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3D CAMERA AUGMENTED AUTONOMOUS MOBILE ROBOT FOR INTRALOGISTICS PURPOSES

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ABSTRACT

Autonomous Mobile Robots (AMRs) are driverless vehicles programmed to perform a variety of tasks and are often used to transport goods or materials. However, there can be several problems with the driving performance of this type of vehicle. Safety in the workplace is important everywhere, but there are some areas that are particularly exposed to safety risks. Limited visibility is the main cause of accidents at work. Yet, robots can map these dangerous areas with their sensors. This paper presents a mobile robotic sensor development that can be implemented to increase the security of robotic warehouses. Testing is necessary in order to check the quality of existing defects in safety elements before delivery and to carry out a risk assessment. The proposed work aims to add a safety element to the robot to prevent the most common problems, i.e., collision with a forklift truck, hitting objects outside the sensor planes or hanging in. Based on the experience with robots gained over the years, the aforementioned problem poses a big challenge. There have been several such collisions. Therefore, the paper proposes the selection and installation of a modern 3D camera and conducts its compliance test with the safety requirements. Moreover, the paper also evaluates the difference between the safety level of a robot without 3D sensor (Alpha) and a robot with 3D sensor (Beta), based on the knowledge of the installed camera.

Keywords: AMR, mobile robotics, LiDAR sensor, 3D vision.

1. INTRODUCTION

AMR systems, typically powered by batteries, consist of multiple vehicles that travel along pre-determined routes [1]. The vehicles navigate the facility using a number of control technologies, e.g., with floor-mounted magnetic strips or rods, optical sensors, or magnet/gyro-based guidance. These solutions make it easier to change the routes and expand the system if, say, the conditions in the facility change. The following types exist:

- Automated trolleys – the simplest type of Automated Guided Vehicle (AGV) with minimal features for the most economical implementation,
- Unit load vehicles - individual vehicles that transport various loads (mainly pallets, crates, wagons or bundles) on forks or on deck,
- Roller handling vehicles – these vehicles handle particularly heavy rolls of steel or paper,
- Towing vehicles - motorized units that pull a series of non-motorized and laden trailers,
- Automated trucks - thanks to its controls, the forklift can also operate without a pilot.

The computer uses wireless connections to control and monitor multiple cars in real time. It uses them to collect data on the current position of each unit and then interacts with the software for targeting and routing logic [2]. It controls vehicles by communicating specific tasks to them via radio frequency – these include stop, start, gear changes, raise, lower, multi-point turns, reverse, track deviation and more.

According to a US survey, 72 percent of manufacturers in the country face a major challenge in avoiding workplace accidents. In 2019, there were 5333 fatal accidents in factories in the US alone. Forklifts can be found in all factories, which are involved in around 97,000 accidents each year. Statistics show that one third of workplace accidents occur while lifting some kind of load [3]. The main cause of accidents at work

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is limited visibility [4]. However, robots can map these dangerous areas with their sensors. Mobile robots have multiple sensor safety systems, including cameras, laser scanners, proximity sensors, which provide data to the path planning algorithm. A common sensor in AMRs is the Light Detection and Ranging (LiDAR) sensor [5]. The LiDAR sensor quickly projects a laser into its surroundings to find the vehicle's position and measure the distance to an object in its vicinity. This allows vehicles to have warning systems, such as different warning fields, which can control the speed of the vehicle depending on the LiDAR sensor data. The first and most important factor is that the mobile robots we manufacture meet the mandatory standards and technical requirements [6]. The Machinery Safety Directive 2006/42/EC is aimed at manufacturers and distributors of machinery and safety components. Mobile robots can be classified as type C standards according to EN ISO 10218-2 Robots and robot structures. It is very important that, once the appropriate standard has been set and the hazards identified, a risk assessment has to be carried out for each hazardous situation under consideration [7,8]. Testing is necessary because defects in safety accessories can be found before they are put into service, thus increasing both the quality and the reliability of the product. It is worth testing the functions that will be used most by the users. Testing after the manufacturing process, therefore, in addition to making the use of defective products safer and saving end-users annoyance, saves the manufacturing company from losses of up to ten times its cost by eliminating rejects, preventing warranty costs from being incurred due to defective products being rejected [9]. In the first part of the publication, the rationale for the research and the standards and conditions to be met are presented. Then the selected camera system and its software and real-world testing are discussed. Finally, the obtained test results are presented.

2. MATERIALS AND METHODS

The tasks of the intelligent pallet AMR from the Robotcenter series are under-running, lifting and transporting Euro-pallets. A state-of-the-art 3D camera system was selected and installed on the robot. Its compliance with safety requirements and the difference in the safety levels of the two robots with the camera installed were tested. [10]. Before we started the physical tests, we had had to examine the software background using the CDS3.7.2 program to check that the sensor fields were properly calibrated depending on the speed. The CDS configuration and diagnostics software is compatible with all industrial safety systems from SICK. The application's design and implementation are made quick and easy by the straightforward user interface. The software provides all configuration and diagnostic data for speedy commissioning and/or effective troubleshooting. CDS can be easily and successfully integrated into the system level of client's automation environment using standard communication interfaces (TCI, FDT/DTM). We checked the protective and warning fields of the robot's sensor with respect to the speeds in the simulation interface of the software as depicted on Figure 2. We then moved on to the real, physical robot tests, where we tried to simulate the situations that the robot would experience in operation [11]. We performed the tests with two types of robots [12]. One robot was the Alfa, which only had an S300 Expert safety sensor that sees down in the sensor plane. The other robot was the Beta robot, which we improved, with a NanoScan3 Pro and two 3D cameras.

The AGV and AMR robots are equipped with scanning laser scanners (LiDAR), which scan the environment in a plane 5 to 10 cm above and parallel to the floor [13]. Although this provides a suitable solution for detecting obstacles, people or vehicles lying on the ground, if there is an obstacle in front of the robot, below or above the plane of the scanning sensor, it cannot be detected by the robot, e.g., shoe toes, forklift truck forks, wall-mounted cupboards, their doors [14,15]. The Beta robot has 3D obstacle detection, so if there is an obstacle below or above the scanning plane of the main laser scanner, it can detect it with high confidence. The size and shape of the safety field and the parameters of the object to be detected are application dependent.

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Figure 1. Visionary-T picture and pictorial vision

The size of the detectable objects must be at least 50mm from a distance of 1.5m (see Figure 1). The LED array emits modulated light continuously as light waves. Its result is 3D illumination. The light is reflected back to the camera [16]. The reflected light wave is evaluated pixel by pixel continuously at the imager. The phase shift between the transmitted wave and the received wave is measured pixel by pixel. The distance per pixel is calculated based on the phase shift [17].

3. RESULTS AND DISCUSSION

The intralogistics systems are autonomous AMR robots based on AGV forklifts. They are used for the automatic transport of components and finished products in a factory or warehouse hall. Standard pallets, containers and material handling vehicles are transported along designated routes. The work of the mobile robots is supervised by a self-developed system. The developed system enables the planning of logistics processes, takes into account the infrastructure of the production hall and the warehouse, as well as the employees moving there. The modular design of AMR robots facilitates the planning of the intralogistics system according to the customer's needs. The software field set values were adequate for the safety requirements.

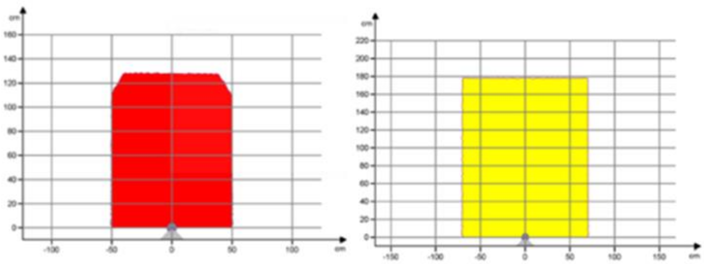

Figure 2. Field set values

The protective field values were defined as follows:

- above 1.2 m/s: protective field 170 cm, warning field 270 cm
- between 1.2 m/s and 0.9 m/s: protective field: 130 cm, warning field: 180 cm
- between 0,9 m/s and 0,6 m/s: protective field: 85 cm, warning field: 150 cm
- between 0,6 m/s and 0,3 m/s: protective field: 60 cm, warning field: 130 cm
- below 0,3 m/s: protective field: 40 cm, warning field: 110 cm.

Then physical tests on seven different objects and two different robots were carried out. The used tools were: tethering cord, boxes of different sizes, a sliding barrier, a forklift truck and human intervention as described in Table 1. Two of them can be highlighted now.

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Table 1. test scenarios

Test 1: A hanging obstacle at the Alfa	Result: Failed!	As the box was out of the sensor's plane, it did not detect it, hit it and continued on its path.	
Test 2: Hanging obstacle at Beta	Result: Passed!	The 3D sensor detected an object suspended 600 mm from the ground and stopped at a safe distance.	
Test 3: Forklift test body 300 mm off the ground at Alfa	Result: Failed!	The forklift cavity test piece, which was out of the sensor's plane, was not detected, crashed into it and crushed it.	
Test 4: Forklift test rig 300 mm off the ground at Beta	Result: Passed!	The forklift test piece was also detected and the robot stopped at a distance of 1000 mm from the forklift test piece.	

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The software check found everything okay, the sensor was calibrated correctly for the speeds. The results of the physical testing of the two robots were also as expected, showing that the improvements have made the Beta robot much safer. The result of the testing is that while the Alpha robot only showed 28 percent compliance, the Beta robot passed all the tests and achieved a 100 percent result as we can see on Figure 3. Thus, it is concluded that the development of the Beta robot has been successful in the safety audit and can be used as a tool in intralogistics, thus increasing the safety level in warehouses.

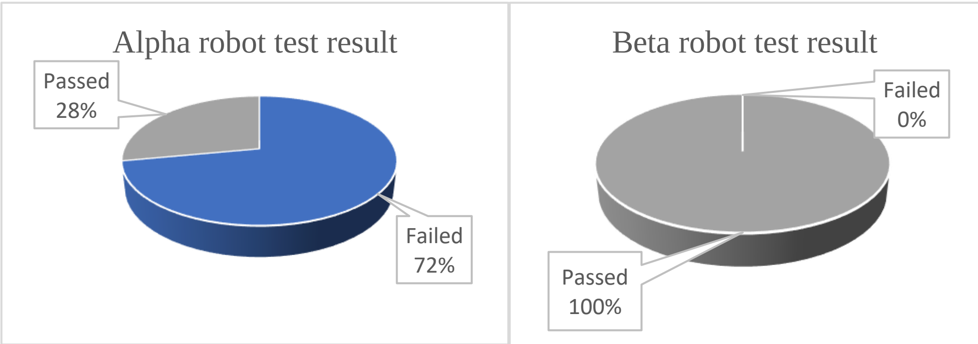

Figure 3. Field set values

LiDAR products, including basic flash LiDAR and 3D LiDAR, have achieved mass production level with corresponding certificates. LiDAR solutions are widely used in autonomous vehicles (collision avoidance), drones (logistics, agricultural plant protection), ITS, robots (smart home), AGV (logistics and warehouse management) [18]. The S300 Expert meets exacting requirements and provides flexibility to meet the demands of mobile applications. Up to 16 protective fields can be configured. The new triple field mode allows three fields - one protective field and two warning fields - to be activated at the same time. This means automatic guided vehicles (AGVs) can be given all around protection and matching safety fields, regardless of speed [19,20].

4. CONCLUSIONS

Material handling is the primary task of robots in logistics. This can be achieved mainly with AGVs, which increase efficiency and are able to perform their tasks for a specified period of time. Such a task could be moving pallets between production lines, possibly moving them out to the collection point, delivering the received raw materials from the warehouse to the production line, or transporting the finished product to the warehouse. The market for logistics systems using AMRs is growing. According to the International Robotics Association's 2019 report on service robots, in 2018 we witnessed a 61% increase in traffic in this area. Testing carried out showed that the Beta robot passed all the tests and achieved a 100 percent result with the implemented 3D sensory system. It is concluded that the development of the Beta robot has been successful in the safety audit and can be used as a tool in intralogistics, thus increasing the safety level in warehouses.
In the future, the next planned development will be lateral sensory development. As well as the projection of a light strip around the robot, to help the employees working in the factory to see how close they can get to the robot.

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