DOI: 10.2195/lj_Proc_oezguer_en_201605_01
URN: urn:nbn:de:0009-14-43640

Comparing sensor-based and camera-based approaches to recognizing the occupancy status of the load handling device of forklift trucks

Vergleich von sensorbasierten und kamerabasierten Ansätzen zur Erkennung des Belegungszustands der Lastaufnahmevorrichtung von Flurförderzeugen

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Real-time data of key performance enablers in logistics warehouses are of growing importance as they permit decision-makers to instantaneously react to alerts, deviations and damages. Several technologies appear as adequate data sources to collect the information required in order to achieve the goal. In the present research paper, the load status of the fork of a forklift is to be recognized with the help of a sensor-based and a camera-based solution approach. The comparison of initial experimentation results yields a statement about which direction to pursue for promising further research.

[Keywords: Forklift, occupancy status, camera, sensor, detection, comparison]

Echtzeitdaten über die Leistungskennzahlen in Logistiklagern sind von wachsender Bedeutung, da sie den Entscheidungsträgern eine unverzügliche Reaktion auf Alarmmeldungen, Abweichungen und Schäden erlauben. Mehrere Technologien erscheinen als geeignete Datenquellen zur Sammlung der für die Erreichung des o.g. Ziels notwendigen Informationen. Im vorliegenden wissenschaftlichen Aufsatz soll der Beladungszustand der Gabel eines Gabelstaplers mit Hilfe eines sensorbasierten und eines kamerabasierten Lösungsansatzes erkannt werden. Der Vergleich der ersten Versuchsergebnisse bringt eine Aussage darüber hervor, in welche Richtung die weitere vielversprechende Forschung verfolgt werden sollte.

[Schlüsselwörter: Gabelstapler, Beladungszustand, Kamera, Sensor, Erkennung, Vergleich]

1 MOTIVATION

Forklifts and other industrial trucks are considered as key performance enablers in logistics warehouses. As such, the optimal utilization and the prevention of waste in relation to the use of forklifts are strongly in the limelight of the decision-makers. A minimal time difference between noticing a deviation and curing it is often desirable. Hence, collecting real-time data about the trucks and the pertaining processes is required for an instant reaction on an operational level and for performance reviews for tactical adjustments. Data collection, however, cannot always rely on traditional concepts and requires new technical approaches in order to generate new (and better) information about the focused areas. Ever new sensors mounted directly on the forklift are possible sources for such information. Likewise, cameras appear to be adequate for this purpose.

One of the main areas of interest for logistics managers on an operational level is the information whether a forklift is actually idle or carrying a load. With the information, the assignment of the vehicles to tasks and orders as well as the monitoring of laden and unladen trips can be supported. In addition, such data can be used for the operation of a new generation of warehouse management systems in which scanning bar codes could be replaced with camera- and sensor-based information.

In the present publication, a comparison is drawn between a camera-based approach and a sensor-based approach of detecting the occupancy status of the load handling device of industrial trucks, i.e. recognizing the load status of the fork of a forklift, for instance. In the article, related work using sensors and cameras in the intralogistics sector is examined, details of the solution concept and experimentation illustrated, and the next steps of intended experimentation and improvement discussed.

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2 RELATED WORK

Different information sources, i.e. cameras, sensors and effectors, can be utilized, depending on the information required for observing a particular process [AKK14]. Cameras, encompassing both so-called smart cameras, which are sophisticated cameras with an integrated processor executing industrial image processing operations, and video streams from regular cameras and industrial image processing algorithms, also belong to these sources [NB14][JP11][TWF11][WFH10]. With the growing computing power, memory capacity and data transmission speed, a vast potential in the sector becomes apparent by means of industrial image processing, enabling automated data collection and process monitoring and control in real time [SG08]. Furthermore, industrial image processing consists of a collection of different algorithms aiming at detecting different objects in the video films based on their characteristics or by means of particular identification markers. Such algorithms can use the color or the form of the object as much as the mere detection of a significant change of a picture template.

Regarding the use of cameras in logistics, the number of research projects and applications is limited. In a recent research initiative, a number of application examples have been developed around a series of use cases from the transport and logistics sector itself and from logistics processes of neighboring sectors [AKK14][AJG14][CFS14]. Mainly, the mentioned publications have centered the early-stage realization of individual functions, such as tracking and tracing, and the utilization of information from video cameras for very narrow application areas. Principally, the publications have portrayed the multitudinous functions supported and, thereby, the wide applicability of such camera-based data. Especially, the merge of two innovative developments, viz. novel control towers and multimedia analytics in the form of a vision-based monitoring tool, have represented the major novelty presented in those publications.

Further research projects from Germany center the examination of the feasibility of substituting barcode readers and light barriers with RFID tags and camera-based recognition and localization in an automated material flow system [WFH10].

Another German research initiative retrieves status information from cameras and industrial image processing techniques [HJG12]. The researchers have selected the camera as their solution technology due to its high flexibility which allows them to deal with unforeseen adaptation needs when it comes to reliable detection of object conditions. Industrial image processing thereby substitutes ultrasonic or laser sensors for purposes of load recognition and fork height detection. In addition, the cameras replace RFID tags or barcodes for product recognition, and even inductive RFID tracks for localization tasks [JHG14][HG12].

Yet another research initiative from Germany aims at fusing sensor information about various statuses of industrial trucks and consignments and, thereby, collecting information about processes in warehouses [BPC13]. Apart from using sensors for various purposes, the vehicles can be located in the field of view of the cameras with the help of cameras mounted on the ceiling, matrix code markers on the forklift and software which analyzes the recorded images and videos.

With respect to sensor applications in intra-logistics, a whole string of projects and applications can be found. An analysis of such projects has already been published earlier [AÖY15], of which an excerpt is presented here again.

Despite studies about future trends showing miscellaneous opportunities due to constantly growing adoption of sensors in smartphones and further devices [DHL13], the vast majority of research projects regarding sensor applications on forklifts and similar vehicles in intra-logistics aim at positioning and localization objectives. With the help of wireless sensor networks, many different approaches to locate objects and to track their position on the warehousing premises are applied [EBM05]. The patents from the past years and decades have targeted the integration of sensors into electronically controlled industrial trucks [Nak83][VDI12] and even the surrounding aspects [SKK02].

With respect to localization, various authors have presented their sensor-based solution approaches. Chou et al. [CFO07] have implemented laser beam sensors on the forklifts and reflective stickers at the storage shelves in order to locate active forklifts, i.e. vehicles that are in operation. Using such a system, it was already possible to gain mere information about forklifts operating in certain warehouse zones. Roehrig and Spieker [RS08] have used a radio positioning system for localizing industrial trucks which are equipped with tags. By means of a Real-Time Location System (RTLS), the tags are located within a network of anchor nodes in the wireless sensor network and, thereby, the position of the detected forklifts. Estanjini et al. [ELG11] have examined the use of wireless sensor networks to gather information about the operation time, the physical location, the collision history and the battery status of a forklift in order to optimize forklift dispatching during the process of loading and unloading trucks. In order to reach the goals, they have adopted received signal strength indication (RSSI) and two-axis accelerometers for their experiments. Moreover, the researchers have applied stochastic learning methods to issue recommendations on improved forklift dispatching rules. Apart from radio location approaches, optical sensors are equally in logistics. Schuldt and Gottfried [SG08] have introduced new approaches to automatic navigation of autonomous vehicles in intra-logistics. As part of the technical components in order to realize their goal, they have applied camera sensors for supervising the environment of the vehicle.

Despite the strong focus on positioning tasks, sensors are applied in logistics processes for other purposes as well [AÖY15]. Fischer and Guenthner [FG10] have looked into the vibration of industrial trucks that their drivers are exposed to during their worktime. Vehicle body vibrations are recorded with the help of a triaxial acceleration sensor under the driver's seat. The research work aimed at collecting information about the exposure to health risks of the drivers and, thus, has not implemented the sensors permanently. Similarly, Schmidt et al. [SSW10] have developed a test methodology for electronic components of industrial trucks in order to detect electrical and mechanical strains with the help of sensors. Chen et al. [CPW12] have installed image sensors on a (miniature) forklift in order to locate and recognize pallets by means of different characteristics, i.e. their shape, vertices, and additional fiducials.

Fusing sensor information about various statuses of forklifts and pallets and, thereby, gaining information about logistics processes on warehousing premises was the central idea of a research initiative from Germany [BKJ14]. Apart from cameras, the system employs sensors for identification and dimensioning of pallets, vehicle positioning and load change detection, so that information about location and time of storage, dimensions and appearance is collected. The pallets are identified with the help of barcodes and ultra-high frequency RFID transponders when passing through RFID gates. With the help of depth sensors, the dimensions of the pallets are recoded. Only the load change detection system is fed by manual confirmation of the forklift driver. By fusing the collected sensor information, the system enables monitoring warehousing processes.

Furthermore, sensor manufacturers offer solutions for measuring different conditions nowadays. For instance, the precise positioning of the fork can be supported by inductive proximity sensors while the fork height can be measured with wire draw encoders, laser scanners or magnetic sensors, the distance to the unit to be retrieved with (infrared or ultrasonic) distance sensors. As well, the inclination of the fork is monitored by a tilt sensor, the remote access control to electronic doors is realized by RFID transponders as well as rear monitoring by laser scanners, and goods identification with the help of barcode readers. As a result, there exist many further sensor technologies for the different functions.

The majority of sensors mounted on industrial trucks focus on (real-time) monitoring tasks. Occasionally, service providers offer data logging means and methods in order to gather, process and evaluate information about forklift activity in the warehouse. In order to offer the service, they depend on sensors already being installed though.

3 Solution Concepts

In the following, a comparison between a camera-based approach and a sensor-based approach of detecting the occupancy status of the load handling device of industrial trucks is to be presented. The sensor-based approach uses an ultra-sonic distance sensor together with a Raspberry Pi single-board computer which has already been published [AÖY15]. The camera-based approach employs industrial image processing algorithms along with machine learning techniques.

Both approaches solution have been tested in a real-world environment. Being situated in the West of Germany and near to the German-Dutch border, the central warehouse of a German distributor of electronic goods has been selected as test site. The warehouse encompasses more than 60,000 square meters and accommodates more than 3.8 million stock-keeping units of more than a thousand different articles permanently in stock. With approximately 12,000 40 ft. arriving containers every day and 30 million units being sold annually, a lot of forklift handling for the purposes of storing entering goods and retrieving exiting articles, respectively, need to be realized in the central warehouse. To be able to do so, the company employs nearly 30 industrial trucks, mainly forklifts and clamp forklifts, for the handling activities.

3.1 Sensor-based detection of fork occupancy

In order to detect the occupancy of the fork, the authors have adopted an ultrasonic distance sensor which has been mounted on the fork mast between the two fork arms. More precisely, the Maxbotix Ultrasonic Rangefinder HR-USB-EZ MB1413 has been applied in order to detect pallets on the fork and, thus, identify laden trips of the forklift truck. The 42 kHz ultrasonic sensor features a resolution of one millimeter and measures distances between a minimum range of 300 mm and a maximum range of 5000 mm. The reading range is perfectly suitable for applications of material handling and indoor transportation in warehouses because a standard EUR-pallet has the dimensions 1200 mm × 800 mm × 144 mm. Figure 1 shows its position on the forklift schematically whereas Figure 2 shows the dimensions of the sensor [AÖY15].

When a forklift takes up such a pallet, the distance between sensor and pallet is reduced from 1800 mm to possibly zero because the fork may exhibit a length of 1000 mm to 1800 mm. In addition, some drivers may take up a pallet in the front area of the fork whilst others prefer to drive through the pallet until it is close to the fork mast. In case of a pallet being less than 300 mm distant from the

DOI: 10.2195/lj_Proc_oezguer_en_201605_01
URN: urn:nbn:de:0009-14-43640

sensor, the distance is not measured. The pallet is detected correctly though. Possible temperature-dependent fluctuations of the values measured by the ultrasonic distance sensor are detected by an in-built temperature sensor and corrected automatically. From the individual values measured, the median or mode value is output and recorded in the log file, not the arithmetic mean which may not even have occurred as measured value. The collected data is transmitted via a Raspberry Pi single-board computer, a wireless LAN (WLAN) stick and the Wi-Fi connection in the warehouse to a central computer where it is recorded in log files [AÖY15].

The decision in favor of the above-mentioned concept has been made in the wake of testing alternative concepts. One alternative concept featured the combination of the ultrasonic distance sensor HC SR04 with the open-source hardware platform and micro-computer 'Tinker-Forge RED Brick' from Germany. Although having proved to be very cost-effective and easy to install, the solution has exhibited low reliability of functioning and the measurements in the initial tests. The sensor would only detect an object's presence in the reading range between 20 mm and 4000 mm but not yield any distance measurement information. Thus, the measured data is without a unit. Furthermore, the readings turned to be varying in dependency of the electrical voltage. Another alternative concept included the infrared distance sensor Sharp GP2Y0A41SK0F and the TinkerForge RED Brick micro-computer. The reading of the selected sensor lies between 40 mm and 300 mm which turned out to be too small for applications in intra-logistics. Possibly, further models with wider reading ranges might have been more useful. In addition, the calibration effort for a single vehicle proved to be too high to be used for an entire forklift fleet though. Both concepts have been rejected because they were inferior to the Maxbotix ultrasonic distance sensor [AÖY15].

The collected data about fork occupancy can be written into log files. A time stamp and a value representing the associated distance measurement are written in each line of the log file. Figure 3 shows the content of a log file of the ultrasonic distance sensor readings.

The concerns of logistics managers and decision-makers with respect to expensive and elaborate sensor equipment of their forklift truck fleet can be addressed effectively by adopting the multi-sensor fusion system because the presented solution can be used with older vehicle models and with newer ones [AÖY15].

Moreover, it is compatible with heterogeneous forklift fleets since it is vehicle-independent and merely requires little space to mount the equipment on the vehicle. Since it is easily customizable to the particular requirements of the respective environment, the solution provides great applicability even to difficult conditions, e.g. a highly metallic environment. In addition, the solution supports diverse analyses about the use and utilization of forklifts and optimization potential to be exploited [AÖY15].

Figure 1. Position of the distance sensor on the forklift

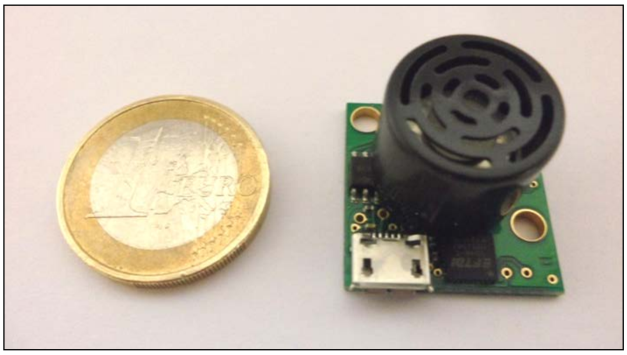
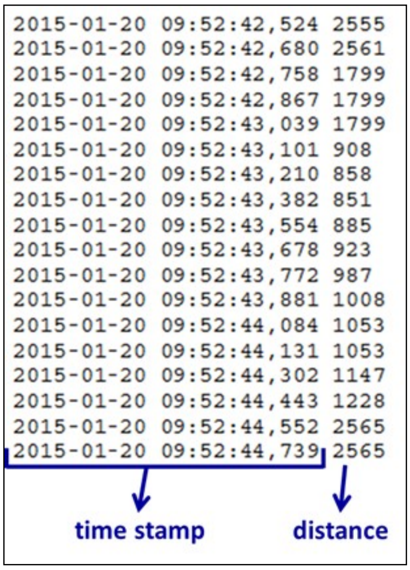


Figure 2. Maxbotix Ultrasonic Rangefinder (HR-USB-EZ MB1413) [AÖY15]



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2015-01-20 09:52:42,524 2555
2015-01-20 09:52:42,680 2561
2015-01-20 09:52:42,758 1799
2015-01-20 09:52:42,867 1799
2015-01-20 09:52:43,039 1799
2015-01-20 09:52:43,101 908
2015-01-20 09:52:43,210 858
2015-01-20 09:52:43,382 851
2015-01-20 09:52:43,554 885
2015-01-20 09:52:43,678 923
2015-01-20 09:52:43,772 987
2015-01-20 09:52:43,881 1008
2015-01-20 09:52:44,084 1053
2015-01-20 09:52:44,131 1053
2015-01-20 09:52:44,302 1147
2015-01-20 09:52:44,443 1228
2015-01-20 09:52:44,552 2565
2015-01-20 09:52:44,739 2565
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Figure 3. Log file of the ultrasonic distance sensor [AÖY15]

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3.2 Camera-based detection of fork occupancy

The camera-based solution approach consists of four major elements: the cameras, the industrial image processing algorithms, a machine learning (ML) library and a library for Augmented Reality (AR) fiducial markers. Parts of the solution approach have already been presented before [AKK14].

For the camera-based solution approach, simple network/IP cameras for security surveillance purposes have been mounted on the ceiling of the warehouse. Although the used cameras depend on the respective application area, sophisticated and expensive cameras with installed processors are not mandatory. Accordingly, a decision was made against expensive camera systems in view of the reluctance of many actors in the transport and logistics sector, which is known as rather hostile towards investment, to make large investments and the bad profitability of expensive monitoring solutions. Simple commercially available network/IP cameras have proved to be sufficient for the observed processes in the ongoing research though since cost of the components has been a crucial decision criterion. This is even truer when existing image processing algorithms can be used for the video analysis of a recorded process. The programming efforts can be carried out with the help of existing open source image processing libraries, such as Open CV with its large programmer community.

Speaking of cameras, certain prerequisites have to be taken into account if high-quality data is to be captured from video streams by means of image processing algorithms [Spi12]. A physically stable environment for the camera, comprising a robust installation and the correct orientation of the camera, the prevention of shocks and vibration, and the guarantee of appropriate lighting conditions in the surveillance area, is dispensable for the reliable and continuous collection of data from video streams. The appropriate lighting conditions concern both the sufficient illumination of the objects and the brightness of the environment. In addition, the cameras need to have an uninhibited view on the objects without any occlusion as well as clean environments without any reflection or line-of-sight obstruction, like dust or smoke.

With respect to image processing algorithms, there exists a bunch of appropriate methods for the diverse application opportunities in the field of transport and logistics. In principle, the detection and tracking of objects in video streams is carried out with the help of four characteristics, color, edges, motion, and texture [YJS06]. Consequently, the different methods for detecting and tracking objects center these four characteristics.

With respect to the ML library, Dlib-ml has been used. Dlib-ml is an open source library targeted at both engineers and research scientists, which aims to provide a similarly rich environment for developing machine learning software in the C++ language [Kin09]. Dlib offers faster training, the same detection rate and significantly lower false positives than OpenCV which is the most popular open source computer vision library. Dlib supports importing and exporting to OpenCV image representation. In the experimentation environment, OpenCV infrastructure has been used for the access to the video streams, and for saving of resulting videos whereas the processing has taken place using structural SVM-based training algorithm of Dlib. After having recorded videos of forklifts firstly, the videos have been converted to individual frames subsequently. Selected frames from the set of all frames have then been determined as the training set. In these frames of the training set, the objects of interests, i.e. the empty and laden fork of the industrial truck, have been labelled with bounding boxes. In the following, the machine learning algorithm has been trained using the training set and the videos processed frame by frame with the help of the ML algorithm in order to find the objects of interest.

As to the AR fiducial markers, ArUco matrix codes have been used for detecting and tracking the forklifts. ArUco is a minimal library for Augmented Reality applications based exclusively for OpenCV [GMM14]. It relies on black and white markers with codes that are detected by calling a single function. In the present application, ArUco high reliability markers have been used in order to track the location of forklifts. The marker codes have been printed and placed on top of the forklift. The reason for choosing ArUco lies in its reliability in detecting so-called high reliability markers (HRM) even for smaller sizes, which has posed a practical problem in many cases of the past. The initial tests were conducted with markers printed on A4 papers and proved to be successful. Thereby, a special printer for the markers is no longer required. Another feature of the ArUco library is that the position and the orientation of the marker can be detected so that we can derive the position and orientation of the forklift from it. Same applies analogously to the possible position and orientation of the fork. Consequently, a region of interest can be determined dynamically for each frame and the pertaining information fed to the ML algorithm.

4 Initial experimentation results and Discussion

The Maxbotix Ultrasonic Rangefinder connected to the Raspberry Pi single-board computer has yielded promising results and performed very reliably in the initial test conducted in the experimentation environment. A problem identified during the series of experiments is the false reads when the forklift drives around a bend. The false reads stem from the stored objects along the path that the forklift passes when making a turn. Since such false reads have only happened rarely and for very short time periods only, they can be ignored without the loss of information by slowing down the sensor reading frequency.

The two states considered during the experimentation were ‘empty’ and ‘laden’. The ‘empty’ state represents the fork is complete empty and does not carry anything whereas the ‘laden’ state contains all residual cases, that is to say those trips with a full consignment and the ones with merely an empty pallet. If the latter two cases needed to be distinguished, an additional ultrasonic sensor could be mounted more above on the fork mast and connected to the Raspberry Pi single-board computer though.

The initial test of ML algorithms for the identification of the empty state of the fork did not yield useful results as the detection of the empty fork has not been recognized in a reliable manner.

Machine learning algorithms seem to work better when they are asked to identify the ‘laden’ state of a forklift carrying an empty pallet, albeit not satisfactorily. However, there is still a need for considerable improvement. Furthermore, the confusion between empty pallets on the fork of an active forklift and the ones stored in the warehouse needs to be addressed and avoided.

A promising approach seems to be visible when the fork is painted with a color pattern with the purpose of easier identification and, thus, increasing the recognition rate. It produced the better results than other computer vision and machine learning test conducted earlier. Whether such a solution can be industrially viable is yet to be examined in close cooperation with industrial partners, as the concern that color patterns on the fork might fade away under the constant and partly extreme strain in a warehouse over time. Figure 4 shows a forklift with an ArUco matrix code marker on its top and a color pattern on the fork.

Figure 4. Forklift with ArUco matrix code on its top and a color pattern on the fork

5 Conclusion

As a result, the comparison of the sensor-based and the camera-based approach has revealed that the sensor-based approach is superior. This has several reasons:

Maxbotix ultrasonic distance sensor connected to Raspberry Pi is the better alternative when only the detection rate at the time is being considered.

The effort of setting up and configuring the sensor is less than in the case of the camera-based solution. Whereas the sensor-based solution requires merely simple configuration, the effort of developing a customized solution based on cameras and industrial image processing is incomparably higher. The Maxbotix sensor with USB connection also allowed a faster development since no soldering and electronics knowledge are required. The ‘Raspian’ operating system, one of the possible operating systems for Raspberry Pi, is a Linux system with a lot of preexisting libraries. One such library is ‘remserial’, which allows serial port forwarding over TCP/IP, has tremendously reduced the programming effort on the Raspberry Pi side.

Also, the effort of mounting the sensor and possibly substituting it for repair or renewal purposes can also be estimated as much less difficult and time-consuming as in the case of a camera-based solution.

Moreover, the cost of both initial acquisition and of continuous maintenance of the sensor-based solution consisting of the sensor, the mini-computer, the WiFi adapter and the powerbank can be considered attractive as it lies below the comparable price of a network/IP camera and the effort required for applying the adequate algorithms.

However, there are also two major critical issues to be considered and ultimately resolved when it comes to a wider and more reliable industrial use: the robustness of the solution and a satisfactory energy supply.

The robustness of the sensor-based solution is such an issue so that a robust casing is inevitable for a use in the rough environment of material handling and warehousing.

Moreover, the question of energy supply needs to be addressed effectively. The problem could be solved either by accessing the forklift’s energy sources or by adding supplementary energy sources, such as portable powerbanks.

As to the camera-based approach, the detection of the fork was not reliable enough for industrial use. The detection of the fork itself without any further modification did not yield any promising results. Same applies to the initial experiments with an empty pallet taken up by the forklift.

DOI: 10.2195/lj_Proc_oezguer_en_201605_01
URN: urn:nbn:de:0009-14-43640

If the camera-based solutions could be improved eventually, so that its detection rates and error rates are similar to the sensor-based approach, the decision problem would shift to a new question: How many forklifts are operating in order to know the number of sensors for sensor based solution? How large is the warehouse, i.e. how many cameras are required for the camera based solution? The ratio of these numbers would be decisive.

6 Future research works

In the future, a 'continuous learning' approach can be pursued with the help of ArUco fiducial markers, Raspberry Pi mini-computers, ultrasonic distance sensors, and Dlib-ml algorithms used altogether. When the reliable distance sensor records a state change, it may trigger a snapshot from the network/IP camera, and ArUco HRM can define the position of the fork, so that the algorithm makes a bounding box around the fork and then labels that bounding box according to the sensor value. Practically, the system learns from the sensor input how a laden forklift looks like and feeds its database with according images. These automatically labeled snapshots can be fed continuously to the machine learning algorithm in order to increase its detection rate over time. After a certain detection rate threshold is achieved, a camera-only solution for the whole warehouse could be rolled out.

Acknowledgements

The authors cordially thank Mr. Heinz-Josef Guido, Mr. Christian Schmidtke and Mr. Ralf Heise for their assistance during the experiments conducted. Moreover, the authors express their gratitude towards those colleagues at the Department of Transport Systems and Logistics of the University of Duisburg-Essen, Germany, that have supported this work actively by means of inspiring discussions and fruitful collaboration.

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