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Exploring the Re-Identification of Industrial Entities on Autonomous Guided Vehicles

Erkundung der Re-Identifizierung Industrieller Entitäten mittels Autonomer Fahrerloser Fahrzeuge

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This study explores the re-identification of industrial entities utilizing automated guided vehicles (AGVs). In particular, the focus of this publication rests on the detection and identification of Euro-pallets in warehousing environments. By implementing such systems for both ground-bound and aerial AGVs, the research analyzes the feasibility of real-time detection and identification of Euro-pallets. The preliminary findings of this study highlight the potential of such mobile, dynamic re-identification system, which may enhance warehousing processes in the future. Current limitations, such as system reliability and transmission protocols, are explored and discussed as well.

[Keywords: re-identification, automated guided vehicles, object detection, logistics]

Diese Studie befasst sich mit der Re-identifikation industrieller Entitäten mit Hilfe von AGVs. Der Schwerpunkt dieser Veröffentlichung liegt auf der Detektion und Identifikation von Euro-Paletten in Lagerumgebungen. Durch die Implementierung solcher Systeme sowohl für bodengebundene als auch für flugfähige AGVs wird die Praktikabilität der Detektion und Identifizierung von Europaletten in Echtzeit untersucht. Die vorläufigen Ergebnisse dieser Studie zeigen das Potenzial eines solchen mobilen, dynamischen Re-identifikationssystems, das die Lagerprozesse der Zukunft unterstützen könnte. Aktuelle Einschränkungen, wie die Zuverlässigkeit des Systems und die genutzten Datenübertragungsprotokolle, werden ebenfalls erforscht und diskutiert.

[Schlüsselwörter: Re-identifikation, automatisierte Führungsfahrzeuge, Objekt Detektion, Logistik]

1 INTRODUCTION & MOTIVATION

Logistics research in many cases studies how to measure and subsequently optimize operational processes. This, in turn, often requires the identification (e.g., in the context of inventorying and shipping) of industrial entities, such as pallets, crates, among others. Since a lot of processes related to the identification (and more broadly speaking, the tracking) of such entities are currently performed manually, prior research involved first describing the current limitations and the corresponding vision of a future warehouse [1, 2, 3], and secondly finding automation solutions for said processes. The results of this research are identification solutions, inspired by pedestrian re-identification approaches, that are made up of a multi-step process. This is due to the fact that prior to identification, detection of the entity in question has to take place.

In this regard, the first development that was published [4] describes the dataset creation process, as well as the process of using object detection and re-identification techniques, in order to identify Euro-pallets based on their chipwood blocks. While this first development provided promising results, it was still limited in terms of the amount and quality (i.e., realism) of the data [5, 6] used. In order to address these limitations, a follow-up publication discussed the use of this approach on a considerably larger real-world dataset [7]. Finally, the use of synthetic data for the training process [8], for instances in which data acquisition capabilities are limited, and the use of graph-based models [9], as to provide solutions for hardware-restricted scenarios, were further explored.

However, the solutions presented thus far are based on a static recording setup. In this sense, if the industrial entity in question, in this case a Euro-pallet, is to be detected and identified, it has to be moved through the a priori set up identification point. This makes the approach rather limited, given that no continuous and dynamic identification is

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ensured. Instead, strategically sound points of identification have to be chosen and the movement of the industrial entity has to be planned accordingly, e.g., by virtue of using conveyor belts.

Due to these limitations, in this publication the authors will explore the possibility of deploying the previously developed identification approaches on automated guided vehicles (AGVs). If this were possible, it would greatly enhance the capabilities of such identification systems, allowing for a more flexible and creative use in modern and future warehousing environments. In particular, the authors will explore the use of a ground-bound and an aerial AGV. In addition, the use of 5G transmission for the processing of the data that are recorded on-board, will be explored as a possibility to ensure real-time re-identification, while working with limited hardware resources and high-quality image data.

2 RELATED WORK

To achieve a comprehensive tracking system, a combination of methods such as object detection, segmentation, classification, and identification are employed [2]. Re-identification plays a vital role in this process, referring to a technique used to track entities of interest across time and a network of cameras [10]. Re-identification has profoundly been studied for different tasks, e.g., vehicle tracking [11], and animal monitoring [12], and most importantly pedestrian re-identification [10]. However, thus far no research has been conducted on re-identification for industrial entities. Prior work of the authors has studied static re-identification methods for industrial entities [4, 5] and their technical intricacies [8, 9, 13]. For this purpose, three datasets were published [6, 7, 14].

Apart from these prior developments, only loosely related research could be encountered. For instance, [15] have proposed a dataset for the purpose of tracking in an industrial setting. The entities shown in this dataset are varying, one of them being pallets. The partially labeled dataset is of great value for object detection and tracking tasks, yet it cannot be employed for re-identification purposes. Other authors have presented ways of identifying industrial entities using microscopic approaches [16].

In the context of mobile object recognition, Chen et al. [17] present an approach for mobile recognition of traffic infrastructure objects, such as asphalt pavements. Images of infrastructure objects can be captured with a smartphone and transmitted to a recognition system via 5G. The system uses AI-based algorithms to analyze the images and subsequently assesses roadway defects and object categories on traffic infrastructure in real time. In contrast to our work, this approach is a mobile recognition system for categorizing infrastructure objects, while our work performs re-identification of industrial entities in addition to mobile detection. The aspect of mobile re-identification is in general what sets our work apart from all other previous publications that could be encountered during our research.

3 KEY COMPONENTS

This chapter will elaborate on the key components needed to implement a mobile re-identification system in a warehousing environment. The chapter is subdivided into the object detection and identification-related software parts, AGVs in question, and the streaming, mobile network and auxiliary systems needed.

3.1 OBJECT DETECTION & RE-IDENTIFICATION

Before being able to identify any subject of interest on a stream, the subject in question needs to be detected in a given frame of the stream. This is in contrast with the use of curated re-identification datasets that provide a priori cropped images of the entities that need to be identified. For this purpose, we use a TinyYOLO [18], trained on images of pallet blocks, as documented in detail in [4]. The resulting images are cropped based on the determined bounding boxes and are used as input to the re-identification model.

The model used for this purpose, again documented in more detail in [4], is PCB [19]. This model is a state-of-the-art re-identification model, developed as a modification of ResNet50, specialized for pedestrian re-identification. It takes the output of YOLO as its input, using it as a query image to be compared to the gallery images, i.e., the images of entities already present in the database. In the case that the given image does not surpass a set threshold, it is deemed a new identity and will be serialized and added to the database.

3.2 AUTONOMOUS GUIDED VEHICLES (AGV)

AGVs are becoming increasingly important in warehousing logistics. They optimize processes and execute tasks that are laborious or associated with health risks [20]. Two different AGVs were used for this work. The first is a ground-bound robot, built on the DJI RoboMaster S1 platform. The second is a micro drone from Bitcraze, called Crazyflie.

3.2.1 GROUND-BOUND AGV

For the ground-bound AGV, we choose to use a DJI RoboMaster S1. The RoboMaster (see Fig. 1) is an educational platform designed for various challenges in the field of robotics. It draws inspiration from the RoboMaster competition. With its open API it can be used as a research platform for further exploration and studies in the field.

For the purpose of re-identification, the RoboMaster is equipped with a camera, a computation unit, and 5G antennas. Therefore, we choose to use a Raspberry Pi 4 single-board compter (SBC) with a Raspberry Pi Camera Module 2 (12.3MP) and a wide-angle lens (6mm 3MP). The SBC is powered via the RoboMaster's internal battery and a DC/DC converter. For communication, an RMU500-Evaluation Kit with a Quectel RM500Q 5G modem is connected to the SBC. The modem supports 5G standalone networks for 5G Band 78, enabling the connection to a 5G campus network.

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Figure 1: The ground-bound AGV, using a Robomaster as its platform.

The components are housed in a 3D-printed enclosure, mounted on the RoboMaster. The camera is adjustable in terms of height and angle and is positioned at the front of the AGV. The antennas for 5G communication are mounted on the sides of the enclosure.

3.2.2 AERIAL AGV

For the aerial AGV, we select Bitcraze's Crazyflie. The Crazyflie (see Fig. 2) is an open-source project, both hardware and software wise. This allows us to customize the drone and to modify the onboard firmware to suit specific use cases.

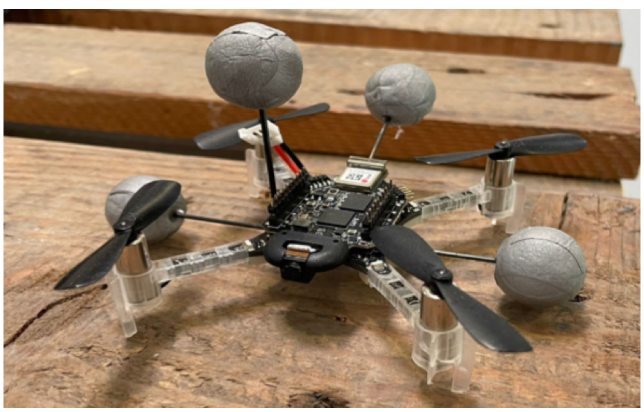

Figure 2: The aerial AGV, using a Crazyflie as its platform.

The base version of the Crazyflie drone has a light-weight design, weighing only 27g. It is equipped with an onboard micro-controller, and an inertial measurement unit (IMU). Its communication capabilities are enhanced through the Crazyradio, a custom USB dongle connected to the respective edge device, that supports 2.4GHz radio communications. A key aspect of the Crazyflie's appeal is its multiple expansion decks that can be attached to the drone, adding new functionalities. The one that is of relevance for the purpose of mobile re-identification is the AI-deck, a computation unit with a GAP8 processor. It allows not only for onboard computation but also for the use of the quintessential AI-deck camera module with a 324×244 px resolution.

For the operation of the aerial AGV, a specific software stack, Crazyswarm, is needed. Crazyswarm is a framework developed collaboratively by the University of Southern California and the Technical University of Berlin [21]. The Robot Operating System (ROS) based framework is specifically designed to be used with Crazyflie drones. It is built on a C++ API implementation called the crazyflie cpp library [22], adding support for functionalities such as external motion capture systems.

In addition, YOLO is combined with a simple PID-Controller based on [23], in order to control the aerial AGV's movement based on the detection of pallets.

3.3 COMMUNICATION & COMPUTING

To enable the continuous and dynamic detection and re-identification of industrial entities, our proposed approach is based on mobile AGVs that can move freely in a warehousing environment. A camera installed on the AGV captures the environment, which is passed to YOLO for the task of object detection. Since the tasks of detection, serialization and re-identification require a significant amount of computational resources, some of the application components must be outsourced to a server or edge device. Especially for the aerial AGV, on-board computation is very limited, due to the low amount of weight that the AGV can carry.

Ultimately, this means that the video stream recorded on the respective AGV needs to be passed to a server. The implementation of an error-free detection and a continuous re-identification process requires this transmission process to be reliable. Due to high data rates, short latency and a high reliability, the fifth-generation technology standard for broadband cellular networks, 5G, is the basis for this real-time data transmission.

The re-identification of industrial entities is classified in the enhanced mobile broadband (eMBB) usage scenario, as the application requires a high degree of mobility and network energy efficiency, as well as a reliable and high data rate to transmit the video stream [24].

In this work, we deploy the application on an edge server that is geographically close to the AGVs and accessible through only a few hops [25]. The transmission of the video stream using 5G in combination with the processing of the images using edge computing represents the technical basis for flexible, high-performance and interference-free detection, serialization and re-identification of industrial entities in real time.

Finally, the open-source framework GStreamer in combination with the Real-Time Streaming Protocol (RTSP) is used to enable real-time streaming from the ground-bound AGV, creating and deploying our own streaming server. The RTSP server functionality of GStreamer allows for seamless transmission and retrieval of multimedia content, making it an ideal choice for a mobile re-identification systems that require real-time streaming for computing video data.

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3.4 AUXILIARY SYSTEMS

For the purpose of AGV localization during movement, a Vicon motion capture system is used. The system acquires data from multiple infrared cameras to estimate the pose of pre-introduced objects in its field of view. These objects are equipped with spherical, retro-reflective markers that reflect infrared light (see Fig. 2). It is necessary for these objects to be equipped with distinct marker configurations, i.e., in unique patterns, to avoid the confusion of two different objects with one another. Four our experiments, a total of 52 Vicon cameras are used in combination with the Vicon Nexus and Tracker software and SDK.

Thus, in order for the AGVs to navigate their planned paths, they receive their positional information from the Vicon system via a 5G campus network. Low latency and minimal jitter are essential network requirements to ensure the smooth functioning of the actuators at considerable movement speeds. The route planning takes place centrally, after which the routes are provided to the AGV.

4 PROOF OF CONCEPT

The combination of the key components presented in the preceding section culminates in our two mobile re-identification solutions proposed in this section. First, the ground-bound AGV, able to move past a pallet in need of identification while providing stable results without stopping. Its inbuilt camera provides images in a high resolution, yielding a lot of details of the pallet block surface structure. In Figure 3, the system architecture of the ground-bound AGV is depicted.

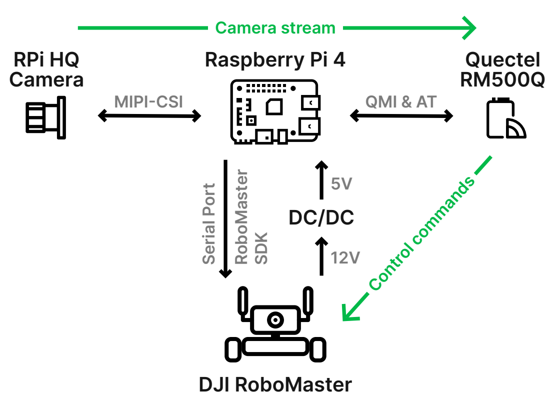

Figure 3: System architecture of the ground-bound AGV.

While a smooth, high FPS stream leading to relatively reliable detection and re-identification results can be observed, some limitations are still to be noted. During motion, the camera has a tendency to slightly shake vertically, which can lead to a reduced accuracy in pallet block detection. Once three pallet blocks are detected and recorded, the re-identification model processes the data, which is a rather computationally intense operation, leading to a delay in the video stream. Finally, the movement of the AGV being dictated by the motion capture system is still work in progress and would ensure a higher reproducibility of our preliminary results.

The aerial AGV uses a combination of YOLO and the motion capture system for its guidance, first detecting pallets in space using YOLO. After the initial detection, the AGV moves towards the pallet in question, until it reaches a target distance at which it starts the detection of pallet blocks. These pallet blocks are then identified analogously as with the ground-bound AGV. As with the ground-bound AGV, the aerial AGV still faces some limitations. For one, the control of the AGV's movement is subject to high latency, therefore needing frequent location recalibration. In addition, the use of the AI-deck makes the maximum duration of flight relatively short, making experimentation increasingly difficult.

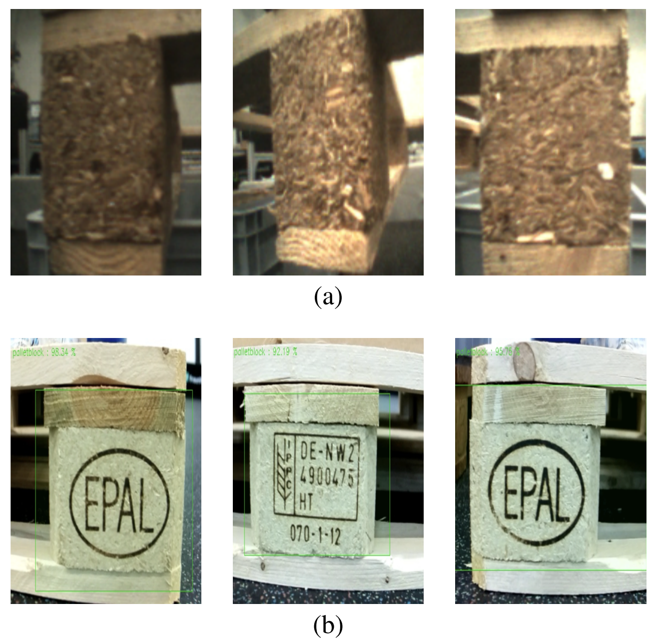

Figure 4: Images automatically recorded by the aerial AGV (a) and the ground-bound AGV (b) using YOLO to detect the three pallet blocks of interest.

Fig. 4 depicts what the images extracted from the AGV's video stream looks like. The quality of these images varies, since it is dependent of the respective YOLO detection result.

As a first attempt to gauge the reliability of the herein proposed mobile re-identification systems, we performed a test with the aerial AGV. This test involved the re-identification of 10 previously serialized pallet block triplets and was repeated three times.

Taken from the results in Tab. 1, an empirical accuracy of 70% could be achieved for this preliminary test. Upon further investigation, it is apparent that a major limitation of the current system is the small distances between the vectorized images in the embedding space of the re-identification model. This phenomenon implies that the re-identification

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Table 1: Preliminary reliability study of the mobile re-identification system.

True ID	Predicted ID		
	Identification 1	Identification 2	Identification 3
1	1	1	1
2	1	2	1
3	3	4	3
4	4	3	4
5	5	7	5
6	6	6	6
7	7	7	3
8	8	7	8
9	9	9	9
10	4	10	7

model has learned representations of the pallet blocks that are very similar to one another, even when the two blocks in question are not the same. In addition, the use of industrial and heavily worn pallets, unlike in the training dataset, might have added to the complications during re-identification.

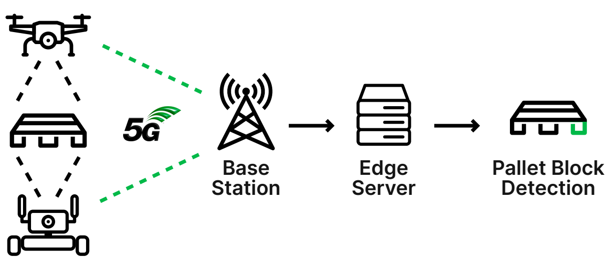

Figure 5: System architecture for the mobile re-identification of industrial entities.

Nonetheless, for a first test of reliability, the mobile re-identification system clearly demonstrates that it works as a proof of concept, while still leaving room for improvement. Finally, the overview of the system architecture used for our experiments can be seen in Fig. 5.

5 CONCLUSION & OUTLOOK

In the future, effort will be put into the optimization of the the mobile re-identification systems presented in this contribution. This involves refining the algorithms and fine-tuning the parameters to improve the accuracy and reliability of the re-identification model. In particular, increasing the distance of the learned embeddings of different pallet blocks, while minimizing those of the same ones is our main goal. The expansion to other scenarios and applications would then ensue. Real-world feedback and data from various scenarios will be incorporated to enhance the performance of the system in general.

In parallel, a focus is placed on the ongoing development and optimization of the AGVs. This involves enhancing the algorithms and techniques used for autonomous navigation, obstacle avoidance, and path planning to enable the AGVs to operate autonomously and efficiently. This could for instance be done by employing Aerostack2 for the aerial AGV navigation [26].

Another important aspect to explore is the analysis of energy consumption and processing efficiency in relation to resource allocation. The implemented edge computing techniques will be thoroughly examined to understand their impact on energy usage and processing performance. By distributing computing resources closer to the devices, the goal is to reduce energy consumption and improve overall system efficiency. This analysis will help identify energy-efficient strategies and further optimize the performance of the system.

Lastly, stress testing will be conducted to evaluate the influence of other network participants. Simulating scenarios with multiple devices and network participants will allow for a comprehensive evaluation of the system's performance under high loads. This testing will help identify any potential bottlenecks, limitations, or areas that require improvement to ensure the robustness and scalability of the network infrastructure.

In summary, the focus will be on optimizing the re-identification process, further improvement of the AGVs, analyzing energy consumption and processing efficiency, and evaluating the system's performance under stress conditions.

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