

Flexible delivery by an autonomous robot in a secure building

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Abstract. In industrial settings, autonomous robotic systems have become more common. Companies use autonomous robots to optimise repetitive, time-consuming tasks and improve efficiency. Strategically integrating robots frees up human resources from manual tasks to boost workplace efficiency and productivity. As they pursue Industry 4.0 goals, companies need autonomous robots to meet strict security standards. This depends on preserving confidentiality regarding sensitive information and protecting personnel health and safety. The mobile robot in this experiment aimed to simplify the transportation of standard load carriers, such as plastic boxes used in Kanban storage racks. A controlled lab environment was needed to recreate the robot's working environment. To streamline delivery, an innovative optical camera and depth vision were added. With this technology configuration, the robot could perform tasks independently. Limiting data retrieval helped the depth camera distinguish conventional boxes. The main project achievement was proving that an autonomous guided vehicle could transport plastic boxes while protecting company data. This method replaced manual part retrieval from secure locations, improving operational efficiency and reinforcing data security.

1 Introduction

The current century is witnessing an undeniable rise in integrating robots into everyday activities of industry and society. These machines are becoming increasingly popular due to their capability to streamline complex and repetitive tasks, including assembly processes and object transportation. It is anticipated and evident that robots are positioned to become essential in the near future. The current focus of robotics research is primarily on developing and producing robots with advanced autonomy levels. Pursuing independence is a crucial element fuelling the extensive implementation of this technology. Robots' ability to navigate complex surroundings and perform repetitive duties is essential in liberating precious working hours for human workers. The research attention is primarily directed toward tasks such as assembly line work and the adequate transportation of components to different operator stations. Companies are exploring robotic automation solutions to replace the manual retrieval of components in these processes. This presents a substantial opportunity for robots to significantly contribute to improving overall business productivity.

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However, the effective implementation of robotic automation faces industrial obstacles, primarily centred on security concerns. Ensuring safety is also a top priority for numerous companies, encompassing employees' well-being and safeguarding physical and virtual data. This dual focuses entail guaranteeing the unrestricted movement of employees without any possibility of disruption or harm caused by robots and protecting the confidential information utilised by robots for decision-making purposes. To address these challenges, the autonomous robot in this project initially utilises a depth camera to evaluate the feasibility using a simplified method. This initial step was undertaken before integrating all the exhaustive security prerequisites outlined by a local collaborating company. The project aimed to facilitate safe movement for a self-governing robot within the company's facilities and demonstrated its competence in handling various plastic containers. It also attempted to create an independent system for locating places for storage and deposits. This objective served as the foundation for investigating and executing feasible solutions, thereby facilitating the use of autonomous robots to transport components within highly secure buildings. Employee safety and data protection are of the utmost importance in this endeavour, ensuring a smooth exchange of ideas within the project.

Many businesses have started transitioning to Industry 4.0 by integrating robotics into their processes, as explained by F. Sherwani et al. [1]. Companies have increasingly adopted robots in production processes to optimise efficiency, as emphasised by J. Sankari and R. Imtiaz [2]. Nuno Correia's study [3] highlighted the use of automated guided vehicles to transport components or items within businesses efficiently. The study showed that deploying an automated guided vehicle (AGV) system made it possible to remove operators' manual transfer of large loads and reduce the excess of containers at workstations. Afonso et al. [4] highlighted the significant time saved by robots, allowing employees to concentrate on activities that automated systems cannot handle while improving workplace security. Moreover, they emphasised the need to recognise and resolve inefficiencies in material transportation and worker activities, especially in relation to managerial decision-making, and acknowledge the constraints for future research in this field. The autonomous delivery of various plastic boxes employing a mobile robot was explained by feasibility tests carried out by Dr. Wurrll's team [5]. The research presented a noteworthy addition to security measures by integrating a vision system that prevents unauthorised disclosure of corporate information. Cheung et al. [6] underscored the criticality of cybersecurity provisions, specifically highlighting the need to safeguard machines against hacking endeavours and prevent the unauthorised acquisition of sensitive information. Companies are right to be cautious when it comes to data security, particularly when it comes to the possibility of information gathering by autonomous devices. Therefore, Autonomous robots must effectively balance safety measures with the flexibility necessary for efficient component delivery.

2 Technology and Methods

A strategic approach had been taken to achieve this research project's goals. This involved combining different existing systems carefully to create an autonomous system that could move independently, detect objects, and grasp them. The central element of this innovative technology involved employing the Mir100 robot as the mobile foundation, as illustrated in Fig. 1(a). This robotic platform was the central component for automating the complex task of transporting boxes within the laboratory setting. The Mir100 robot is a highly adaptable mobile platform that demonstrates exceptional performance in delivering boxes while also offering a wide range of opportunities due to its ability to work with different modules. These modules, consisting of a hook and a robotic arm, enable the robot to perform various tasks in addition to its primary function of delivering boxes. Using this combination of state-of-the-

art technologies and interchangeable parts, the study intended to show how the mobility, object detection, and grasping capabilities of the Mir100 robot were all seamlessly integrated. This approach demonstrated the flexibility of the selected solution and emphasised the possibility of enhancing the robot's abilities to handle various tasks in the laboratory.

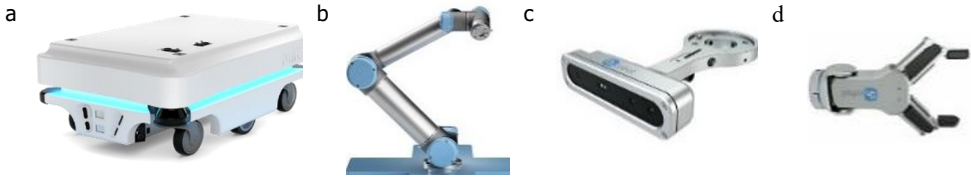


Fig. 1. Solution components: (a) Mir100, (b) UR16e, (c) RG6 Finger, (d) Onrobot eyes

Integrating a UR16e motorised arm from Enable Robotic, shown in Fig. 1 (b), into the Mir100 robot was a crucial improvement in the research project's advancement. The UR16e arm enhanced the robot's capabilities with its user-friendly control, impressive 16 kg payload capacity, and ability to work with different gripper types. This integration optimised object manipulation to achieve the project's goal of a flexible self-driving system, object recognition, and effective object manipulation. The robot arm was equipped with an RG6 Finger Gripper and an Onrobot Eyes camera, shown in Fig. 1 (c-d), with optical and depth vision capabilities. The gripper's high degree of flexibility, with an opening width of 150mm, made it exceptionally well-suited for handling used boxes. This outperformed other alternatives, such as palletisers [7] and suction cups [8]. Incorporating a camera streamlined the process of conducting feasibility testing, which was essential for evaluating the viability of the research project. Ultimately, the autonomous robot was created by incorporating a chassis between the mobile base and the robot arm, resulting in the final assembly, as depicted in Fig. 2 (a). The study was conducted in a laboratory, providing convenient access to crucial components for the robot's optimal performance in different scenarios. In contrast to a traditional industrial building, a laboratory offered a highly adaptable workspace that promotes and enables experimentation. Controlled laboratory environments reduced risk elements like employees and sensitive company data that could hamper testing-specific situations like industrial evacuation. The robot's autonomous mobility was tested in the lab using barrier-free delivery, an obstacle-blocking path, and a men-free zone. As shown in Fig. 2 (b), the robot employed LIDAR sensors to create a laboratory map which allowed the robot to navigate independently.

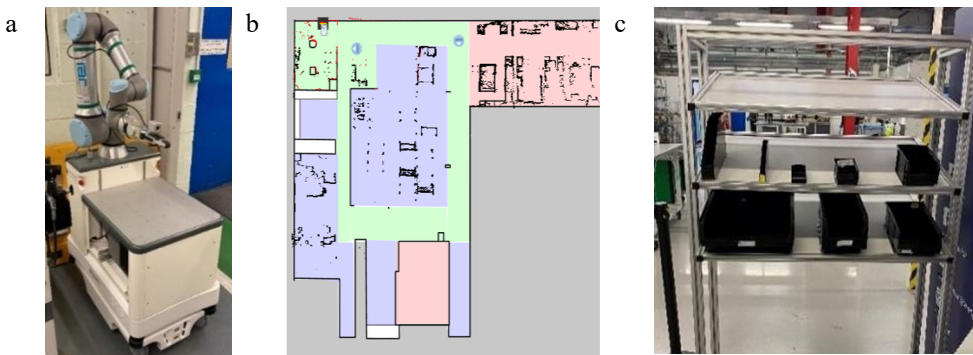


Fig. 2. Experimental Setup: (a) Robot Used in the Experiment, (b) Navigational Map, (c) Standardised Boxes and Kanban

Scenarios were defined by map colours: green enabled normal circulation, blue allowed occasional positioning for people's passage, and red was forbidden. Additional zones handled emergencies or special situations. The implementation of real-time obstacle detection enabled the robot to adjust its trajectory, guaranteeing secure engagement with its environment, including identifying and avoiding a person's presence. Factors considered involved the possibility of interference between the robotic arm and the camera while in motion. The testing process focused on optimising the positions of the arms to reduce their size and attaching the camera to the robot chassis to hide it from view.

Two experiments were performed to determine the project's viability. The initial test sought to independently ascertain the robot's capacity to transport boxes between various locations without human involvement. The second test aimed to assess the robot's capacity to identify boxes using a depth camera, thereby removing the need for an optical camera in this task. These tests aimed to evaluate the overall effectiveness and feasibility of the robotic system in accomplishing the desired project goals. Eight standardised plastic boxes designed for a Kanban system, as depicted in Fig 2 (c), were available for box delivery. The assessment centred on the robot's ability in precisely capturing and transporting each box. The robot was to place all boxes in designated storage and deposit areas. The storage units, equipped with sloped shelves, enabled easy access to the boxes for the recipient, as depicted in Fig. 2 (c). Additionally, the deposit areas included kanban with flat shelves. The robot must proficiently grasp boxes in different orientations and accurately position them in the designated spaces. To ascertain that the delivery capacity of the robot exceeded that of a single individual, various drop-off locations were simulated in accordance with a methodology resembling that of Quang-Vinh Dang et al. [9]. In order to accomplish this, the dimensions of the structure were assessed in the laboratory building to ascertain the duration needed for the transportation of components. Additionally, the potential to include intermediate stages along the robot's trajectory was also considered to improve its flexibility. In order to streamline the transportation of boxes to the assigned drop-off areas, multiple codes were experimented with to control the robot. The utilised code was modular, specifically designed to be easily understood and used.

Three methods were utilised to detect boxes, with each technique employing markers of different levels of prominence on the boxes. Calibration was crucial to ensure that the robot could accurately detect these markers. A 10 by 13 checkerboard was used to set coordinates for the robot's arm movement and box grasping. It also required resolving any precision concerns regarding the mobile base. Calibration involved taking multiple photos from different angles to ensure accurate marker detection. The initial approach entailed identifying a checkerboard affixed to the boxes, allowing the robot to determine the object's spatial position and retrieve the box, as depicted in Fig. 3 (a). The efficacy of this method was evaluated by conducting a trial with a series of six aligned boxes to gauge the robot's proficiency in collecting all of them. The second approach employed QR codes to ascertain the precise location of the box and direct the robot during the retrieval process, as depicted in Fig. 3 (b). The testing consisted of four aligned boxes, each with a QR code. The objective was to assess the robot's ability to correctly identify the corresponding component by scanning the QR code. The ultimate approach employed a depth camera to perceive the 3D structure of the box, as shown in Fig. 3 (c), enabling the robot to retrieve it without markers. Once again, the checkerboard was utilised to position the robot precisely. In order to achieve marker-free box detection, the boxes were digitally modelled in three dimensions, which functioned as a point of reference for precisely determining the location of the physical box. This enabled the camera to accurately identify the shape of the box, as shown in Fig. 3 (d).

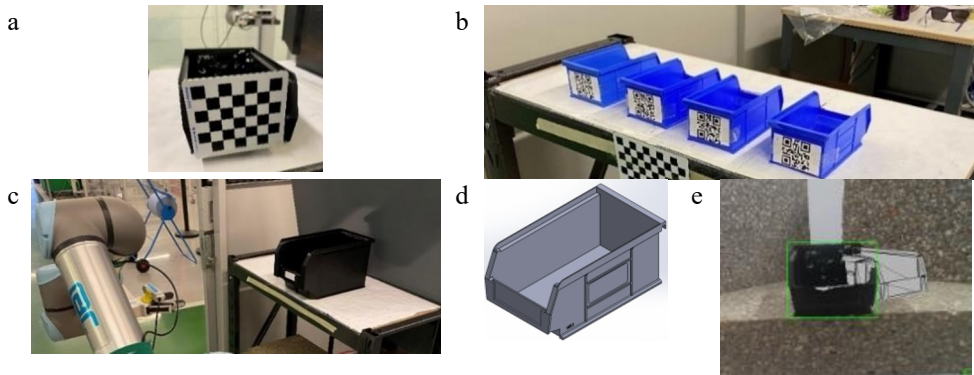


Fig. 3. Kanban boxes configurations: (a) checkerboard box, (b) QR code boxes, (c) Estimate Pose Object, (d) 3D modelling of a box, (e) Box Detection Failure

3 Results and Discussions

The feasibility study showcased the robot's capability for independent and secure locomotion, skilfully evading individuals. Moreover, the robot equipped with a movable camera could guarantee that no sensitive information was recorded while it moved within secure buildings. The robot proficiently manipulated boxes containing components, skilfully gripping them in different orientations, effectively accomplishing the tasks of loading, delivering, and unloading six boxes at an assembly station situated 100 metres away within a duration of 14 minutes. Consistent with the observations of PT Lin et al. [10], the robot's base allowed for a positional uncertainty of ± 10 centimetres. This may sometimes result in challenges when detecting boxes or achieving precise grasping, particularly if the robot is not correctly positioned. In addition, the robot may encounter difficulties where the arm unexpectedly rotates in unintended directions at its base, resulting in being stranded. The robot consistently recognised boxes by utilising checkerboards and QR codes. However, it may encounter calibration difficulties in inadequate lighting conditions, impacting its ability to detect boxes. The use of depth sensors to detect boxes produced inconclusive results under challenging conditions, such as low lighting or unclear backgrounds, as shown in Fig. 3 (e). Under ideal circumstances, such as adequate illumination, a simple backdrop, and a distinguishable colour, the robot can identify and grip boxes without any requirement for markings precisely.

Future research endeavours can be made to improve object recognition by utilising sophisticated detection systems such as multiple depth cameras or LIDAR systems. Furthermore, it is essential to investigate alternative methods, such as suction cups, in order to facilitate the movement of larger and heavier boxes that lack edges. Enhancing the accuracy of the robot's movements is necessary to optimise the delivery process and improve reliability. Improving the robot's smoothness can further enhance the efficiency of time during the stages of loading and unloading boxes. The primary objective is to create a self-governing robotic system that can transport components without needing an optical camera, thus protecting sensitive building security data. Implementing security measures is the first step towards improving productivity in high-risk sites.

4 Conclusions

This research assessed the viability of employing an autonomous robot to deliver goods within a secure building. Multiple aspects were examined to demonstrate the robot's proficiency in executing its mission. The preliminary assessments evaluated the robot's capability to navigate independently without relying on a camera. The initial objective had

been effectively accomplished - the robot could navigate a building securely and without jeopardising human safety. Subsequently, the robot's ability to capture various categories of plastic containers was tested - the robot could securely grab small plastic containers without affecting the possibility of accidentally scattering the contents contained within. However, the robot encountered difficulties with larger boxes, because it could lift empty ones whilst could not support the weight when objects were placed inside its gripper. Ultimately, the final test demonstrated the potential for identifying boxes with or without markers. While marker detection is the most dependable approach for detecting boxes, using 3D models, although less reliable, offers the benefit of not requiring markers to be equipped on all boxes. This method of recognising 3D models appeared to be the most promising solution for the future.

We express sincere thanks to BAE Systems for their essential assistance and supply of a thorough case study during this experiment. Their expertise in secured industrial environments had significantly enhanced the achievements of the research endeavour. We appreciate their cooperation and anticipate ongoing collaboration in future projects.

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