Concept of Automated Load Detection for De-Palletizing Using Depth Images and RFID Data

Christian Prasse∗, Sebastian Skibinski∗, Frank Weichert†, Jonas Stenzel∗, Heinrich Müller† and Michael ten Hompel‡

∗Fraunhofer Institute for Material Flow and Logistics, Dortmund, Germany
†Department of Computer Science VII, Technical University Dortmund, Dortmund, Germany
‡Chair for Materials Handling and Warehousing, Technical University Dortmund, Dortmund, Germany

Abstract—In this paper, we present a novel concept for the detection of loading positions of parcels or bins on a pallet to enable automated order picking using knowledge about the packing pattern model. The approach comprises (1) a new combination of pattern model data and PMD-camera-generated point clouds and (2) a novel concept of RFID data management using a Binary data on Tag / Schema on Net and semantic coding approach. The latter enables the use of additional services like storing of loading positions on auto-id devices (RFID-tags) in a wider concept of the Internet of Things, while the former presents an alternative approach in the context of contour check and position detection of unit loads for automated de-palletizing.

Keywords—Computer Vision, De-Palletizing, Contour check, Semantic compression, Data storage management, RFID, Internet of Things, PMD camera, 3D Imaging

I. INTRODUCTION

Typical logistics processes became significantly more complex and dynamic during the last years. Among other things, this is driven by internationalization of supply chains and global competition, new trade corridors, and privatization in emerging countries [1]. Shorter product life-cycles, mass customization, and stricter quality requirements [2], [3] underline the need of more efficiency in this field of business. One classical solution to this dilemma is the use of automated systems. When properly dimensioned and highly utilized, such systems operate very efficiently and effectively. Especially in high-wage countries a increasing automation in facility logistics is unavoidable to keep up with global competition. But also countries with lower costs for labor use modern technologies to increase efficiency. For example german companies for intralogistics equipment register the highest rates of growth in export trade for so called BRIC-states (Brazil, Russia, India and China) in 2010 [4]. In some industrial sectors like food, brewery, chemistry, plastic and wood, automated palletizing is established as a quasi-standard for production subsequent packaging of goods [5].

Usually unstacking of palletized goods is processed manually. High demands on flexibility (e.g. different size and shape of goods) are just one reason against fully automation. Today’s available high-performance solutions are often too cost-intensive to make them economically justifiable. Accurate and stable handling of goods is no longer technical challenging but the detection of an exact gripping position, especially transportation of the pallet after removing typically used load securing measures (e.g. wrapped film etc.) could cause translational and/or rotatory displacements of the load. Hence known packing positions (nominal) are no longer valid and this gap has to be detected individually [6]. Beside the need to make de-palletizing more efficient to compete in global markets, humanization of labor is an important issue. High physical stress because of manually carrying heavy stocks and adverse working conditions (e.g. cold store) can be reduced or avoided by using automated handling solutions [5], [7]. However, the advent of new technologies may alleviate these challenges; especially, Computer Vision using PMD sensors and RFID Technology are particularly promising.

The task outlined above is structured in four sections. Following this introduction containing a general motivation for this work, the state of the art is presented for automated de-palletizing, TOF and PMD technology as well as RFID data transfer and data management in Section I-A. Next, two concepts for (A) automated load detection using PMD technology (cf. Section II-A) and (B) storing palletizing data for automated load detection (cf. Section II-B) are introduced. In Section III a brief overview of in progress testing results will be shown. Finally, Section IV recapitulates the main statements of the paper and gives an outlook on the future work.

A. Background

![Fig. 1. Groups of contour detection systems](image)

a) automated de-palletizing: In general, the existing solutions for contour detection in the context of automated de-palletizing can be sorted as shown in Figure 1. Category A (cf. figure 1, left side) includes all solutions appropriating...
a known pattern model of the pallet load. The majority of systems employed in industrial de-palletizing applications so far, do not contain any sensors (cf. figure 1, A0), e.g. preprogrammed gantry robots process bulk de-palletizing tasks in a strictly controlled environment very efficient, but they fail in adverse environments where the pallet’s position is not well defined [8]. Moreover the grippers could be equipped with specific sensors to detect the pallet’s outline, A1), due to iterative approximation of the detection process this leads to high sampling intervals. Further alternatives to the named solutions are simple systems employing light barriers [9] respectively light curtains (cf. figure 1, A2). Photonic Mixing Devices (PMD) are an innovative approach of Time of Flight (TOF) sensors. Today PMD technology is used for classification and detection of single objects [10], [11] providing volume and coordinates, e.g. for packages [12]. In combination with the packaging pattern model this technology leads to an efficient alternative for contour detection (cf. figure 1, A3). On the right part of the schematic (B) shown in figure 1 different ways to detect the outline of loading goods are represented, without having any information concerning the packing position. In these cases the shape, position and orientation of loading goods have to be acquired by using complex sensor systems. The combination of 2D camera and laser scanner to obtain the third dimension [8], [13], [14] is widely spread in the industry (B1). These systems are characterized by high flexibility. Falling prices are promising an increasing market share compared to non-vision-based solutions [15]. Vision systems with additional assisting sensors like structured light [16], [17], multiple laser spots [6] or range sensors [18] (cf. figure 1, B2) are also available on the market. Even though nominal position data of the pallet load is not required, complete knowledge of the object is mandatory (image / CAD model), respectively primitive segmentation methods are used [17]. For a very limited range of different loading objects, light curtains or light grids (B3) could be possible applications.

b) TOF and PMD technology: Common 3D-Sensors often use Time-of-Flight (TOF) measurement principles for environment detection. In this area, Photonic Mixing Device (PMD) sensors have appeared as a cost-efficient solution for a broad variety of applications in automation engineering. These PMD sensors surpass other 3D imaging systems (e.g. laser rangefinders, stereo vision) in several domains as the measurement system is very compact, has no moving mechanical parts and has a high acquisition rate of up to 100 Hz. A PMD sensor measures the distance to an object by emitting modulated infrared light and determining the phase shift between the emitted and reflected light. Thus the relation between the measured phase shift \( \Phi \) and the modulation frequency \( \omega \) results in the object distance \( d \):

\[
d = \frac{c \cdot \Phi}{2 \cdot \omega}
\]

The sensors’ output is a two-dimensional depth map where typical resolutions reach from \( 16 \times 1 \) to \( 200 \times 200 \) depth measurement points. In addition to the distance measurements, the sensor also delivers a grey scale image with the same resolution.

The accuracy of the sensor depth measurement mainly depends on the used modulation frequency and the reflectivity of the observed objects. A higher modulation frequency results in a higher accuracy of the sensor measurements (cf. [19]) as objects with high reflectivity also do. The PMD sensor used in this paper has a resolution of \( 64 \times 50 \) depth pixels and a field of view of \( 30^\circ \) (horizontal) and \( 40^\circ \) (vertical). It has a typical depth measurement repeatability of \( 12 \text{mm} \) for objects with a reflectivity of \( 90\% \) (e.g. white cardboard packages as used in our test setup) [20]. Depth discontinuities within the test setup, e.g. the distance between the packages and the floor, lead to measurement errors (so called “Flying Pixels”, cf. section 2) which are handled as outliers by our algorithm (cf. description of the preprocessing step in chapter II-A).

The measurement principle also leads to an unambiguity range of the PMD sensor that is dependent on the modulation frequency. Figure 3 visualizes the unambiguity range of a PMD camera using a modulation frequency of \( f_{\text{mod}} = 20\text{MHz} \). Objects that are beyond the range of \( 7.5\text{m} \) will be seen at a distance of \( d \mod 7.5\text{m} \). This constraint of the PMD camera does not have an impact in our test setup as all objects are less than \( 7.5\text{m} \) away from the sensor.

\[
\text{Fig. 3. Unambiguity range of a PMD camera}
\]

c) RFID data transfer and data management: RFID-Technology use in logistic systems is eclectic. Distinctive features are, among others, the amount of data, which is stored, and the cruising range of the tags. The amount of storable data spans over a wide range depending on the application: While the actual identification requires only small storage
capacities (some bits), the electronic product code (EPC) requires more storage capacity (64-256 bit). For example, baggage tags in aviation may need a storage capacity up to 1 Kbit. Also, the cruising range significantly differs depending on the application. Tags can be used locally but also the data can be required at several positions along the supply chain. If the operating range is limited to one location, stationary (in-ground) and object-accompanying positioning of RFID tags can be distinguished. Using stationary tags in systems of automated guided vehicles enables not only localization, but also storage of data along the guide way [21]. Manufacturing logistics is a possible field of application for object-accompanying tags. Besides a unique ID of the product, the RFID-tags may also contain controlling information like machining sequence, error logs and time stamps [22]. An example of the additional use of data along the supply chain is product coding for food. In addition to the EPC as an unique ID, the date of expiry, the weight and the prize may also be stored on the tag to support several production and distribution processes. Another example is the decentralized control of material handling systems as described in the vision for the Internet of Things in Logistics [23]. In this paper, a RFID-tag is used to store the storage scheme of a euro pallet load which is described in chapter II-B. To realize the novel contour check an efficient and adequately fast data transmission is mandatory. This is especially necessary to process the considerable amount of data. Therefore, an efficient communication between tag and read/write unit is needed. Because of physical limits concerning the air interface, the optimization of data management seems to be unavoidable. Besides this challenge, missing international standards and a wide range of different hardware make an extra-company-wide application of tags expensive. Every company along the supply chain has to provide different read/write units to work with varying tags.

II. CONCEPT

In the following sections, the concept of automated load detection using RFID-based data storage and PMD sensors is described. At first, the combination of this a-priori information with the PMD depth measurement data is explained in detail (cf. chapter II-A). Afterwards, the data model, reading procedure and data distribution of the load data is described.

A. Automated load detection using PMD-Technology

The novel automated detection of the euro pallet load could be presented by a pipeline – the whole process is visualized in Figure 4. The schematic representation of the automated load detection pipeline can be subdivided into three groups of tasks. The first one is the acquisition of the PMD depth data and preprocessing as well as of the loading state facilitated by a central database to store the RFID tag data. Accordingly, the main part of the pipeline, the model fitting, follows. This step can be again subdivided into two tasks, coarse fitting of the layer associated model $T$ into the PMD point cloud $P$ and fine fitting of the individual models $T_i \in T$. Our approach is currently designed and optimized for cuboid-shaped parcels that can be of different dimensions and proportions arranged on multiple layers on an euro pallet. Therefore, the model $T$ consists of $n$ tuples $T_i$ describing one cuboid (e.g. one parcel).

Previously to the fitting algorithm a preprocessing step is essential in order to exclude erroneous pixels caused by the acquisition process from further model fitting pipeline. The point here is to distinguish between two characteristics of artifacts, which are responsible for invalid depth tuples. First, commonly under- or overexposed sensor pixels are caused by inappropriate integration times, but can also have their origin in surfaces of high reflectance e.g. parcel tape. Second, outliers are not detected automatically by the PMD camera, so that the outlier detection has to be done afterwards.

After the preprocessing of PMD depth data the initialization of the model is done because of performance, but also of robustness considerations. Therefore a suitable initial point for the model is needed. As a good initial point for the model the arithmetic average of all significant points has proven successful. Now in the coarse model fitting step the position of the whole model is supposed to be refined. This is done by using an iterative approach based on key components of the Iterative Closest Points (ICP) concept [24]. The basic idea of the ICP algorithm is to register two point clouds in a common coordinate system by an iterative approach. In each iteration step, the algorithm selects the closest points as correspondences and calculates the transformation (translation and rotation) for minimizing the deviation between the two point clouds.

The detection of the euro pallet load utilizes only the point cloud $P$ respectively $Z$ (the PMD depth data) in terms of Cartesian coordinates and a 3D palletizing model $T$ but no second (additional) point cloud. In view of the efficiency of computing time this is a contributing factor and an advantage over the ICP algorithm because the time-consuming calculation of the correspondence between a point $X_{ij} \in Z$ and

![Fig. 4. Schematic representation of the automated load detection pipeline](image)

![Fig. 5. Visualization of the three different stages of automated load detection: (a) a given pallet load, (b) acquired point cloud dataset, using a PMD camera and (c) detection of the pallet load – the model is drawn in black, detection in green.](image)
the model $T$ is not required. In each iteration step of the coarse fitting approach several transformations $\theta_i \in \Theta$ are computed (translations regarding the $x$ and $y$ axis at $\pm \tau_i$ and rotations regarding the $z$ axis at $\pm \rho_i$) and afterwards the best fitting model is selected. The variable $\tau$ defines the upper bound for the sum of all translations and $\rho$ the upper bound for all rotations. Both $\tau$ and $\rho$ are multiplied after each fitting iteration by the corresponding diminuation factors $\tau_f$ and $\rho_f$. Additionally, the number of iterations can be limited by a constant $\mu_{\text{max}}$. Because misplacements of packages are also very likely to be locally present, we need to refine each detected cuboid shaped parcel $t_i \in T$ individually. Induced by the 2.5D depth image and performance considerations the refinement procedure is performed always only for the top-most layer of parcels called R:

$$R = \left\{ r \mid (r = t_i \in T) \Rightarrow \left( i = 1 \land f_i = 1 \land t_i^z = \max \left\{ t_j^z \mid t_j \in T \Rightarrow (j = 1) \land (f_j = 1) \right\} \right) \right\}$$

(2)

with

$$t_i^z = \max \left\{ t_j^z \mid t_j \in T \Rightarrow (j = 1) \land (f_j = 1) \right\}.$$  

(3)

In contrast to the coarse fitting step transformations have to be computed for each $t_i \in R$ and all supported kinds of transformations $j$. The parameters $\lambda$ and $\phi_0$ define the expected number of point per unit area and factor for the permissible deviation respectively. All transformations have to fulfill two requirements in order to be appended to the set of possible transformations. At first the model must stay interior the bounds of the point cloud (ensured by the “inrange” function). Second the transformation of a singular parcel must avoid any kind of intersection with other detected parcels (ensured by the “intersects” function). Considering these both assumptions the transformation can be defined for one fine granularity iteration. Finally after the coarse and fine granularity fitting procedures the results have to be verified in order to ensure robustness and prevent passing of maybe uncorrectable load information to the following process chain (cf. Figure 5c).

**B. Storing palletizing data for automated load detection**

Basic requirement of using a known pattern model for detection is the availability of packing data at the local handling device (de-palletizer). For that reason the data from building the unit load (palletizing) has to be linked to the pallet. The most pragmatically way is to store the packing positions in a database and mark the pallet with a number. For de-palletizing the number has to be imported to the control system of the handling device (e.g. robot). Normally, an 1D barcode is used to automate this process. In the following sections three alternatives are presented to fulfill the provision of needed data, Figure 6 gives a brief overview.

1) **Data on Net / ID on Tag:** Enhancing the ID-process of the pallet radio frequent identification technique (RFID) could be used. Low frequent tags working in a wafe band between 125-135 kHz can be attached on or in the pallet foot. Beside, indivisibility is no longer necessary because of using radio technology an additional advantage is the flexibility (changing of data). Basic RFID-tags, analog to barcodes, just store an unambiguous identification number, which will be read out at an ID-point (handling device). As mentioned in Section II-B the processing data (loading position) is stored in a database. Using the tag’s ID, the corresponding set of data could be identified. Main drawback is the dependence on permanent access to the network, which is getting worse if the application should work globally (beyond companies borders) and internet access is mandatory. Another disadvantage is the provision of every company along the supply chain with different read/write units to work with varying tags. To solve this problem [25] developed the so-called Unified Data Capture / Communication Protocol (UDC/CP), an auto-ID abstraction layer model [26]. This middleware enables the connection of varying types of auto-ID components to one control unit. By means of different methods, access to single tags, processing of events and states of the hardware is facilitated. Access to block-oriented data carriers (like tags) can be granted by so called mappings. For this purpose XML-based keywords containing the name, type and address of the attribute are assigned. Beside, encoding and encrypting are made possible by this approach.

2) **Data on Tag:** If the complete set of data (pattern) should be stored on tags, the system is independent from any network but some problems are still to solve. Active 868 MHz tags provide an adequate writable data storage of several MBytes and can be attached on or in the pallet’s foot. Especially plastic pallets with integrated active transponder are available on the market. RFID tags are organized in blocks with a small amount of memory. Reading a block is an indivisible operation and it always needs the same access time independent from the amount of needed data. In order to minimize the number of required blocks the data should be coded and mapped to the blocks by well known techniques. This could be done by Huffman coding [27] and an offline approach to solve the knapsack problem [28]. Because of breaking up central storage strategy the information is distributed in the logistic network and raises the robustness against central control unit breakdowns. In addition to the need of minimizing access times storing larger amount of data, physically limited by the air interface, information should be encrypted to prevent unauthorized manipulation.

3) **Binary data on Tag / Schema on Net:** The binary data on tag / schema on net concept is a combination of Data
on Net / ID on Tag and Data-on-Tag concepts. Through a compression of the data, before transferring it to the tag, a binary format is generated. A specific schema (key) to transfer the data into binary format and back is provided via the global network. It can also be cached; once it is applied, a connection to the net is no longer necessary. This method not only decreases the amount of data which has to be exchanged but also the necessary storage space. With regard to the system performance the compression of the tag data is designed as semantic coding, which means that, from the process' point of view, compression depends on the type of data (e.g., time stamp) or process step (e.g., de-palletizing). Hence, every single semantic data pack is compressed individually to reduce the critical access time. Furthermore, the binary data on tag/schema on net concept guarantees a minimum amount of security issues because having the key is a must to be able to decode the data. Concerning sensitive data like loading list of pallets or routing information, the use of an encrypting method is recommendable [29]. At least several aspects have to be quantified in the near future (e.g. degree of compression), but summarizing the advantages this concept should be pursued for further investigations.

4) Data storage management: In order to assure efficient access times for reading of or writing on RFID-tags, it is necessary to know the exact position and length of the data set as well as minimizing the needed block space. Using paging and segmentation concepts, well known in memory management of Operating Systems, could be a promising approach. The main idea is to divide the tag’s blocks into segments with variable length. An index unambiguously addressing a segment and the dedicated set of data is stored in a Table of Content. An additional table (Mapping Table) holds the allocation between index and attribute name. Following the mapping table’s index, the table of content refers to the location of the data set. Figure 7 is showing this procedure.

Main drawback concerning this concept (table of content, mapping table) is the additional need of storage capacity which is no longer utilizable for intrinsic data. In further studies the trade-off between additional storage capacity and access time has to be quantified.

5) Palletizing data model: By storing only relevant data on the RFID-tag, the loading scheme is stored in a simple format. Each parcel of the pallet load scheme is represented as a cuboid and stored as a model data tuple \( t_i \) in the following format:

\[
\begin{align*}
    t_i = (a_i^x, a_i^y, b_i^x, b_i^y, c_i^x, c_i^y, c_i^z, h_i).
\end{align*}
\]

n data tuples \( t_i \) form the model of the whole pallet load, namely \( T \). The coordinates \( a_i^x, a_i^y, b_i^x, b_i^y, c_i^x, c_i^y, c_i^z \) describe the \( x- \) and \( y \)-coordinates of three upper corner points (position vector in the x-y space) of the cuboid. Furthermore, \( h_i \) contains the \( z \)-coordinate of the upper plane of the cuboid which is the same for all vectors \( \vec{a}, \vec{b}, \vec{c} \). The scalar \( h_i > 0 \) defines the height of the respective cuboid. All metrics are stored in millimeters.

III. Evaluation

The evaluation of the automated load detection could be divided into two aspects which are of main interest, one the one hand the runtime of the algorithm (cf. Figure 8), on the other hand the accuracy of detection (cf. Figure 9). Before presenting the analysis, the experimental setup is described. The setup consists of a PMD camera (PMD-Tech, 03D201AB), which is mounted at 3.1 meters above the ground and above the center of the euro pallet and a number of parcels with a dimension of 30cm \( \times \) 40cm \( \times \) 26cm. The PC system used in this context comprised the following components: Intel Q6700 3GHz (Processor), 2GB DDR2 PC1066 (Main Memory). The first aspect, the algorithm runtime is dependent on the number of parcel layers and the number of parcels on each (visible) layer. Figure 8 visualizes this dependency. But beside this general conclusion the curves show a linear ascent which is identical for all layers. Additionally it should be mentioned that coarse fitting is in principle independent of the number of parcels. For an evaluation of the accuracy a single parcel was displaced by a defined distance and direction. Three different amounts were used in each trial: 5, 10 and 15cm. The objects have been shifted both along the \( x \) axis and \( y \) axis. Figure 9 shows within a box-and-whisker diagram the deviations between target position as actual position. Thereby, the absolute value of the mean range for all translations is below 2cm. In case of a shift along the \( y \) axis the detection seems to be a little worse than shift along the \( x \) axis (in the current state of the development). For a translation of 5cm the median is around 0.8cm, at 10cm around 0.7cm and at 15cm around 0.4cm. In consideration of the fact that the single upper/lower outliers are below 4cm, the automated load detection using PMD-Technology is suitable as an alternative approach for determining euro pallet loads.

To quantify the benefit of the presented concepts (data transmission, storage, and compression), fundamental evaluations, especially concerning the trade-off between storage capacity and additional amount of data for a table of content as well as the degree of compression using semantic coding are currently taking place at the IML.

IV. Conclusion

Concerning the combination of PMD-camera generated point clouds and known packing pattern models, first evaluations provide a promising approach in terms of accuracy of
position detection and shortened runtime. Hence this could be a competitive alternative to existing solutions. Identifying or developing methods for optimizing the detection of significant smaller packages as well as online detection of dynamic (moving) unit loads are challenging tasks for prospective research. 

Even if the needed data transfer for detection will theoretically operate without the application of RFID tags, the main advantages and the trend in identification of logistic objects during the last years towards auto-ID using radio frequent technologies, confirm us to use this technique. Beside the quasi-encrypting, the Data on Tag / Schema on Net departure, including semantic coding seems to hold a potential compared to common compression methods, because as inherent to the functional principle the runtime should be significant lower. In order to verify and quantify this enhancements, fundamental tests have to be performed.

REFERENCES


Fig. 8. Visualization of the runtime with subject to the number of parcels and layers

Fig. 9. Visualization of the accuracy of detection by different deviations (5, 10 and 15 cm): (a) objects have been shifted along the x axis and (a) objects have been shifted along the y axis.

(a) shift x axis
(b) shift y axis