AUTOMATION OF MATERIAL HANDLING PROCESSES IN THE CONTEXT OF PALLET POSITION IDENTIFICATION ACCURACY/RELIABILITY – A CASE STUDY OF AUTONOMOUS MOBILE ROBOT (AMR) OPERATION

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Abstract

The paper discusses the problem of pallet identification accuracy in the context of material handling process automation. The need to ensure the correctness and efficiency of the internal transport process performance has caused the necessity for developing solutions that can correctly identify the pallet's position by an autonomous mobile robot (AMR). Following this, the authors present the results of conducted tests focused on the problem of pallet detection and proper positioning of the AMR. They presented the main assumptions taken for the proper performance of the field tests and discussed the obtained results. The work ends up with a summary and directions for further research.

Keywords: autonomous mobile robot, reliability, accuracy, material handling process, automation

1. INTRODUCTION

The concept of Industry 4.0 and related new technologies such as automation or the Internet of Things combined with Artificial Intelligence has revolutionized industrial logistics today. At the same time, they have raised new challenges for companies such as, among others, the necessities of faults/errors elimination, ensuring full information flow at each stage of conducted processes, as well as providing flexibility and responsiveness to emerging changes. This problem is especially visible in developing and operating internal logistics systems, such as material handling systems.

In the context of automation of internal logistics processes, one of the interesting issues is the accuracy/reliability of pallet identification in the context of ensuring the correctness and efficiency of the internal transport process performance. The problem under consideration lies in the area of ensuring the safety of autonomous transport systems, aimed at providing solutions that allow the system to respond correctly to the presence/occurrence of humans or other obstacles.

In the known literature, different classifications of AMR safety issues can be found. For example, in [1], a classification based on the applied methods is presented, including sensor type, safety function and robot zone. Furthermore, one can find classifications based on defined safety aspects such as motion control, planning, prediction, psychological factors (e.g. [2]), as well as design, pre-collision and post-collision approaches and risk analysis (e.g. [3]). The summary of conducted research in this area is presented by the authors in work [4]. Following this, the literature in a given research area can be divided into three main categories: 1) safe workplace for human safety, 2) development of collision avoidance systems and 3) risk management. In this article, the authors focus on the second problem, the development of anti-collision systems in the context of selecting a suitable pallet identification system in the storage area. This research problem is widely investigated in the literature.

The basic AMR safety solutions analyzed in the literature take into account several performance parameters and safety indicators used, the infrastructure required for their implementation, or the type of robot used (service/industrial) [4]. Additionally, one of the most crucial aspects is the type of obstacle detected (static/dynamic). The report presents the classification of selected solutions to the robot obstacle detection problem [5]. Among others, aspects such as the inaccuracy of the obstacle location error (e.g. [6]) or the distance between the robot and the obstacle (e.g. [7]) were distinguished. However, despite meeting safety standards, unforeseen problems may arise due to the peculiarities of the different navigation systems and technical solutions used in robots. Some of these problems, with examples, are summarized in Table 1.

Table 1 Examples of obstacle detection problems

Obstacle detection problem type	Example	Reference
Changing the range of scanning zones	Minimising the range of scanner zones when the robot is close to the loading ramp	[8]
Influence of obstacle trajectory on detection speed	Faster detection of obstacles moving in front of the robot	[7]
Shape and colour of obstacles	Problems with detection of black obstacles	[9]
Obstacle surface texture	Delayed detection of an obstacle when its surface has many holes	[10]

These problems may also occur in the implementation of automated processes in the warehouse area. Therefore, the paper presents the results of conducted tests to detect a pallet to be transported by an autonomous mobile robot (AMR). Performance tests were performed with an AMR placed on a hard surface with a measurement system consisting of two Intel RealSense Depth Camera D435 mounted on the AMR and a pallet. The efficiency and quality of position detection were checked for different distances of the pallet from the robot and different lateral displacements. Additionally, the case of a rotated load was also considered. The obtained results allowed for the conclusion on the reliability of a material handling process in the context of errors occurring in the area of pallet identification during its retrieval from the storage area.

2. AUTONOMOUS MOBILE ROBOT – MAIN ASSUMPTIONS FOR THE RESEARCH CARRIED OUT

Research related to pallet position identification was carried out using AMR, which was equipped with an appropriate navigation system that distinguishes between two location systems: global and local. The global layout is defined in space by a pattern in the form of a static map (map layout). Its definition in relation to static obstacles in space is constant in time. On the other hand, the local layout is defined during system start-up (Odom layout). Because the platform can be launched in any place or space, defining the current position of the platform requires knowledge of the transformation between the local layout and the map layout - global localisation is responsible for this. Breaking the localisation problem into two system transformations allowed to make corrections based on global references to the real world and local displacement measurements. **Figure 1** shows the systems used to determine the platform's position in space.

In order to automate the process of handling loads, it is necessary to implement algorithms for recognising the load units that the robot will carry. Depending on the load's shape, type and material, an algorithm corresponding to the given parameters and appropriate for the robot's workspace are used for recognition. In order to achieve the desired effect, algorithms based on the fusion of measurements from 2D laser scanners, depth cameras and RGB cameras are used, which, based on segmentation, ROI (Region of Interest) algorithms and HOG (Histogram of Oriented Gradients) description, enable the recognition of people and the registration of their route on a global map of the object [11].

Other scenarios for the robot's path determination are adopted depending on the type of obstacle encountered. In the case of static obstacles, the robot's route is determined to ensure an optimal path avoiding the obstacle.

For dynamic obstacles, the process requires route correction depending on the motion vector of the detected obstacle.

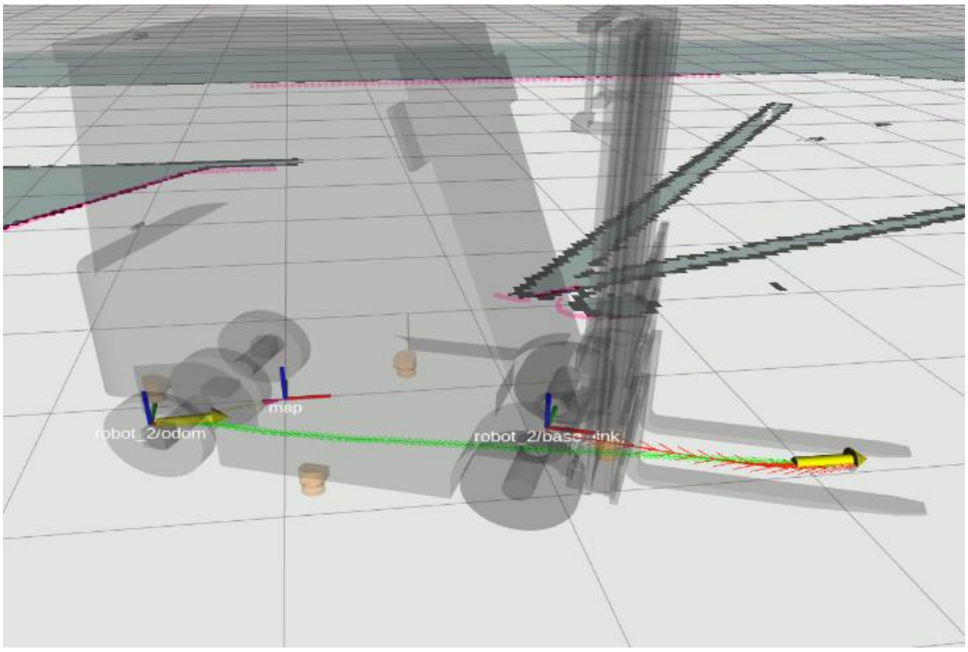

Figure 1 Scheme of systems used to determine the position of the platform in space

The tests of pallet detection by AMR were carried out taking into account the primary stages of the pallet picking process:

1) detection of the load unit and determination of its rough position,
2) positioning the robot in front of the pallet,
3) simultaneously monitoring the pallet's exact position and controlling the actuators to pick it up.

Therefore, the identification execution starts with the determination of the approximate position of the pallet, which is defined by the location in the workspace of the area where the operators deposit it. These areas are plotted on a map used by the robot. Appropriate navigation algorithms are used to position the robot in front of the pallet. The task of picking up the pallet is therefore reduced to searching for the exact position of the pallet and controlling the actuators in such a way that the robot's forks are in the pallet's recesses (possibly symmetrically with respect to the central axis).

Many algorithms for object detection can be found in the literature. This study was based on the use of a point cloud-based pallet recognition method based on data from a depth camera. A RealSense camera was used. Therefore, preliminary tests were carried out in the first step to evaluate the input data (point cloud) (**Figures 2a** and **2b**).

Based on the obtained data, point clouds are noise-distorted and imprecise, resulting in distorted images of objects. Points further than 4m from the camera are most suitable for object shape detection and determination. Points more than 2m from the camera can provide position data, but it will not be a precise position. For this reason, it was decided to mount the cameras at the ends of the forks, thus reducing the distance between the potential position of the pallet and the camera. This arrangement means that, when the load is picked up, part of the pallet can be seen in the field of view of the cameras at first and then only its recess. Unfortunately, mounting the cameras at the ends of the forks raises the potential problem of keeping the cameras clean and prone to mechanical damage. These factors suggest that the algorithm should also be prepared to work with data from a carriage-mounted camera if it turns out that another device will provide a sufficiently precise point cloud for longer distances. Research is ongoing on this issue. The observations described led the authors to develop an algorithm based on palette-specific edges. For this purpose, the authors chose IHT (Iterative Hough Transform) as the basis for the pallet position search module. A package called PalletFinder was then designed and implemented to search for lines, classify them, match the lines to a pattern and determine the exact position of the pallet.

The pallet detection module provides the position of the pallet in the form of a vector whose attachment point coincides with the geometric centre of the pallet and whose direction coincides with the central axis. Picking up the load unit starts with an appropriate fork height adjustment, and then the drive and torsion wheel adjusters strive to achieve the highest possible parallelism and a small distance between the carriage axis and the pallet vector. A set of sensors mounted on the carriage provides information about the correct positioning of the load.

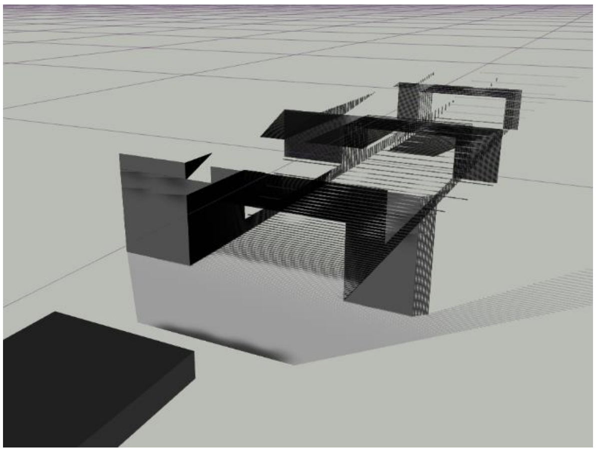

Figure 2a Pallet view from depth camera - view a

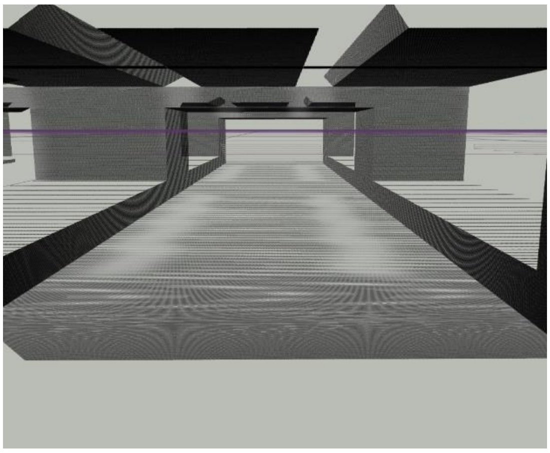

Figure 2b Pallet view from depth camera - view b

3. PALLET DETECTION PROCESS TESTS

A robot was placed on a flat, hard surface with a measurement system consisting of two Intel RealSense Depth Camera D435 mounted on forks and a euro pallet. The efficiency and quality of position detection were checked for different distances of the pallet from the robot, different lateral displacements, and the case of a rotated load was also considered. For each position tested, at least 100 measurements were carried out with the PalletFinder package. The retrieved position was compared with the actual position. The measuring system scheme is given in **Figure 3**. The pallet searching process is viewed in **Figures 4a** and **4b**.

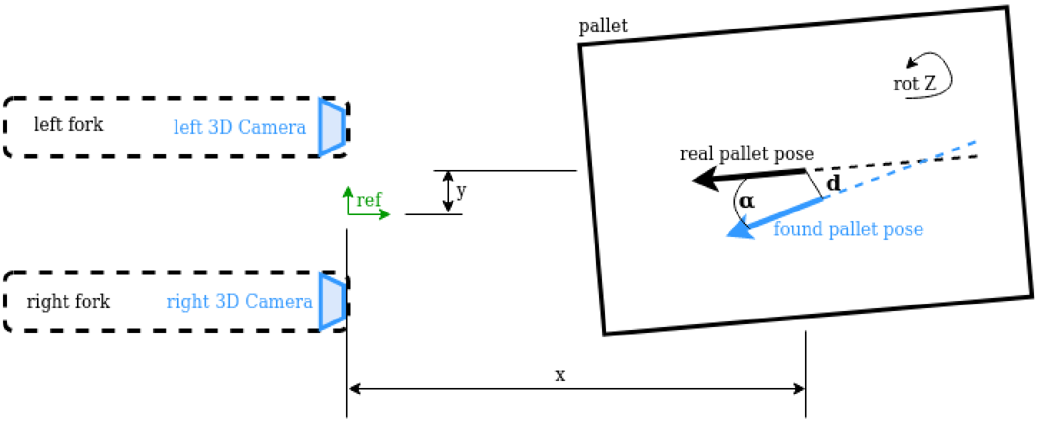

Figure 3 Measuring system scheme

Figure 4a Pallet searching – 1st view

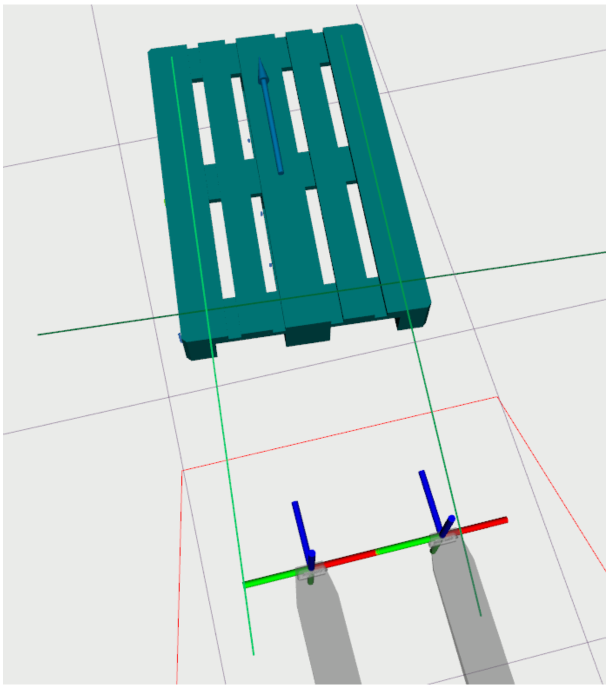

Figure 4b Pallet searching – 2nd view

3.1. Obtained results

The selected obtained results from conducted tests are presented in **Table 1**.

Table 1 Pallet detection results under simulated conditions

No.	**X-axis displacement [mm]**	**Y axis displacement [mm]]**	**Z axis rotation [°]**	**x/100 of retrieved positions [%]**	**Mean position error d [mm]**	**Average orientation error α [°]**	**Comments**
1	2000	0	-20	-	-	-	symmetrical with respect to +20°
2			-10	-	-	-	symmetrical with respect to +10°
3			0	70	21	0.6	
4			+10	46	32	0.6	
5			+20	63	24	0.8	
6		100	-20	52	35	0.8	Visibility threshold.
7			-10	14	32	0.7	Low visibility of the right side.
8			0	76	16	0.6	
9			+10	55	34	0.7	Low visibility of the right side.
10			+20	73	17	0.7	
11		200	-20	0	-	-	Left side not visible.
12			-10	60	22	0.6	
13			0	68	19	0.5	
14			+10	48	34	0.8	Low visibility of the right side.
15			+20	72	19	0.6	
16	1500	0	-20	-	-	-	symmetrical with respect to +20°
17			-10	-	-	-	symmetrical with respect to +10°
18			0	96	9	0.3	
19			+10	95	10	0.3	

20			+20	98	11	0.4	
21		100	-20	94	10	0.3	
22			-10	89	13	0.4	
23			0	93	12	0.3	
24			+10	98	8	0.3	
25			+20	87	12	0.4	
26		200	-20	60	11	0.4	Low visibility of the left side.
27			-10	93	12	0.3	
28			0	95	10	0.4	
29			10	82	12	0.4	
30			20	94	9	0.4	
31	1000	0	-20	-	-	-	symmetrical with respect to +20°
32			-10	-	-	-	symmetrical with respect to +10°
33			0	100	<5	<0.3	
34			10	99	<5	<0.3	
35			20	89	5	<0.3	
36		100	-20	45	6	0.3	Visibility threshold of the left side.
37			-10	100	<5	<0.3	
38			0	100	<5	<0.3	
39			+10	97	5	<0.3	
40			+20	100	<5	<0.3	
41		200	-20	0	-	-	Left side not visible.
42			-10	73	5	0.3	Low visibility of the left side.
43			0	100	<5	<0.3	
44			+10	98	5	<0.3	
45			+20	100	<5	<0.3	
47	500	0	-5	-	-	-	The robot has partially driven under the pallet. Some values cannot be checked (collision).
48			0	100	<5	<0.3	
49			+5	100	<5	<0.3	
52		50	-5	-	-	-	
53			0	100	<5	<0.3	
54			+5	100	<5	<0.3	

3.2. Results analysis

The pallet was retrieved correctly for most of the cases examined. Situations in which the load was rotated proved to be particularly troublesome. This is because others hide some characteristic fragments (e.g. the front blocks hide the rear ones). For some cargo settings, the camera cannot detect the board line because it is at too acute an angle - the principle of the depth camera is to combine images from 2 cameras. However, only one of the tested cases resulted in an inability to find the position of the pallet (No. = 11); in this case, the robot reported an error.

The position and orientation error increase for more considerable distances between the robot and the pallet. However, it is essential to note that the errors are small enough to allow the robot to pick up the load accurately. In other words, if the pallet were identified, it would be picked up in any case. Position accuracy increases significantly as the pallet is approached. The same is true for the effectiveness of the retrieved positions (it is more often correctly identified). The repeatability of PalletFinder's measurements was high enough to conclude that the measurement system used to determine the actual position of the pallet for short distances was not accurate enough. In other words, the measuring system returns similar results for short distances, which is its limitation. However, the accuracy obtained is sufficient as the load is taken up correctly.

It should be noted that the position and orientation error is mainly due to the quality of the point clouds provided and the manufacturing quality and condition of the pallet itself. The test was performed with a new and clean euro pallet. In the case of damaged pallets (losses, deformations), the tested error rates increase. The robot can still pick up the pallet but needs more measurements. As PalletFinder works at a fixed frequency, which is limited by the computational power, this requires a reduction in the pick-up speed.

4. CONCLUSION

The paper focuses on the problem of pallet identification by AMR operating in material handling systems. The necessary sensors, i.e. a 2D laser scanner, a depth camera and an RGB camera, were used to correctly perform the planned tests related to the process of identification, retrieval and transport of the load. Their application enabled the full scope of manoeuvres in choosing the best solution for detecting the pallet object, also enabling the detection of other obstacles.

The results obtained allowed, on the one hand, to identify fundamental problems in the pallet identification process. On the other hand, they can be used in the design process of autonomous storage systems. In the future, it would also be worthwhile to develop studies considering a damaged or loaded pallet.

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