An Approach for 3D Object Recognition of Universal Goods

Bernd Scholz-Reiter, Hendrik Thamer, Claudio Uriarte

***Abstract*—**Today, unloading processes of standard container units are mainly executed manually. An automatic unloading system could automate this labor and time intensive process step. The crucial challenge in developing such a system is the object recognition of goods with undefined shape and size. The development and the successful market launch of the Paketroboter© has shown the feasibility of the correct detection of cubic goods inside a standard container unit. Nevertheless, there exists no established system that is able to unload universal packaged goods. The requirements for a suitable object recognition system for goods with undefined shapes are very high. In the case of an high error rate, the automatic unloading process has to be aborted or a manually intervention is necessary. This paper presents a concept that aims to develop an object recognition system for classification and pose detection of universal packaged goods inside a standard container unit. In order to classify different packaged goods inside a less lighted container unit significant sensor data is required. On the basis of the sensor data, the object recognition system detects all goods and calculates suitable 3D gripping points for the manipulator unit. Therefore, range images from Time-of-Flight cameras and simulated images are used for image analysis.

***Keywords*—**Image Processing, Machine Vision, Object Recognition, Range Image Simulation

I. INTRODUCTION

Due to increasing global trade flows, a continuous growth of transported packaged goods is observed [1]. Usually, the transport of bulk mass goods is realized by use of standard packaging units like boxes, cartons and sacks. They are not palletized and are transported in standard transport units. Typical transport units are containers for sea transport, unit load devices for air transport or swap body platforms for national transport.

Today, unloading processes of not-palletized goods are mainly executed manually [2]. Automatic unloading of transport units and the following transfer of the goods into further processing logistic systems is still a technical challenge. Solving this problem could improve global supply chains and reduce transport costs.

In Europe, about 64% of the imported goods are suitable for automatic unloading due to their size, shape and weight [2]. Hence, the economic relevance of automatic unloading is very high. The main shapes of packaged goods can be summarized to cubical, cylindrical and sack-like [2]. Concerning object recognition for cubical goods, the development and successful market launch of the Paketroboter© [3], [4], has shown the feasibility of automatic unloading of cubic goods. Furthermore, other solutions regarding object recognition of cubic goods are developed like [5], [6]. However, actually there exists no established system that is able to detect and classify universal packaged goods. The big challenge is the object recognition for goods with undefined shapes. In the case of a high error rate within the object recognition system, the automatic unloading process has to be aborted or a manual intervention is necessary. Therefore, the object recognition method has to be very robust and reliable.

Furthermore, an automatic unloading system for packaged goods needs a suitable sensor system for acquiring images of the unloading scene. In order to obtain as much information on shapes of universal goods in packaging scenarios as possible, depth information about the scenario is necessary. Additionally, the sensor system needs to be insensitive to bad lightning conditions and shadowing inside the container. These requirements are satisfied by Time-of-Flight (TOF) scanners that are able to obtain range images. By using more than one TOF cameras, a fusion of multiple range images is necessary in order to increase the detection performance of the sensor system.

Afterwards, these range images are analyzed in order to detect significant features. By reference to these features the related object class of the packaged good is estimated. The detected features are compared with features of previous defined object classes and assigned to a related object class. Every object class has special characteristics and features like possible gripping points. The automatic unloading process refers to the bin-picking problem and is not completely solved at the moment [7].

The following section describes the state of the art concerning 3D image acquisition and object recognition methods. The third section presents the different image acquisition methods which are used for mapping simple packaging testing scenarios. For object recognition, the images are acquired by TOF scanners. Additionally, a simulation platform will be developed in order to simulate range images of packaging scenarios. The fourth section presents the concept for classification of the object type and pose estimation of the packaged goods. The paper ends with a short summary and an outlook for further research activities.

II. STATE OF THE ART

Object recognition for universal packaged goods inside a container is only possible with spatial information. Especially, reliable data about the depth is important. Therefore, the first subsection presents 3D image acquisition techniques. The second subsection gives a short overview about the field of object recognition methods.

A. 3D Image Acquisition

All electronic and electromechanical components of a system constitute the hardware. For the data acquisition in 3D image recognition, cameras and scanners are normally used. Depending on the working principle, the hardware can be grouped in intensity and distance sensors.

Photo and video cameras belong are the best known types of the first group. Among these, the most widespread sensor type for the object recognition is based on the Charge Coupled Device (CCD) technology [8]. The intensity of the light reflected by an object is measured by a matrix of photodiodes, which then deliver the gray value of each pixel as a 2D matrix. These photodiodes can only measure one wave length, which is normally the color green, with a wave length around 500nm. The gathered intensity is then displayed as a black and white image. In order to acquire color images, three CCD sensors with 3 different filters are used in order to measure 3 different wave lengths, normally with the colors red, green and blue (RGB). Because of the architecture of these sensors, the maximum image refresh rate lies around 25-30 Hz. [8]. The most widely used sensor sizes are 800x600 and 1024x768 pixels. The resolution of the camera cannot be blanket defined, but can be easily calculated when the sensor size, the distance of the focused object and the aperture angle are known. For example, a camera with a sensor size of 800x600 equipped with a lens with a 40° aperture angle and a distance of 5m to the object of interest will reach a lateral resolution of around 5mm pro pixel.

In the second group – the distance sensors- the distance between the sensor and an object is measured through different principles. The LIDAR (Light Detection And Ranging) scanners, commonly referred as laser scanner, belong to the most well known sensors of this type. A light source inside the scanner sends a light ray to the object to be measured. The light travels to the object and is partially reflected back to the sensor, which measures it. The acquired data is then usually delivered as a matrix with the XYZ coordinates of each point and can be easily displayed as a scatter plot. Depending on the working principle of the sensor, these scanners can be divided into ToF and phase scanners. The ToF scanners measure the time that ray of light takes to travel to the object and reflect back to the sensor. This ray, which is produced by a laser or infrared light source, triggers a time counter in the integrated electronic. When the reflection comes back, the clock is stopped. Since the speed light is known and does not depends on the atmospheric pressure, humidity or ambient light, the distances to the objects can be easily calculated. Accuracies in mm demand very complex electronic, since the light takes just 6,6 picoseconds to travel a distance of 1mm. The one dimensional light ray can measure the distance of one point (1D-sensor). To measure the second dimension, a plane has to be created. For this the light ray is directed with rotating prisms or mirrors in order to scan a plane around the sensor. To scan the whole work space, the scanner is normally rotated with a pan unit, transforming the working plane to a working cone. The LMS-200 from Sick is a widely spread ToF scanner, with a rotating mirror. It has an angle of 180° and a angular resolution of 0,25° and a measuring range from 0.1 to 30 m. The lateral resolution of this scanner is about 22 mm when measuring objects at 5m.

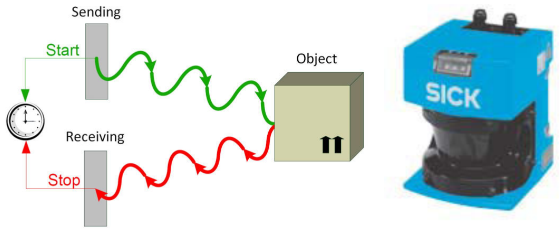


Fig. 1 LMS-200 ToF scanner from Sick

An alternative to these scanners are the phase scanners. They also measure the light that is reflected by an object. Contrary to the ToF scanner, they don't measure the time needed for the light to travel to and back from the object, but the phase displacement of the reflected light, which can be correlated to the distance of the object. As the ToF scanners, they have a laser source, which is directed with a rotating mirror or prism. Because of the working principle and electronics, they can measure higher distances, make more measurements per second and have in addition a better angular resolution. A good example of these scanners is the Leica HDS6100. Since phase scanner are much more expensive than ToF scanners, the later are preferred for automation tasks.

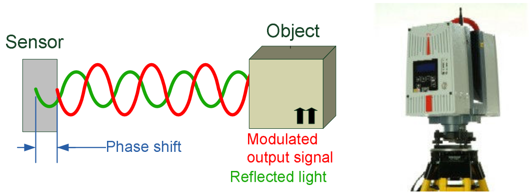


Fig. 2: HDS6100 phase scanner from Leica

An alternative aproach can be achieved though stereoscopy. To achieve 3D information, two cameras are mounted parallel to each other separated by just a couple of centimeters. Through the combination of the so-called half images, this is the signals coming from two cameras, a 3D image can be obtained. For the data fusion, points of interrest in both images are identified and their respective angle to the camera axis is measured. Based on this information, both images are combined into a new image with the depth information. An advantage of this method, is that regular CCD cameras can be used. This way not only static images can be obtained, but also as video signal with depth information. The dissadvantage though, is that the image merging is not performed in the camera electronics but through external preprocessing. Eventhough it can be done in realtime [9] it is still time consuming and extra hardware is required. The complex calibration needed for proper distance measuring constitutes another disadvantage. A widespread stereoscopic camera is the Bumblebee3 from Point Grey.

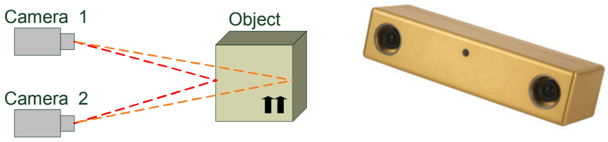


Fig. 3: Bumblebee3 Stereoscopic Camera from Point Grey

Scanners based on a rotating mirror technology have the disadvantage, that the whole scene plane by plane gets scanned. Depending of the mechanical configuration, such a process can take upto 2 seconds. Aditionally, they only deliver the coordinates in space of the points belonging to the surface of the object. Intensity information of the object, this is information of colour, and image gradient are not measured. One of the latest developments in 3D sensors, are the Photonic Mixing Devices or PMD Camera. These cameras offer a solution to the disadvantages of the classic laser scanners and stereoscopic cameras. They deliver a combination of 2D and 3D information of the scene as a video signal. At the time, these cameras have a resolution of 204x204 pixels, which is comparable to the resolution of a ToF scanner and enough for object recognition. Their working pronciple is based on the complementary Metal Oxide Semiconductor (CMOS) technology. A light source in the camera ilumitates the objects with modulated light. The PMD sensor measures the phase displacement of the phase of the light that is reflected by the object. As in the phase scanners, the distance to the object can be then computed. Since the whole scene is measured at once, the sensor can deliver a measurement every 1/25 seconds. 3D video is possible without any external preprocessing. One big disadvantage of the PMD technologythough, is the rather small measurement range of 7,5 meters. For object recognition in the logistic this doesn't represent a problem, since normally the objects are near the camera. In the standard configuration, the camera is delivered with a lens with a 40° angle of view, which can be changed if needed. The lateral resolution of this camera is about 17 mm when measuring objects at 5m.

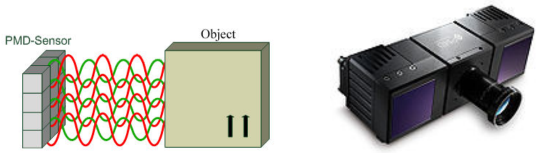


Fig. 4: CamCube 2.0 from PMDTec

B. *Object Recognition*

Object recognition methods usually classify objects to special related object classes. Therefore, detected characteristics of special features like surfaces, patches and edges are extracted from sensor data and evaluated. Object recognition issues can be divided into two types [11].

The first type is the classification of a single object to a related object class. The second type contains the classification of multiple goods. Here, the pose of several objects are detected and then a classification to their related object classes (scene analysis) is realized. The image is segmented into different regions and afterwards, the regions are classified independently from each other. Figure 5 shows the general steps of an algorithm for detection and classification of objects in a scenario.

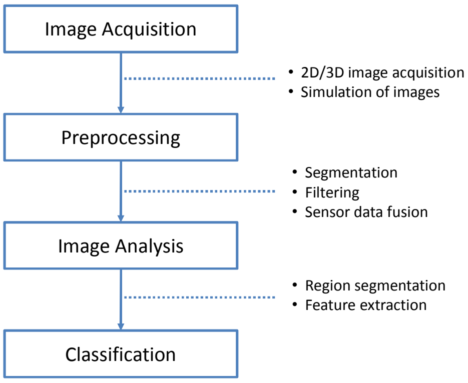


Fig. 5 Usual working flow of object recognition systems

In the first step, a suitable 3D image acquisition technology is used in order to acquire range images of the scene. For reducing noise and segmenting relevant parts in the range image, a preprocessing step is performed. In the case of multiple sensor data, a fusion step is included. Afterwards, image regions which possibly contain single objects are segmented and relevant features are extracted and used for the following classification step.

The methods for classification are usually based on the analysis of features of the objects [12]. There exist many possibilities to classify the detected objects. Possible approaches are the classification by comparing to a complete model of the object or by analyzing single features [13]. Figure 6 gives an overview of different object recognition methods. Pattern based methods analyze single features of objects. They include statistical methods, structural methods, artificial neural networks and logical methods. Object based methods compare whole objects and contain template matching operations, estimation techniques and algebraic methods [14].

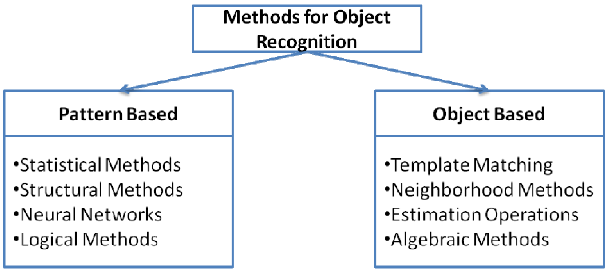


Fig. 6 Methods for Object Recognition [14]

Pattern based methods use different properties and relationships of object features. These methods perform the detection only by considering single features without regarding the entire object. Artificial neural networks are very suitable for recognition issues without systematic knowledge. Initially, the network requires training to be able to solve recognition tasks. Additionally, the network has the ability to change the input-output behavior by adapting the intern threshold weights. Figure 7 illustrates an artificial neural network. Artificial neural networks are not only able for object recognition in images, they can be also used for camera calibration in a 3D vision system [15].

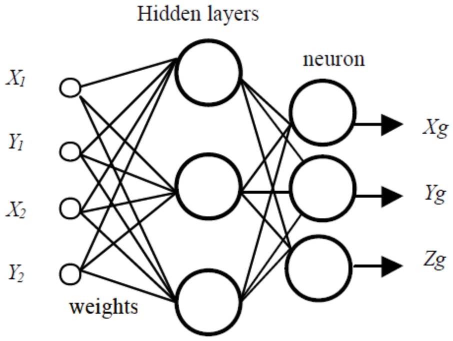


Fig. 7 Artificial Neural Network [15]

By contrast, object based methods consider the whole object in the sense of a particular combination of their characteristic features. A very common method for object recognition from 3D images is template matching. They consider each object prototype as a vector of characteristic features. The recognition process is realized by assigning the investigated object to the specific object class that fits best to the measured object parameters. The assignment can be calculated by various ways. Exemplary methods are computing the minimum distance and correlation [14]. The minimum distance is the Euclidean distance between the feature vector of the investigated object and the feature vector of the regarded object class. The object is assigned to the object class with the highest minimal distance. The correlation of two images f and g is computed by (1). A disadvantage of correlation techniques is the high computation time. By transforming the images into the frequency domain, the computation time can be increased [14].

$$(f \otimes g)(x) = \int f(y)g(x+y)dy \qquad (1)$$

There exist a lot of matching methods which use registration techniques from image data to predefined models like [17], [18], [19]. They belong to the class of model based recognition techniques and can be classified in two categories: feature-based and intensity based methods [20].The main advantage of these techniques is the invariance regarding rotation, translation and scaling of the investigated objects.

III. RANGE IMAGE ACQUISITION

The research of this paper focuses on the object recognition process for universal goods. Therefore, the used sensor data are simulated range images. Additionally, the concept is evaluated by range images that are acquired by the following setup which is used by the ROBOCON project. This project covers the complete unloading process of universal goods from a container unit and image acquisition techniques [21]. The next section describes the image acquisition of range images by using TOF scanners from real packaging scenarios. Afterwards, a concept and the requirements for a simulator platform for range images are presented. Finally, both range image data (the TOF range image and the simulated image) are analyzed by a software system that detects and classifies all objects in the range images.

A. Image Acquisition by TOF cameras

Due to bad lightning conditions inside the container unit, TOF image acquisition techniques are the only technologies which are usable for making 3D ranges images inside the container. For this purpose laser scan cameras are used, for example the LMS 200 from the company SICK (figure 1).
The measurement resolution is 10 mm and the measurement accuracy is about 35 mm. Due to the measurement principle, the camera is suitable for the use in the less lighted container. The camera works line-based. Therefore, the camera tilts to map the whole packaging situation.

Within the research project many packaging scenarios are reconstructed and scanned. The created scenarios include packaging situations with goods from every defined object class (cubic, cylindrical and sacks). Additionally, it is possible to create simple testing scenarios for object recognition. The resulting range images can be used for evaluating the object recognition concept.

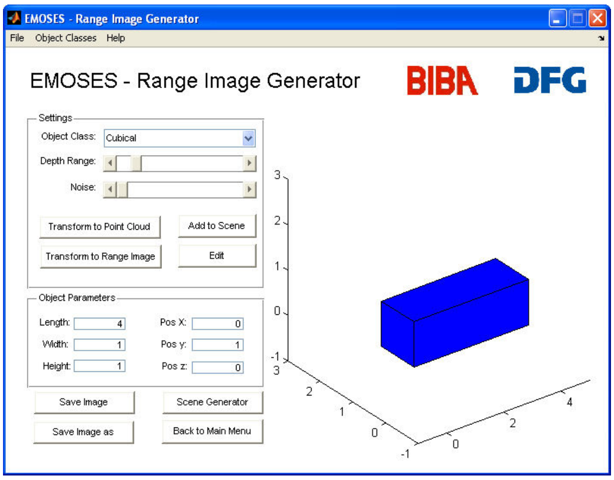
Figure 8a shows a 2D image of an example of a packaging scenario with cubical goods. The corresponding 3D range image is illustrated in figure 8b.

Fig. 8 2D image (a) and 3D image (b) of a packaging scenario [10]

B. *Range Image Simulation*

Additionally to using range images of TOF scanners, a simulation platform for creating range images of packaging scenarios will be implemented. Within the test environment, depth information for the previous defined object classes and complete scenarios should be generated. Through the simulation environment, it is possible to create range images from different viewpoints of the scene. Currently, the work concentrates on the simulation of objects in simple configurations. In the future, realistic packaging scenarios will be considered. The simulation platform is implemented in MATLAB, which provides a wide variety of mathematical and image processing functions.

First of all, parameters like height or width are determined for the predefined object classes. Additionally, simulation functions are implemented in order to simulate depth information as 3D point cloud. Using the simulation functions for creating different test scenarios, some parameters need be selectable. The parameters of the objects should be variable in order to simulate random instances from an object class. Another important aspect is the density of the depth information. A low density of the depth information reduces the computation time, with a high density of the depth information more data for object detection is available and thus the quality of the process increases. In real cases, the sensor information is influenced by noise. Therefore, a possibility to simulate the noise has to be included into the simulation platform. Figure 10 shows the prototype of the main Graphical User Interface of the platform.



Object Class: Cubical

Length: 4
Width: 1
Height: 1
Pos X: 0
Pos y: 1
Pos z: 0

Fig. 9 Graphical User Interface of the simulation platform

Due to the simulation, range images without scattering effects or measurement noise can be generated. Thereby, the object recognition system can be tested under ideal conditions and the theoretical performance can be evaluated. In the case when noise is not simulated, the preprocessing step in the image processing sequence is also not necessary, because the simulation only generates points on the surface of the objects. Another advantage of the simulation is the complete reproducibility of experiments.

Besides generating range images of instances from the object classes, the software should be able to generate packaging scenarios. They are characterized by a packing pattern and a translation or rotation of individual objects within the scene.

IV. SYSTEM CONCEPT FOR OBJECT RECOGNITION

After presenting the generation of the used range images, these section describes the whole system concept. Figure 11 illustrates the architecture of the system. Since the focus of this paper lies on the object classification and pose detection of universal goods the following illustrations concerns these parts of the concept more in detail.

A. *Preprocessing*

As described before, the simulated sensor data does not need a preprocessing step when no noise is simulated and ideal range images are generated. In the case of modeling noise or analyzing range images that are acquired by TOF cameras, preprocessing is necessary. If more range images of the same scene are used, a fusion step for range images within the preprocessing is necessary. Before the sensor data fusion is possible, a registration between the single range images is required. A registration is a transformation that maps the first point set onto the second one [13]. Besl and McKay proposed in [22] a registration method which is based on the iterative closest point (ICP) algorithm. For each point of the first set, a corresponding point from the second set is assigned by computing the nearest Euclidean distance. Subsequent, the rigid transformation is estimated. Therefore, the algorithm determines when the mean distance between the matched points is below a predefined threshold value.

The fusion of the registered range images will be accomplished by applying the approach of Curless and Levoy [23]. Here, an integrated surface model of the range images is constructed by a zero set of a volume density function. A detailed description of defining the density function can be found in [23].

After the fusion step, the position of the container needs to be determined because it cannot be assumed that the position in realistic scenarios is always equal. Therefore, an initial segmentation step is performed to distinguish between container body and container content. The distinction is necessary for a collision detection during the unloading process.

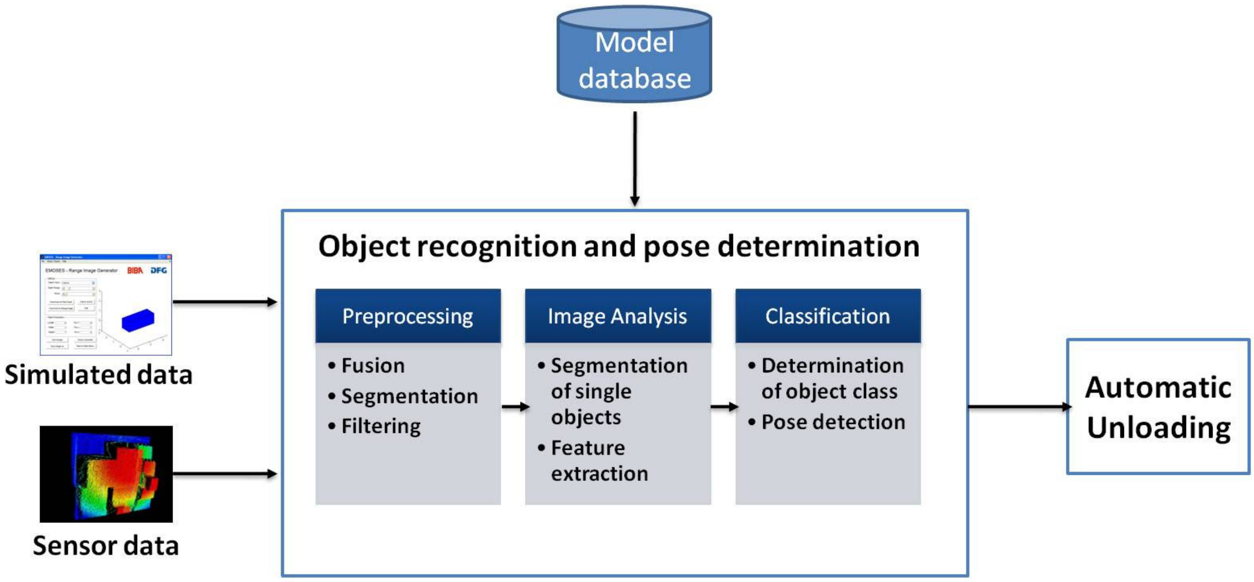


Fig. 10 Concept of the system architecture

For object recognition the distinction is not mandatory. However, due to a reduced image size the computation time of the image analysis step reduces. A possible solution is the determination of a clipping volume, which is an iterative adaption process as it is presented by Kaiser in [24].Another necessary preprocessing step is the filtering of the images. Due to the measurement principle of the TOF camera, the resulting images are influenced by noise that is caused by scattering effects. These effects influence the distance information and have a Gaussian distribution [25].

Hence, a median filter is applied to the range image, because the filter is suitable to this kind of noise. The main advantage of the median filter is the smoothing of the image with preserving of edges and corners for further image analysis steps. Based on the measurement principle of a 3D sensor, the size of the mapped area depends on the measured distance. The greater the measured distance the greater the mapped area. Therefore, an adaptive median filter will be applied which takes the distance into account as it is proposed by Swadzba et al. [26]. In this case, the size of the filter mask is changed according to the distance. Pixels with larger distance values are filtered with smaller filter masks and vice versa. Thereby, characteristic structures at large distances are not blurred, and noise at small distances can be removed [26]. After the preprocessing step, the image data is ready for further image analysis steps.

B. *Image Analysis*

Initially, regions have to be identified which represent single objects. Therefore, segmentation techniques will be used again. The scan line approximation technique is suitable for this kind of task. The technique can detect all kind of edges in range images. Jiang and Bunke distinguish between three different kinds of edges which can appear in a range image [27]. Jump edges are described by discontinuities in depth values, for example when an object is occluded by another object. Crease edges arise when surfaces meet and are characterized by discontinuities in surface normal. The third type are smooth edges which replace discontinuous curvatures. The scan line approximation technique detects these edges by scanning the range image row by row. Thereby, the algorithm approximates the rows and columns of the image with one dimensional curves [28]. The technique assumes that the objects in the image can be modeled by implicit quadratic surfaces and thereby by polygons. For edge detection, a horizontal scan line is moved from top to bottom over the polygon and the intersections of the scan line with the polygon are computed. The main advantage of the scan line approximation technique is the reduction of edge detection problem from 3D to 2D by using line by line scanning.

Afterwards, the information about the edges is used to extract features. Feature extraction is an area of image processing which involves certain algorithms to detect and isolate various desired portions of a digitized image [29]. A feature is characteristic attribute in the image that can describe a specific object. Usual features in object recognition are geometric characteristics like corner points, surfaces, patches and related areas. The first step in further research activities is the definition of features of the predefined object classes.

C. *Classification*

In the last step the detected object is classified according to a related object class. Therefore, the detected features of a segmented region are compared to features of predefined model class. The model is stored in a database which contains information about the features of each object class. Subsequent the comparison, a registration of features of the scanned point cloud and the point cloud of the model will be performed. The objective of the registration step is to define a transformation between the sensor data and the predefined data model. A suitable method for the registration of the features is the ICP algorithm, as it is described in the preprocessing part. Thereby, the registration is made between the object in the range image and the different models. If a registration of detected features to a model is possible, the related object class can be assigned.

Another approach that will be tested during the implementation of the concept is the application of registration techniques that are successfully used in 2D images. They can be distinguished to intensity and feature based. A popular method of intensity based registration technique is computing the correlation between the image of the model and the sensor data. The result is a correlation factor that determines the degree of matching between object and model. Hence, the preprocessing step is essential for applying correlation techniques because the image is influenced by measurement noise which influences the value of the correlation factor.

The following automatic unloading process needs information about the position of the good and about possible gripping point of the detected packaged goods. Therefore, suitable gripping points of every object type will be defined and identified in the range image and committed to the mechanical manipulator unit.

V. CONCLUSION

Due to globalization, the amount of transported packaged goods is still growing [1]. One possibility for realizing efficient logistic processes is the automation of manual processes. Nowadays, processes of unloading goods from container units are mainly executed manually since automatic unloading of universal goods by manipulator units is still a big challenge. Especially the type classification of universal goods is the bottleneck of the process automation. Therefore, 3D image acquisition and object recognition techniques are presented that are suitable to determine the pose and the type of the single packaged goods. Afterwards, the concept is described that includes three different image processing steps. The used range images are acquired by simulation and by TOF cameras from the hardware setup. First, the relevant content of the image should be segmented from irrelevant image regions. Second, the influence of noise by applying filter algorithms is reduced. In the third step, relevant features are extracted which are finally classified to a related object class.

In further research, the presented concept will be realized. This includes the definition of object classes and their corresponding relevant features, implementing the simulation platform for acquiring simulated range images of objects and packaging scenarios. Thereby, it will be possible to realize the feature registration from the sensor data to the model. Afterwards, the concept will be evaluated by using various testing scenarios.

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Bernd Scholz-Reiter (born in 1957) holds a degree in Industrial Engineering from the Technical University Berlin (TUB). Following his PhD (TUB, 1990), Bernd Scholz-Reiter served as post-doctoral fellow in the department for Manufacturing Research at IBM T.J. Watson Research Center in Yorktown Heights, U.S.A. From 1994 to 2000 he held the Chair for Industrial Information Systems at the newly founded Brandenburg Technical University at Cottbus, Germany. In 1998 he founded the Fraunhofer Application Center for Logistic Systems Planning and Information Systems in Cottbus, which he headed until 2000.

Since November 2000 Bernd Scholz-Reiter is full professor and holds the new Chair for Planning and Control of Production Systems at the University of Bremen, Germany. Since 2002 he also serves as Managing Director of the BIBA – Bremer Institut für Produktion und Logistik GmbH (BIBA) at the University of Bremen.

Since July 2007, Bernd Scholz-Reiter is Vice President of the German Research Foundation (DFG).

Hendrik Thamer was born in Bad Soden/Taunus, Germany in 1981. He graduated from the University of Oldenburg in 2009 with a diploma in computer science focusing on embedded systems and micro robotics.

Since 10/2009 he has been working as a research scientist at the University of Bremen with Prof. Scholz-Reiter. His research interests are in the field of 3D object recognition and image processing as well as in developing of image processing systems for quality management in micro production.

Claudio Uriarte works as a research scientist at BIBA – Bremer Institut für Produktion und Logistik at the University of Bremen, Germany. His research interests are in the field of 3D object recognition.