available commercial AGVs used for industrial cleaning operations and select cleaning operations that AGVs can replace. We may need to modify the platforms with additional tools in order to achieve the selected operations. The project will achieve the objectives of,

- Develop a working example of using cleaning AGVs to clean and sterilise the floor of the chiller
- Redesign the cleaning procedures in which AGVs will take part in cleaning operations
- Develop an AGV system for the proposed cleaning operations based on commercial AGV platforms

8.0 Bibliography

N/A

9.0 Appendices

9.1 Vehicle navigation methods

All AGV functions are based on their automated guidance functions, which guide AGVs to know where the target is and how to find a path. AGVs can be categorised into environment guided vehicles and self-guided vehicles based on different navigation methods.

9.1.1 Environment guided

Environment guided AGVs navigate based on pre-known environment information, which usually provides physical path lines and landmarks for the vehicles to follow. These lines and landmarks can be magnetic tapes, painted lines/tags, rails, inductive wires, laser beacons and RFIDs. These AGVs are usually implemented with basic collision-free functions to prevent crashing onto people or other equipment in the shared facility. These AGV systems are usually centralised, which will assign tasks to each vehicle based on the system's general optimisation. However, as

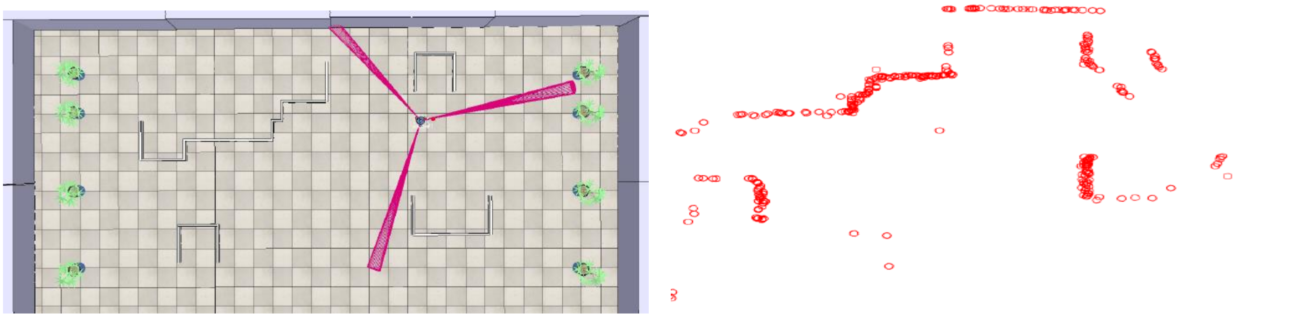

Figure 9.1.2 Simultaneous Localisation and Mapping (SLAM)

Figure 9.2.1 Unit load AGVs

environment guided AGVs rely on pre-set paths, they are unable to find alternative paths while the assigned paths are blocked. Implementing environment guided AGVs require modification to the operating facility, such as installing magnetic tapes in the ground or placing landmark tapes at dedicated loading/unloading or operating stations. While setting up the operating facilities will cost a large portion of the investment, the unit costs of the AGVs are meagre. Therefore, environment guided AGVs are feasible to implement in new facilities without much disturbance by other entities.

9.1.2 Self-guided

Some other AGVs are self-guided (also known as free navigation) in the operating environment. They are usually implemented with high-performance sensors, such as laser, infrared, ultrasonic and RGB cameras, to provide a precise real-time perception of their surrounding environment. The most popular technology used for self-guided navigation is called Simultaneous Localisation and Mapping (SLAM). As the example in Figure 9.1.2, AGVs map the surrounding environment in real-time based on the sensed information. The central system assigns tasks to each self-guided AGV, and they plan their path and navigate to target locations individually. While any obstacles block the planned approaching path, self-guided AGVs will be able to update and find an alternative path to avoid them. In some advanced systems, the central system can provide general guidance to each AGV while assigning their tasks, and they will find their detailed routine based on the situations of the surrounding environment. The unit costs of self-guided AGVs are higher than the environment guided AGVs, yet they are more flexible and robust in a complex and dynamic environment, such as meat processing facilities.

9.2 Vehicle functions

Currently, AGVs are used in various industries. Based on different application scenarios, AGVs are developed with different functions. These functions can be categorised into four main types: unit load vehicles, forklifts, towing vehicles, and autonomous mobile robots.

Figure 9.2.2 Forklift AGVs

9.2.1 Unit load vehicles

Unit load AGVs are the most common autonomous-driving platforms designed to transport items in the workspace. They are used to carry one or more objects. This type of AGV usually does not load up/off items by themselves, and they require other equipment (such as conveyors and robotic arms) or humans for loading and unloading. Conventional unit load AGVs (Figure 9.2.1) are available as flat AGV platforms, and the storage mechanism of unit load AGVs is exchangeable to fit different application scenarios. In the manufacturing scenario, particular in the food and beverage industry, unit load AGVs are usually attached with a cart which can be loaded with a mixture of different items, and they are used for delivering goods, tools and parts between different workspaces. Unit load AGVs can transport humans in some high-risk zones to ensure humans are restricted in the safe areas, and they can also help humans carry heavy objects while forklifts are not available or applicable. A proposed example of using unit load AGVs in the meat processing industry is introduced in section 5.2.2.

9.2.2 Forklift

The forklift AGV (Figure 9.2.2) is a unique AGV integrated with a forklift for lifting palletised items and deliver to target locations. They can be used when the supporting legs of the packages have enough clearance from the ground and can be lifted. Comparing with manually operated forklifts, the forklift AGVs are designed for 24/7 non-stop efficient

Figure 9.2.4 Examples AMRs with different functions

operations and handle heavy payloads and high stocking operations. They can eliminate human errors in operations and reduce human risks in heavy load workspaces. The forklift AGVs take less space without the driver seats and can operate the limited spaces. Details of how to use forklift AGVs are introduced in section 5.2.1.

9.2.3 Towing vehicles

This type of AGV is designed for towing carts. They are similar to the unit load AGVs with a more extensive towing power yet unable to be loaded with items. They are usually used in large manufacturing facilities and the farming industry where large quantities of items (supply kitting parts or crops) need to be transferred between operating workspaces for long-distance. They are usually compatible with the unit load AGVs to increase their towing power and load capacity. The meat processing industry may be for towing livestock outside the processing facility and carcases in the storage room.

9.2.4 Autonomous mobile robots (AMRs)

AMRs are designed for all other functions except handling materials. For special functions, they are attached with additional equipment and tools, such as robotic arms, brushes, screens, cameras, etc (Figure 9.2.4). They are also implemented with sophisticated perceptive and decision-making systems which are based on sensing and filtering technologies, Artificial Intelligence, machine learning, high-performance computational power and high-speed network communication and data transmission capability. Because of their perceptive capability, they are usually self-guided and can move in the workspace without direct coordination by the central system. Therefore, AMRs are designed to work collaboratively with humans or independently for the desired tasks. A typical example of AMR is the AGV attached with a robotic, which can perform picking sortation operations by itself. In the farming industry, this type of AMR is used for picking up high-value fruits from trees. In the automobile assembly line, it can pick all required parts from the warehouse and assembly them automatically to the car frame. It can provide extra operating ranging for robotic arms in meat processing tasks (details in section 5.2.1).

Another example is the automated vacuum cleaner which has been domestically available in many families. It is implemented with brushes and vacuum modules. It uses SLAM and a fusion of sensing technologies to navigate the shared human-machine environment safely. Similar applications are also commercially available for cleaning and disinfection ARMs used in hospitals and public areas. The proposed use of cleaning the meat processing facilities is introduced in section 5.3.1.

9.3 Mechanical abilities

Another way to distinguish AGVs is to be based on their motion mechanisms which provide different motion capabilities.

9.3.1 Fixed wheels

The fixed wheels AGV has wheels fixed to the chassis on both sides. The wheel speed of each side can be controlled individually, in which they can run at different speeds. This type of AGV achieves rotation and turn motions by controlling each side running at different speeds and creating a motion differential. For outdoor applications, such as in the smart farming industry, caterpillar tracks can be attached to allow AGVs to work on complex terrains. For indoor

Figure 9.3.3 AGVs with Omnidirectional wheels and Mecanum wheels

tasks with low speed and low payload requirements, two-wheel-drive AGVs are the most common solution at a low cost. Two motors drive two wheels under the chassis with an additional castor wheel for balancing the platform.

9.3.2 Steering controlled

The most common motion mechanism for industrial AGVs is the steering controlled AGV. It is similar to conventional automobiles, in which both the speed and direction of the wheels are controlled to achieve two-degree-of-freedom (linear and turn) motions. Based on their application scenarios and function requirements, the motor can drive multiple pairs of wheels directly. The direction of each wheel can also be controlled separately in order to improve the motion flexibility of AGVs.

9.3.3 Omnidirectional wheels

AGVs using wheels with special mechanical structures which allow sliding along non-motion directions are called omnidirectional rovers. There are two typical types, which are omni wheels and mecanum wheels (Figure 9.3.3). AGVs using these types of wheels can achieve three-degree-of-freedom motions (surging and swaying translation and yawing rotation). They usually have three or four wheels that can be driven individually. By controlling the wheels at different speeds, the AGV can move in any linear direction on the surface and change its heading direction simultaneously. Omnidirectional AGVs are the most flexible wheel-based AGVs, and they are feasible to be used in any compacted area. However, due to the special mechanisms of their wheels, they can only be used for indoor applications with flat surfaces.

9.3.4 Legged robot

Currently, the most advanced AGVs are the ones using legs for motion functions. Inspired by animal mobility mechanisms, the legged robots can have four, six, eight or more legs that provide motion support and balance the platforms. Rather than rolling the wheels, they sway each leg to move and change leg orientations based on the centre of mass to balance the body. They have significant advantages in their motion capabilities, which are feasible for all terrains and floor conditions. They can walk on muddy, wet or slippery surfaces and climb stairs and slopes. For two-leg AGVs with robotic arms attached, they can duplicate all human movements and replace humans completely in repetitive manual operations.