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# Objects Alignment in Point Cloud data for 3D Scanner Coordinate System based on Radon Transform.

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**Abstract**—Our research department is currently developing a 3D Volume and Shape Scanner for large-scale Cargo – Mail in cooperation with air logistics partner. Shipments are sorted in the logistics center of the external partner and then placed in air containers. Also the bin packing problem will be solved in order to achieve the greatest possible efficiency in the use of container space. For these purposes, it is necessary to know not only the size and weight of the shipments, but also the overall shape.

The paper describes a partial part of solved problem a unique algorithm of alignment of detected shipments to the coordinate system of the scanner. The algorithm for aligning objects to the scanner coordinate system is applied directly in 3D point cloud data and is based on the use of the Radon transform.

The paper describes the proposed algorithm and also gives a brief introduction to the whole issue of 3D scanner design for large shipments. Finally, the achieved results are discussed.

**Keywords**—Point Cloud, 3D scanning, Radon transform, Data alignment.

## I. INTRODUCTION

The paper is devoted to the description of the algorithm of shipment alignment in the 3D scanner coordinate system. The scanner is developed for the needs of a partner in the field of air logistics. Currently, the sorting of shipments in the logistics center is done manually by the staff. Manual handling causes unwanted delays. Operators need to take extra time to measure dimensions, scan barcode etc. As shipments come in different shapes, this leads to complications and delays. Non-automated processing increases costs and processing time.

These reasons gave rise to the application or development of a 3D scanner of shipment shapes. A fully automatic solution is required. The scanner must acquire all relevant data, including weight, in a single pass. Data will be sent to the parent system for further processing.

The developed scanner is designed as a one-pass device measuring the surface and basic dimensions of shipments even for awkwardly-shaped packages or packages with irregular shapes up to a pass-through dimension of 2 x 2 m.

During the initial research it was found that there is currently no solution available on the market that would meet the specified parameters. The main limitation is the size of the shipments while maintaining the necessary accuracy. The available solutions, such as Quantum Frame from B&W solutions GmbH [1], do not usually meet the dimensions of the maximum shipments to be processed although this would

otherwise be an appropriate solution. Similarly, solutions based on the frequently applied KEYENCE sensors of the LJ-X8x00 series are limited to a maximum distance of 1400 mm [2]. A solution based on Lidar, e.g. Omron [3], [4], is promising. However, the disadvantage is the time of the measurement, which leads to blurring for non-stationary objects. The throughput dimension of 2 x 2 m is strictly defined by the already installed Shipping Pallet X-Ray Scanner.

For these reasons in particular, modern Time of Flight (ToF) technology was chosen for the development of the scanner [5], [6]. Time-of-Flight is a very efficient technology that measures distances to obtain depth data. For this purpose, a light source integrated in the camera emits light pulses that hit the object. The object reflects the light pulses back to the camera. Using the time required for this, the distance and thus the depth value can be determined for each individual pixel. As a result, the 3D values for the inspected object are output as a spatial image in the form of a range map or point cloud. [7]. Compared to ordinary 2D cameras, the ToF sensor has an optical system with an exceptional ability to handle height differences, not only in 3D inspections, but also in intensity inspections.

## II. DESCRIPTION OF THE PROPOSED SYSTEM

A pair of ToF sensors is used to sense the surface and shape of the shipments “Fig. 1”. The sensors sense segmentally at a limited angle. Individual 2D slices in the X-Z plane are obtained from these sensors. Y-axis displacement is provided by a roller track with an incremental displacement sensor.

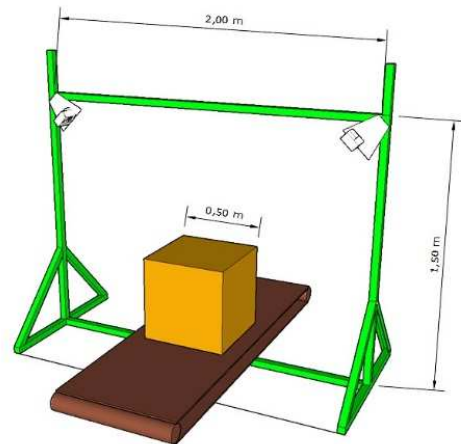


Fig. 1. Configuration of the laboratory model workplace

The data is then fused into a coherent 3D parcel in the form of a point cloud [8], [9], [10]. From the data thus obtained, it is then necessary to extract the shipment itself and determine its dimensions.

The determined parameters are then provided to the parent system for further processing - sorting the packages into the Cargo storage space. A significant problem is posed by the variety of container shapes according to the different types of aircraft storage compartments "Fig. 2".

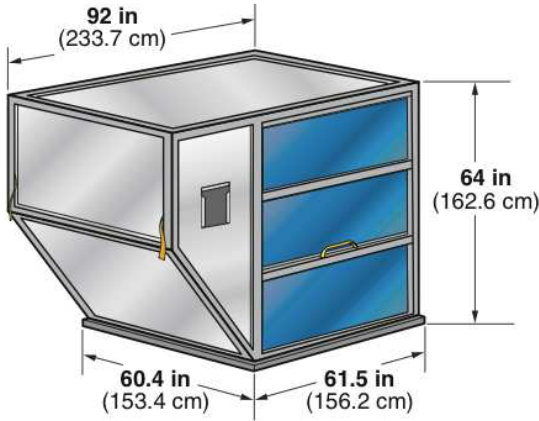


Fig. 2. Examples of Unit Load Devices, type LD-1 Boeing [11]

Optimally loaded containers result in less chance of shipping damage due to items being crushed or damaged during aircraft acceleration and lead, of course, to a more economical use of expensive air transport

A number of partial problems are solved in the developed system, mainly:

- Fusion of data from individual ToF sensors.
- Slip of objects on the roller track - leads to inaccuracies in length determination.
- Compensation for bias in length determination. Used ToF sensors exhibit significant non-linearity.
- Alignment of objects relative to the scanner coordinate system. Independently on shipment rotation on conveyor.
- Separation of measured objects from the background (shipments arrive in completely unpredictable shapes).
- Suppression of noise and false detections.
- Reduction and filtering of point cloud vertexes number.
- and many others...

The entire implemented device is developed for the client as a Vision tunnel equipped by ToF and vision sensors "Fig. 3". The scanner should be designed as a one-pass scanner that provides us with all relevant data. The system will provide us with shipment dimensions with acceptable accuracy. The most important of the supplier's parameters is dimensions' accuracy better than 10 mm.

Since the used ToF sensors working at the NIR range (940 nm), they are more resistant to daylight and artificial light sources. Sensors operation speed is 6 MS/ps, so scanning speed is not limiting conveyor speed.

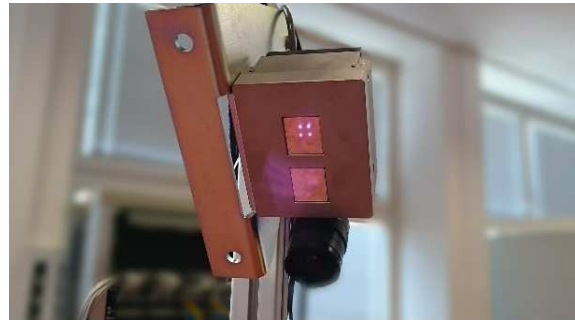


Fig. 3. Used NIR ToF sensor working at wavelength 940 nm equipped with a RGB camera.

In addition to Depth map as a Point of Clouds, we also get the visual information. The 3D scanner Can be equipped with barcode readers and Automatic weight measurement.

The following part of the article is devoted to an original solution for aligning detected parcels to the scanner's coordinate system according to the longest edge. The input data are already fused data from the left and right ToF sensors and individual measurements in the Z coordinate.

### III. ALGORITHM FOR ALIGNING OBJECTS TO THE SCANNER COORDINATE SYSTEM

During the processing of the 3D data, it was necessary to solve the problem of aligning the objects according to the orthogonal coordinate system of the scanner. Conventional electromechanical procedures cannot be used. Shipments are manually placed on the conveyor belt by the operator or by means of a lifting trolley. Shipments can be placed in any direction. A further complication is the completely unpredictable shape of the consignments "Fig. 4".



Fig. 4. Examples of a complicated shipment shape.

However, the client has set the requirement for orthogonal dimensions so that the X-axis is the axis with the greatest dimensional variability, the Y-axis the smaller, etc. During the design process, the following simplifying parameters were also established:

- Only one shipment goes through the scanner at a time.
- The shipment is always touching (lying) on the transport roller track.

The usual approach in these situations is to use principal component analysis (PCA). Aligning 3D data in a coordinate system using PCA is an effective tool for identifying the principal components of data and subsequently transforming them into a new coordinate system [12], [13].

The first step in using PCA for aligning 3D data is to represent the initial and target sets of points in matrices  $X$  and

$Y$ , where each row represents one point and each column represents one coordinate. Next, the covariance matrices  $C_X$  and  $C_Y$  are calculated for the initial and target points. The covariance matrices contain information about the correlation between individual point coordinates [14].

PCA is then performed on the covariance matrices  $C_X$  and  $C_Y$ , leading to the derivation of matrices  $\Phi_X$  and  $\Phi_Y$ , which contain the eigenvectors corresponding to the largest eigenvalues of the covariance matrices. The transformation matrix  $T$  is then calculated as (1):

$$T = \Phi_Y \Phi_X^T \quad (1)$$

This transformation matrix  $T$  allows for the initial points to be moved to the target coordinate system.

It must be emphasized that the correct use of PCA for 3D data alignment requires careful data preparation and good interpretation of the results. Improper data preprocessing or inadequate control of the results can lead to alignment errors and inaccurate results. In our case, the use of PCA proved to be inappropriate due to significant noise that disproportionately increased the variability in the other axes. Also, the computational speed was not satisfactory.

In order to speed up the alignment process and simplify the implementation in C language in the target platform, an algorithm based on the application of Radon transform [15], [16] was developed. Aligning 3D data in a coordinate system using Radon transform is a sophisticated method often used in various fields such as medical imaging, computer. The Radon transform is a mathematical operation that allows extracting valuable spatial information from volumetric data and provides information about its orientation. Combined with discrete methods, it is possible to find the rotation angle of an object in 3D space based on its 2D projection.

The condition for the correct operation of the proposed algorithm are already fused data from the left and right ToF sensor with minimal error, as well as data from individual scanner gauges "Fig. 5".

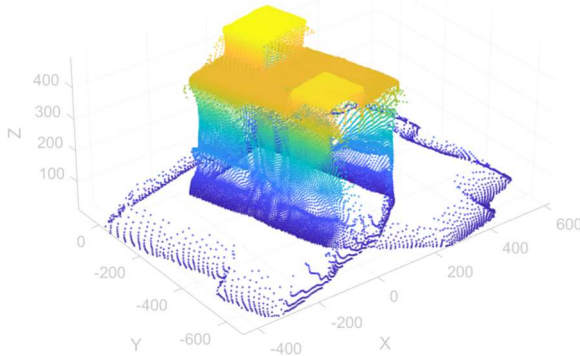


Fig. 5. Correctly fused and prepared data entering the algorithm. (The object is rotated by an unknown angle)

The rotation of the objects in the  $X$ - $Y$  plane is unknown. As well as the shape of the objects and their dimensions.

To begin the process, we start with 3D data represented by the volume  $V(x,y,z)$ . This volume contains information about the intensity or properties of voxels in different spatial coordinates  $(x,y,z)$ . For successful rotation, a projection of all points onto the  $X$ - $Y$  plane is performed. Due to the simplifying condition 2 - "the object is always touching (lying) on the transport roller track", this reduces the problem of point

projection onto the plane. Thus, by superimposing a 3D point cloud onto a 2D projection using perspective projection, the floor plan of the object is extracted "Fig. 6". The resulting binarized floor plan with zero values in the  $Z$ -axis can be subjected to Radon transform "Fig. 7".

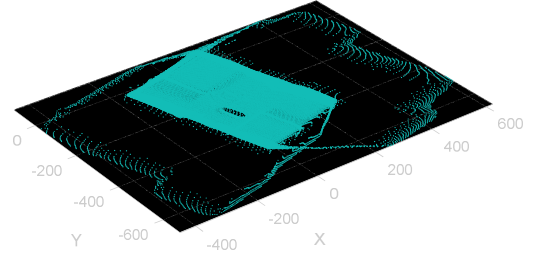


Fig. 6. The floor plan of the object.

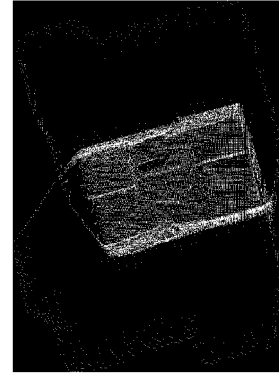


Fig. 7. Binarized floor plan with zero values in the  $Z$ -axis.

The discrete Radon transform  $R(\rho, \theta)$  of the prepared floor plan is computed by summing the pixel intensities along the in-plane lines parameterized by  $\rho$  and  $\theta$ . In discrete form, it can be expressed as (2):

$$R(\rho, \theta) = \sum_{x,y} I(x,y) \delta(x \cos(\theta) + y \sin(\theta) - \rho) \quad (2)$$

where  $I(x,y)$  is the value of the image at point  $(x,y)$ ,  $\theta$  is the angle of rotation and  $\rho$  is the distance from the center of the image along the line at angle  $\theta$ ,  $\rho$  is the distance from the center of the image along a line at an angle  $\theta$ , and  $\delta$  is the Dirac delta function [17].

The result is a Radon accumulator with clearly distinct maxima "Fig. 8".

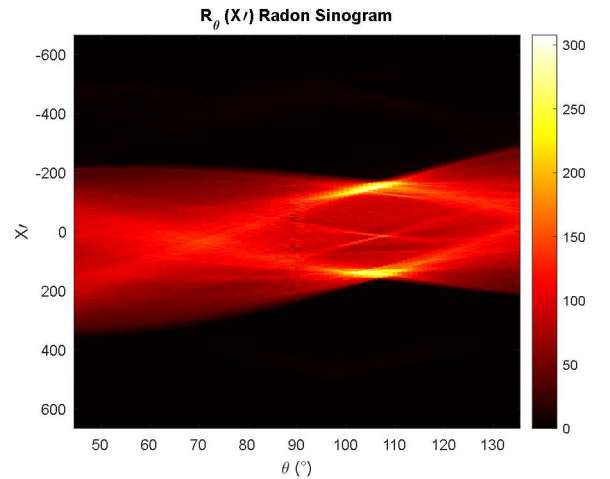


Fig. 8. Radon accumulator with clearly distinct Angle maxima at 16 deg (106 – 90 deg).

The extreme of the function is then evaluated (3).

$$(\rho_{max}, \theta_{max}) = \arg \max_{\rho, \theta} R(\rho, \theta) \quad (3)$$

For each angle  $\theta$ , the value of  $\rho$  corresponding to the maximum value in the transformed image  $R(\rho, \theta)$  is sought. This maximum value represents the rotation angle of the object. A pleasant advantage of the proposed procedure is speed, since the tedious computation of the inverse radon transform is eliminated. The obtained rotation angle can be used to compensate for the rotation of voxels in the point cloud [18].

The general rotation of an object, or the whole point cloud in space, can be written in the vector form (4), where  $R$  is kernel of geometric rotation about the axis. [19].

$$x' = Rx \quad (4)$$

Matrix  $R$  is an orthogonal matrix (5).

$$R = R_z(\alpha)R_y(\beta)R_x(\gamma) \quad (5)$$

It is important to emphasize that for our purposes it is not necessary to distinguish the distance of the edges of the objects from the center of the sensing system. Only the evaluation of the compensation angle is important.

The transformation is performed only in the yaw rotation. Thus, the angles  $\beta$  and  $\gamma$  are zero, the  $R_y$  and  $R_x$  matrices are unitary (6).

$$x' = \begin{bmatrix} \cos \alpha & -\sin \alpha & 0 \\ \sin \alpha & \cos \alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} x \quad (6)$$

The result is the alignment of the 3D shipment objects in accordance with the scanner's coordinate system. This step is very important for further processing and evaluation of the dimensions of the shipments "Fig. 9".

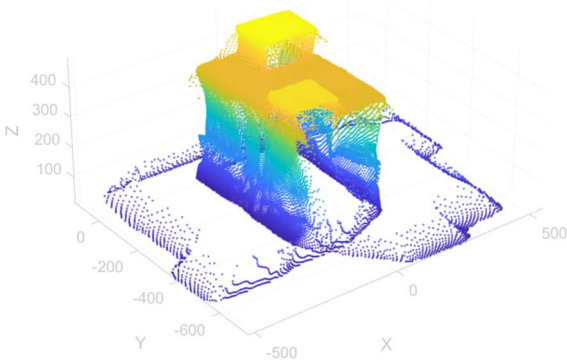


Fig. 9. Result – The object aligned according to the scanner coordinate system.

The "Fig. 10" shows an example of rotation compensation for a more complex circulation with more phantom flare.

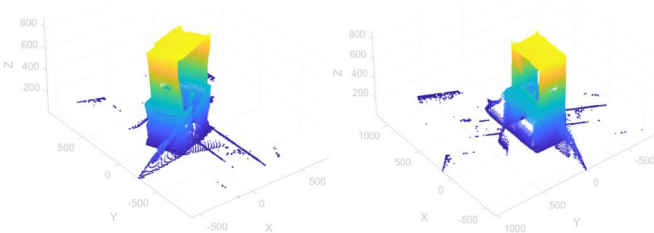


Fig. 10. xample of rotation compensation for a more complex circulation with more phantom flare.

## IV. RESULTS

The proposed procedure is currently being intensively tested in operation. The object rotation compensation procedure appears to be sufficiently robust and error-free. The procedure is also not adversely affected by manual placement of packages on the conveyor belt. During the testing phase, some unforeseen conditions had to be treated. For example, it turned out that in some cases the operator deliberately stops the object from moving or even switches the conveyor operation - due to repeated X-ray. These conditions were dealt with by methodical instructions to the operator. No interventions in the proposed algorithm were necessary.

During testing, the proposed method was found to be insensitive to the presence of noise. The presence of points outside the real object does not cause distortion of the compensation angles. This property is particularly important in the area of object placement on the substrate (roller track). In this area, it is not always possible to reliably separate the object from the background. Despite this, the proposed method reliably compensates for the rotation of the object.

The "Fig. 11" shows the results of the angle determination for different levels of separation from the background. In the middle row are the calculated object footprints in the X-Y plane. The bottom row shows correctly rotated objects. The presented algorithm shows no error in the determination of the angle.

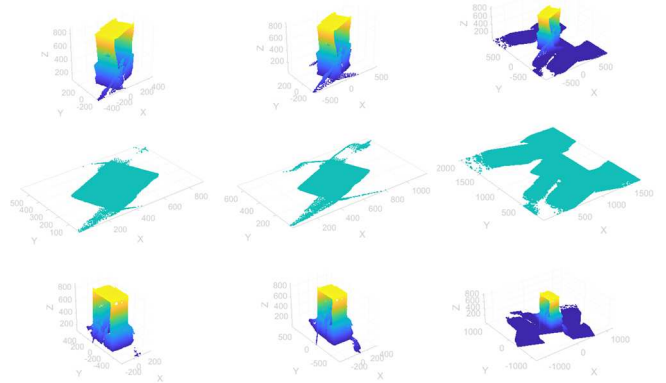


Fig. 11. Example of RT method insensitivity to background data.

Although the speed of computation was not a key parameter for us and we preferred simplicity of implementation in lower-level languages, we managed to speed up the algorithm considerably with some optimizations. To speed up the calculation, we limit the angle in the range  $45^\circ - 135^\circ$  and work with accuracy of  $1^\circ$ . This accuracy has proved to be quite satisfactory for our purposes.

We have also gradually reduced the amount of data (reduced the resolution of the sensors). It turned out that the resolution reduction even has a positive effect in reducing the noise information.

## V. CONCLUSION

The proposed algorithm significantly simplified the implementation of the alignment of objects on the conveyor belt in the scanner coordinate system and enhanced the stability of the system. We consider the problem of rotation compensation already solved in the 3D scanner design.

The 3D scanner system helps organizations more accurately optimize their processed shipments by capturing

and providing accurate dimensional and volumetric packaging information. At the moment we are achieving the following parameters:

- We achieve system accuracy in Working Range: 0 – 4m in depth  $\pm 5$  mm.
- 2 mm temporal noise in 1.5 m, typical.
- Size of shipments to 2 x 2 m.
- Time of slice acquiring less than 40 ms.

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