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A smart Warehouse 4.0 approach for the pallet management using machine vision and Internet of Things (IoT): A real industrial case study

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ABSTRACT

Printing companies are commonly SMEs with high flow of materials, which management could be significantly improved through the digitalization. In this study we propose a smart Warehouse 4.0 solution by using QR code, open-source software tools for machine vision and conventional surveillance equipment. Although there have been concerns regarding the usage of QR in logistics, it has shown to be suitable for the particular use-case as pallets are static in the inter-warehouse. The reliability of reading of QR codes was achieved by using multiple IP cameras, so that sub-optimal view angle or light reflection is compensated with alternative views. Since surveillance technology and machine vision are constantly evolving and becoming more affordable, we report that more attention needs to be invested into their adaptation to fit the needs and budgets of SMEs, which are the industrial cornerstone in the most developed countries. The demo of proposed solution is available on the public repository *https://github.com/ArsoVukicevic/PalletManagement*.

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1. Introduction

All manufacturing-oriented companies, both SMEs and large corporations, are on a daily basis faced with the problem of managing a large number of different articles: which may vary from various raw materials to components and parts. Thus, the success of each business depends on the continuous and fluent flow of the parts in the supply chain [1]. However, the real-world situation is usually opposite, since there are huge problems in establishing of the reliable supply chain, leading to increase on inventory levels to fight against fluctuations and other disturbances. Modern management strategies, including Lean and World class manufacturing (WCM), define an unwanted level of inventory (raw material, work in progress, or finished products) as waste since they occupy working capital [2]. So, if there is no successful warehouse management in every company in the supply chain, all these issues cannot be properly addressed.

The new industrial platform – Industry 4.0 [3-6], aims to ease and automate the tracking and management of material flow, thus improving it on the global level (supply chain management) and on the local level (warehouse management). New Warehousing 4.0 solutions are based on the Smart Products. Therefore, they need to be identifiable at any time – which requires sophisticated technology [3]. The new approaches are based on the application of QR (Quick Response) code and RFID (radio-frequency identification) tags, and other I4.0 technologies such as IoT, cloud and data mining [7, 8]. Tracking of unique products allows lifecycle management of single-item customized products and optimization of their production flow [9].

In general, solutions based on QR and RFID have been the most widely used since they are affordable and easy to use. These are important aspects, since the companies in many countries are lagging behind with Industry 4.0 technology adoption [10]. Although there are concerns regarding the security of QR code, it has been widely used in marketing (opening web-page URL written in QR code) and/or product tracking [11]. On the other hand, RFID technology uses RFID tags for storing information, and corresponding antennas to read and write data to the tag [12] with possibility to use data encryption. Although the RFID technology is more attractive, since much more data can be stored in the tag, there is a serious concern about bad influence of the RFID technology on the human body. It is a non-ionizing type of radiation, but some researches show that it could have a negative impact on the human body in a long-term period [13, 14]. Therefore, the range of antennas used in the industrial RFID solutions has been limited to below 0.1 m, although the range could be more than 1 m [15]. It means that RFID tags cannot be read from the distance, but from the vicinity, like the classic one-dimensional barcode. The possibility to read QR code from the distance by using high-resolution cameras becomes the advantage of the QR code over the RFID technology.

In 2012, Qian *et al*. investigated the possibilities of tracking two-dimensional QR codes in the food industry, and compared them with the RFID technology [16]. Their evaluation found that the implementation of mentioned solutions increased overall cost for 17.2 % but increased efficiency and sales up to 32.5 %. Liang *et al*. proposed usage of QR code for automatic separation and identification of equipment [17]. In the recent study from 2020, Liu *et al*. proposed a system based on IoT that enables remote reading of barcodes for the purpose of implementing "smart cities" concept [18]. Regarding the industry practice, QR codes are widely used for employee authentication[1] – however, it is not widely used in the logistics. This is because the QR technology has not been shown as reliable in cases where it needs to frequently read moving objects (i.e. baggage check in airports, markets etc.). The leading manufacturer of industrial solutions for the barcode-based tracking of pallets is the Cognex[2] company, and their solutions are based on using industrial cameras and accompanying information systems. However, limited budgets and complexity of such solutions is the major obstacle for their wider usage among SMEs. On the other side, development of dedicated solutions was limited with costs of professional industrial cameras, which are needed for ensuring high quality of images for reading QR codes from distance.

The SME from the printing industry, a use-case in this study, was considered as the representative case because there are literally hundreds of different variations (formats, weights, colors, origins, fiber orientations, surfaces, printing characteristics, etc.) of paper in the production process and supporting materials that are used daily [19]. Particularly, this study focuses on covering the needs of SMEs since they generate the most workplaces and GDPs of developed countries - thus covering their needs may have considerable impact on the economy and society [20, 21].

The starting assumption of this study is that above-mentioned barriers for QR code application are vanishing with the technological progress, since even a standard IP camera delivers images with 8+ megapixels. And when it comes to the transport of materials within a company, it is important to emphasize that forklifts and pallets still represent the gold standard [1], like in this use-case. However, to the best of our knowledge, there is no scientific study, nor publically available solution, that assesses their potential and usability for a particular industrial purpose of tracking pallets in the inter-warehouse of a printing company. Accordingly, the aim of this study was to investigate how QR code, machine vision and IP cameras could be adapted for improving pallet management in a representative SME printing company.

[1] http://www.mytimestation.com [22]

[2] https://www.cognex.com/ [23]

2. Materials and methods

2.1 Machine vision

Computer vision (CV) is an emerging scientific field that falls under the umbrella of Machine learning (ML) and Artificial intelligence (AI). It groups algorithms that performs decision making on the basis of observed visual inputs. CV is primarily focused on making higher-level decisions by processing data that may not be only 2D images, but also point clouds, meshes, videos, etc. On the other side, Machine vision (MV) is nowadays identified as a subfield of CV that refers to the use of CV and image processing techniques in industry setups (which means use of dedicated industry cameras, lenses, PCs, etc.) for making decisions (commonly real-time). Typical examples of the use of MV in manufacturing industry are dimensional inspection [24] and defects inspection [25].

2.2 Internet of Things

The term Internet of Things (IoT) refers to the use of devices connected to the internet, with the purpose to measure and collect data, or control remote devices. Similarly, with the increase of the use of IoT, there is appearing Industrial IoT (IIoT) as a separate scientific topic. As two key underpinning technological pillars of the Industry 4.0, the use of CV and MV together with IoT shown a high potential for solving wide range of problems. Particularly, with the advances of networking and constant increase of IP cameras affordability and quality of images that can provide in real-time. Accordingly, they have appearing as possible replacement for more expensive industrial cameras – especially for task such are reading QR code and tracking material flow in warehouses.

2.3 QR code technology

Understanding the key concepts of QR technology is necessary for its successful application in industry, since a developed solution needs to meet related industry standards[3]. The QR (Quick Response) was invented back in 1994. by Japanese company Denso Wave[4], and it is composed of parts shown in Fig. 1 The gray area indicates a clear zone with no data. Square elements in corners (bottom left, top left and right) are used for detection of scale and orientation of the code. Different colors show specific zones that contain version, format, and QR code information. There are about forty versions of QR code, and the most commonly used are versions 1 and 2, which have 21 × 21 and 25 × 25 modules, respectively (dimensions determine amount of data that could be written). The data zone also contains elements necessary for correcting errors on printed codes, which enables reading damaged QR codes. There are four code correction levels[5]: L (7 %), M (15 %), Q (25 %), and H (30 %). In this study, we used version two with the M correction level.

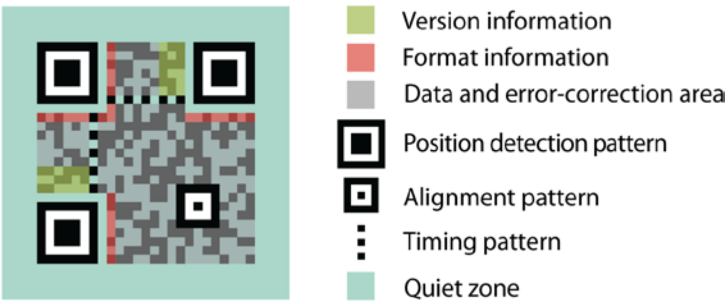

Fig. 1 QR code composition as documented by the Denso company

[3] *https://www.iso.org/standard/62021.html* (ISO/IEC 18004:2015) [26].
[4] It was initially invented for the purpose of tracking manufactured parts in the automotive industry.
[5] It should be taken into account that error correction levels are related to the magnitude of the QR code (a greater degree of correction requires larger dimensions of the code).

2.4 Used equipment

The development of the procedure was completely done in lab conditions, by using minimized QR codes observed with multiple conventional USB web cameras. Particularly, this was possible because technologies utilized in this study have robust interface for accessing various types of cameras with minimal change of software code. The equipment used for the deployment into the real-industry conditions included a conventional PC, network switch and NVR device connected with 8MP Dahua IP cameras that were mounted on the warehouse roof construction.

3. A case study: Proposed pallet management system in real industrial environment

Photo from the use-case factory is shown in Fig. 2 The current practice for managing the material flow in inter-warehouse is based on the standard principles of work orders in the printing industry [19], [27-29]. Trained employees control material disposal and storage zones, and the space is used in accordance with current needs and requirements determined by the weekly work plan and customers' requirements. Due to the dynamics of the business, and the company growth, there is an increasing need for a system able to ease the control of pallet flow and prevent frequent delays. Particularly, the continuous and increasing production often results in accumulated inter-resources/products, significant space congestion and waste of time that employees spent to search for missing pallets and parts necessary for the initiation of further manufacturing processes. Although the warehouse space is graphically coloured, it rarely easies employees' efforts because of the previously explained reasons.

3.1 User requirements

From the SME management standpoint, the disadvantages of the current practice are:

- Due to the high frequency and overload, forklift drivers often do not comply FIFO rules – which results with misallocated pallets.
- Pallets that are misallocated significantly increase the time needed to afterwards find and sort the pallets available in the warehouse. For the company, it is very important to be able to quickly identify complete work orders and the location of their pallets (tabs).
- Failure to accurately and efficiently inventory all available pallets in the storage causes delays in subsequent manufacturing operations. Process engineers have reported that the delay could be up to three hours - causing significant losses in the profit and productivity.
- The solution needs to be easy to use and accessed by both management and employees on the site. It should be able to deliver a fast report, which contains documented current status and alignment of materials (pallets) through the production space.

Fig. 2 A typical temporary or intra-warehouse of a printing SME. After finishing one operation, the tabs are stacked on pallets until they are requested by a following manufacturing process

3.2 Pallet management by using QR code, machine vision and IP cameras

Concept of the proposed solution is illustrated in Fig. 3. The solution was released as a series of modules, which do particular tasks: 1) Image acquisition, 2) QR codes detection, 3) User interaction (GUI), and 4) Reporting.

The image acquisition was carried out with conventional IP cameras that were fixed on a roof construction (Fig. 4c). Key components of the surveillance[6] system are IP cameras, network video recorder and central management software. The central PC-server runs the Python application (the GUI was developed by using the Qt5 library), which processes incoming images on user request. Beside the standard Python libraries for data structures and numeric, OpenCV (image acquisition and processing) and python-docx library (generation of MS Word documents) were used, together with the QR code library for processing QR codes. Detailed architecture and UML workflow diagram of the solution are given in Fig. 4 In Fig. 5, we present the captures of our implementation in an SME that annually processes ~40 million tabs of paper.

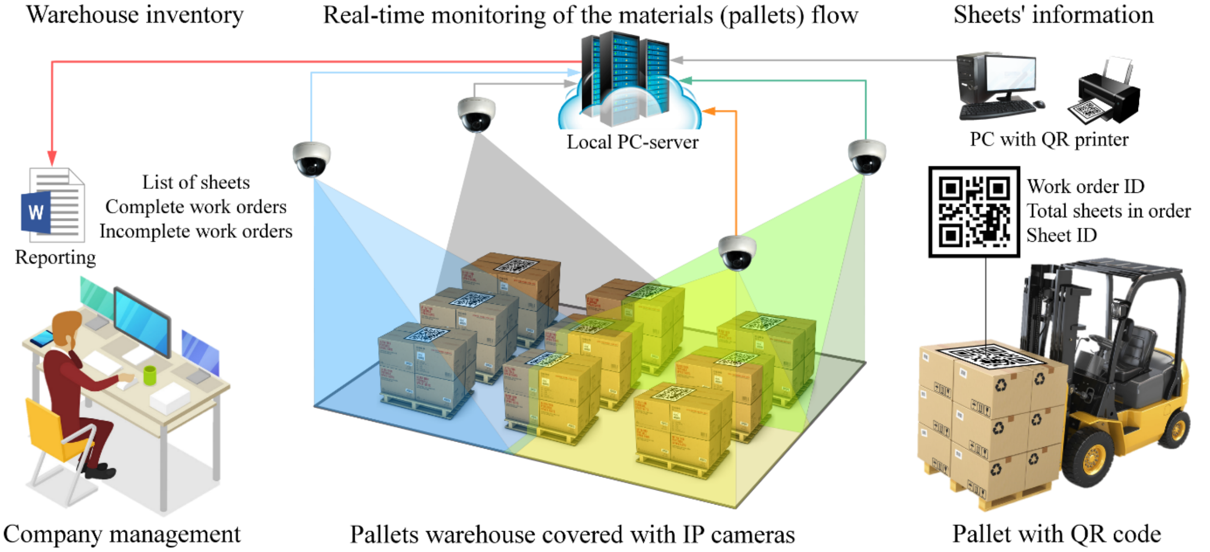

Fig. 3 Concept of the proposed solution

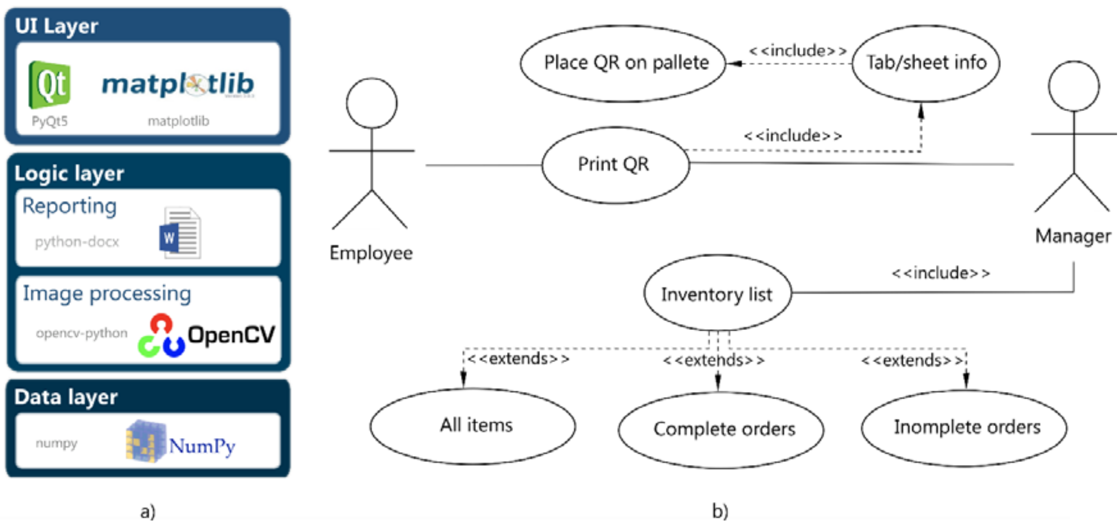

Fig. 4 Software architecture and UML Workflow diagram of the proposed solution

[6] For the purpose of this study, we used DAHUA IPC-HFW2831TP-ZS 8MP WDR IR Bullet IP Camera (4x), with DAHUA PFS3010-8ET-96 8 port Fast Ethernet PoE switch. Host PC had CPU 1151 INTEL Core i3-8100 3.6 GHz 6 MB BOX, results were visualized in HISENSE 40" H40B5100 LED Full HD digital LCD TV and printed on Printer HP LaserJet Pro M102a.

The starting point of the workflow is the moment when a manager assigns a work order to an employee. Orders physically represent a series of tabs / sheets transported on pallets with forklifts (Fig. 4, right). For each incoming tab, one has to print an appropriate QR code by using the proposed software application. The generated QR code contains the following information that determine one tab: 1) work order ID, 2) total tabs within the order, and 2) tab ID. The adapted format of the string data written in QR code is "XXXX ,YY/ZZ": the XXXX indicates the order ID (maximum is 9999 annually), YY indicates the total number of tabs in the work order (maximum 99) and ZZ indicates the tab ID. Below the QR code (which is not readable to humans), we print readable information and time of the code generation, which are fused on a single file and printed on the printer connected to the local network (Fig. 5b). The sample QR code placed on the pallet is shown in Fig. 5d, while the print format is shown in Fig. 5e. The left side of the screen is reserved for user commands (printing QR, querying detected tabs etc.). Visualization of results is done in the middle of the screen, while on the right side are lists of the inventory result. The user is allowed to query the inventory list with respect to orders (complete, incomplete) and tabs. In order to enable fast and intuitive inspection, we colored items found in the lists – so that the red items/orders indicate error, yellow items indicate incomplete orders and green indicate complete orders. On this way, employees could easily spot complete orders, and initiate the accompanying manufacturing process that waits for these pallets to be transported through the manufacturing hall. Another supported functionality is the generation of MS Word reports, which include a list of all orders and corresponding tabs (grouped on complete and incomplete). In this way, the company could document and track the pallets flow and management through time - with the aim to spot bottlenecks and make improvements.

Fig. 5 Preview of the implemented solution: a) Large screen and server (including PC, switch and NVR device) placed in the protective box; b) Printer placed in the protective box; c) Dahua 8MP IP camera mounted on the roof construction; d) QR code placed on the top of the palate; e) QR code format

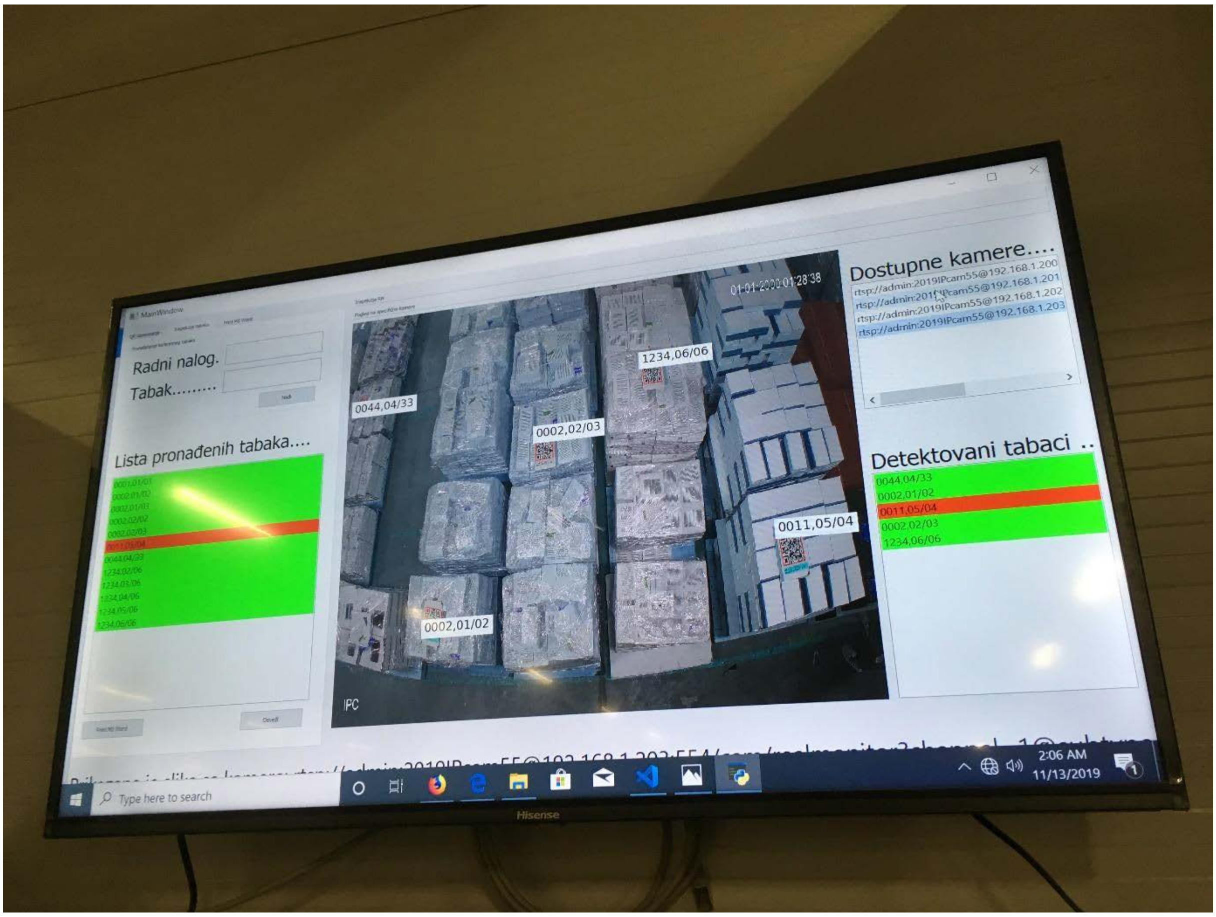

Fig. 6 Capture of the system usage in industry conditions. The upper left are commands for querying and printing of QR codes, while the below are lists of tabs (a user is allowed to view all tabs or only tabs that belong to particular work orders). In the middle are visualized positions of tabs that belong to a particular work order. On the right side are a list of cameras and a list of tabs visible on the particular camera

4. Discussion

Materials Management Systems (MMS), independently or as part of Enterprise Resources Planning (ERP) systems have been one of the interesting and promising directions for the development of supported hardware/software supply chain platforms in recent years [30]. Although the available ERP solutions are numerous and varied (from complex to simple ones), there is still a significant lack of ERP modules or independent systems that can enable (near) real-time monitoring and monitoring of material status and flow at the store level (warehouses, warehouse monitoring and inventory tracking). For this reason, the need for research and practical work to address the problem identified is justified and it could lead to results that can make progress for both the industry and the scientific community. Since the most of printing companies are SMEs, investment into complex or expensive commercial solution often represents a major obstacle towards their digitalization. Accordingly, the proposed solution was developed with aim to avoid these obstacles (the overall hardware installation costs were about 2000 EUR), and it represents so-called “low-cost automation” [31, 32]. Particularly, we emphasize the needs of SMEs because they generate the most of the GDP and employment opportunities in developed countries [20]. Therefore, although there are more robust and general-purpose ERP solutions – still a lot of effort needs to be invested into development of dedicated solutions for specific problems. To sum up, dedicated alternatives, such as the proposed solution, may represent a valuable improvement of the current pallet management practice and may result with considerable impact in SME industry sectors. Accordingly, we made the proposed solution available on the public repository: *https://github.com/ArsoVukicevic/PalletManagement* [33].

In this study, the reliability problem of QR readers [34] was solved with the usage of multiple IP cameras. Briefly, if one camera fails to detect a pallet (due to a suboptimal viewing angle, lighting etc.), another IP camera commonly succeeds. On this way, chances that some pallet may be omitted are drastically decreased. We emphasize that the solution was realized by using four 8-megapixel Dahua IP cameras, and we do not recommend to use low-resolution or lower-tier brands. The aforementioned pixels and the number of cameras have shown to be quite sufficient to cover a space of 10 x 20 meters from the height of about 4.5 meters (which corresponds to the height of the roof support in the manufacturing hall). Furthermore, we preferred to print QR codes on a conventional PC printer, in A4 format, which is widely used in offices. Although we have not experimented with smaller paper sizes, the assumption is that a professional QR printer could be also used - but, in this way, one would increase the cost of equipment and software development. The major limitation of the proposed solution is that the reading QR code is its sensitivity to folding – which we solved by cardboard carrier. The remaining concern of reading false QR codes (e.g. that could appear on products or parts available in factory) or misuse and misplace of QRs is unlikely to happen in industry environment by company employees. Regarding the impact of the developed system on the logistics in the considered company, as the inventory list is done in terms of a few seconds – the achieved speed is incomparably higher than the possibility of a manual search and inspection of the warehouse by employees. In particular, we remind that, based on the employee experience and reports, manual searching for the missing pallets can take up to three hours. For this reason, the advantage of the digitized system is obvious and there was no need for statistical analysis of the performance improvement. Finally, the solution is easily adaptable to various environments – as the only adjustment needed is mounting of conventional IP cameras. The further work on this topic may be regarded to improvement of security, trackability and integrability into existing ICT platform, for which various technologies could be applied including blockchain [35].

5. Conclusion

Beside technological advancements that bring Industry 4.0, the flow of products and raw materials within companies is still underpinned with forklifts and pallets. Since management of pallets in inter-warehouse still depends on human factors, many companies are faced with delays caused by operator's inability to timely manage large amounts of pallets. As a representative use-case, we considered a SME company from the printing industry since there are literally hundreds of different variations of paper (formats, weights, colors etc.) in the production process. Although there are available commercial warehouse barcode-based solutions for tracking pallets, complexity and cost of such solutions represent major obstacles for their wider usage by SMEs (which budgets are limited). As an alternative, we assessed the low-cost solution for the pallet management with QR code, machine vision and IP cameras (demo is available at *https://github.com/ArsoVukicevic/PalletManagement* [33]). The compact solution was developed by using free open-source software libraries and conventional surveillance equipment. Although there have been concerns regarding usage of QR code-based solutions for tracking, we report that it is suitable for the particular purpose of warehouse inventory since pallets are static. Reliability of the solution was ensured by using multiple IP cameras, which ensures that if one camera fails to detect QR code another one will compensate for it. The recent evolution of IP cameras (which now have 5+ megapixels) made them affordable and efficient tools for reading QR codes from larger distances. Thus, we conclude that more attention and effort need to be invested into investigation and adaptation of widely available technologies that could fit the needs of SMEs.

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