Research Paper
Academic Platform Journal of Engineering and Smart Systems (APJESS) 10(2), 41-46, 2023
ISSN: 2822-2385
Received: 07-Sep-2022 Accepted: 13-Jan-2023
https://doi.org/10.21541/apjess.1297168

A Novel Method Determining the Size and Angle of an Object Using a Depth Camera Without Reference

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Abstract

In traditional methods, a fixed object is taken as a reference for size determination. The size of the other object is calculated by comparing the dimensions of this reference object. However, when it is desired to measure objects at different heights, the measurement of the reference object must also be changed. In the study carried out, the size and angle of the products flowing through the line were determined by using a depth camera. The data set was created by taking the measurements of an object of known dimensions from 34 different distances. The mentioned data set consists of the ratio of the number of pixels of the edges of the object to the lengths of the edges. By comparing the correlation between the obtained data set and the distance values, a mathematical equation was extracted with the help of the MATLAB program. With the help of this equation, regardless of the height and color of the object, only the distance to the camera and all 3 dimensions can be calculated. In addition, the angle of the object with the software-generated reference line was calculated by taking the long side of the object as a reference. In this way, the size and angle of the products flowing through the line were determined with a single camera without the need for a reference object and without any color and size discrimination.

Keywords: Depth Camera; Dimension Measurement; Angle Measurement; Mathematical Model

1. INTRODUCTION

Our sense organs perceive the physical and chemical stimuli in our environment and carry them to the centers in the brain in certain ways and enable them to be interpreted. eyesight; It improves our ability to perceive, comprehend and predict events quickly and manages our intuition at every moment of our lives. For the formation of three-dimensional vision; The same images should fall on the same points (visual center) of both eyes from different angles. When the images taken at these points are sent to our brain, our brain combines these two images taken from different angles into a single image [1]. When there is some difference between the images, our eyes can make the images equal with the fusion (overlap) mechanism. The remaining amount of difference is eliminated by our brain and a three-dimensional image is formed. Although 2D images are used to detect objects in today's robotics studies, they are insufficient because they lack depth sensing features. Depth cameras are needed to detect features such as size, distance and angle. The wide field of view is an essential feature for robotic applications where it is vital to see as much of the scene as possible. The Intel® RealSense™ D435 camera, which is used in the study and has a range of up to 10 m, can be easily integrated into many studies for this purpose. When we look at the literature studies, many studies with depth cameras are encountered. Some of the work done are listed below. M. S. Ahn et al. analyzed and modeled the aforementioned sensor in a study in the field of robotics. [2].

Lee et al., in their study, examined the systematic or unsystematic depth errors that occur in image processing with a depth camera and studied the methods applied to eliminate this situation [3]. In yet another study, Ji-Ho Cho and colleagues used a single depth camera to represent human figures on three-dimensional televisions, detecting pixels that could not be processed due to variable environmental conditions and conducted studies to solve this situation [4]. Ji-Seong Jeong et al. performed parallel visual processing and visualization in real time [5]. In this application, the image was processed with a depth camera at 30 fps and viewed.

In their study, Adi and Widodo measured the distance of an object with the help of a stereo camera. Based on the center of the object, they obtained the measurement of objects 3-6 meters away with 4% error with the Euclidean distance measurement method. [6]. Kim performed the distance measurement of the leading vehicle in the article study. It measured the distance to the detected vehicle using the AdaBoost algorithm based on ACF-aggregated channel features. In his experiments in different road environments, he estimated vehicle detection with 87.5% accuracy, distance estimation with 92.8% accuracy and the time required for processing as 0.76 seconds per frame [7]. Lin et al. detected guava fruit and branch using RGB-D camera. In this way, they ensured that the fruits could be collected without hitting the branch. A 3D image was obtained by using the central location of the detected fruit and the nearest branch information. The experiment was successful between 94% and 98% and showed that fruit detection can be used in harvesting robots [8].

Parr et al. investigate the performance of five depth cameras in relation to their potential for grape yield prediction. The error performances of the cameras were compared with the data they obtained [9]. Kurtser et al. made vine yield estimation in their study. By using the depth information obtained from the RGB-D camera, they obtained the size data of the grape bunch. With the data they obtained, they made estimations with an error margin of 2.8 to 3.5 cm. [10]. Wang et al. conducted a study on counting mango fruits and measuring product size at the same time [11]. RGB-D camera, stereo camera and ToF (time of flight) sensor were used to measure distance, which is a necessary information for calculating fruit size. They preferred RGB-D camera in terms of cost and performance. However, as a result of the study, they stated that it is not very practical to use the RGB-D camera under direct intense sunlight. Maeda et al. performed an area measurement application using a depth camera to determine the tomato leaf area. [12]. Zheng et al. have studied the non-contact size measurement of vegetables using a 3D depth camera [13]. In this study, the key points are extracted by detecting the vegetable from 6 points. In this study, 4 vegetables were measured from a distance of 60 cm and deep nets were used as a method.

Cuong et al. made object detection and measurement of this object using a 3D depth camera[14]. Before the measurement, they studied preprocessing, object detection, extraction of key points and deep interpolation, respectively. With the application of interpolation, the edges and corners of the shape are created more clearly. The images used in the study were taken from a flat object on a fixed table. Hantong XU and colleagues worked on 3D modeling using the Microsoft Kinect V1 depth camera. In this study, he deduced the shape of the material to be 2-dimensional plane and reflected from a third point behind the plane. In this study, firstly, the two-dimensional position of the material is determined with the image taken from the RGB belt, and then the shape of the product is extracted from the reflection by using the depth feature with a third point according to the position. Thus, it is possible to extract the three-dimensional shape of objects with complex shapes by a different method other than drawing. [15]. Li Wu et al. used a depth camera to follow the growth of a potato plant. By making color classification with the depth camera, they made an estimate on the development and elongation amount by considering the morphological change on the plant [16]. Ruchay et al. instantly measured the body size of a cattle with the help of a depth camera. While doing this, they used a Microsoft Kinect V2 depth camera and obtained a three-dimensional image by using the depth-reflected measurements from the camera. Such manual animal body measurements have turned into a more functional and practical method with the help of a depth camera [17]. Griffin et al. studied the detection of objects and their distance from the camera by using the depth measurement created by camera movement with the artificial intelligence model they trained [18]. In this study, the calibration of the camera was achieved by using measurements taken from multiple products. The increase in pixels in the image as the object gets closer to the camera and the decrease in the pixels obtained as it moves away is the main obstacle for us to reach the real dimensions of the object in the image. As with other 3D sensing modalities, active stereo systems suffer from this problem. In mass production lines, it is an important problem that the products that pass through the conveyor are stacked and packaged at the end of the line, and that the incoming products arrive at the right angle and know their dimensions. While calculating the spatial and orientational determinations of an object with traditional methods, an RGB camera is usually used and a reference object is placed next to the object to be measured. Calculations of the object to be measured are made based on the pixels of the reference object. However, when measuring objects of different heights, the reference object must be changed continuously. In addition, color detection is also needed as there may be objects of different colors. In another method, dimensions and orientation angles can be measured by taking measurements from different angles with two different 3D cameras. However, this brings with it the cost problem.

In this study, the distance of the object on a plane to the 3D camera is calculated with a mathematical equation, and size, size and orientation (angle) calculations are performed. In this way, the necessary measurements were obtained with a single camera without the need for any reference object and a second camera on the plane. In addition, this process was carried out without the need for color separation. In this article, after the introduction, the main features of the 3D depth camera are mentioned in the second part. In addition, with the mathematical model we obtained, object size determination and angular calculation studies are explained. In the last part, the evaluation of the size and angle determinations of the objects, independent of color and size, is included.

2. MATERIALS AND METHODS

In this section, size and angular calculations of the objects flowing from the conveyor line are mentioned. In addition, the hardware features of the depth camera used in the study are expressed.

2.1. Intel® RealSense™ D435

3D cameras are imaging devices that allow three-dimensional reproduction of depth perception in images as experienced by human vision. The depth camera can simultaneously capture the color and geometry information of any object at the video frame rate. Used to capture depth data and color data on real-world objects [19].

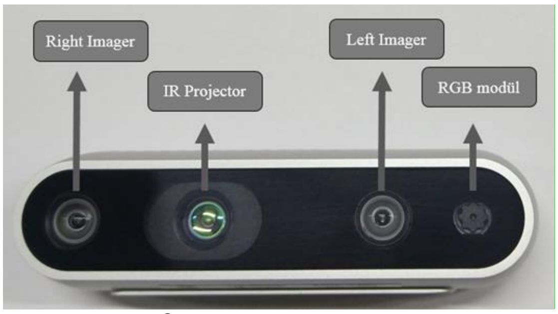

Figure 1. Intel® RealSense™ D435 Camera

Intel® RealSense™ D435, one of the depth cameras, was used in this study. The general structure of the camera is as shown in Figure 1. This camera is designed for devices to gain the ability to see, understand and interact with their environment, as well as learn from their environment. Ideal for fast-moving applications, this 3D camera; Thanks to the depth sensor, it offers a very wide field of view with a global shutter.

2.2. Object Detection

In this section, the image processing steps on the images taken with the 3D depth camera are mentioned. Thresholding is done between the 3D camera and the surface of the object. In this way, as in Figure 2, the area between the surface and the camera is perceived as logic-1, and the area under the surface as logic-0. Figure 3 shows the thresholded picture.

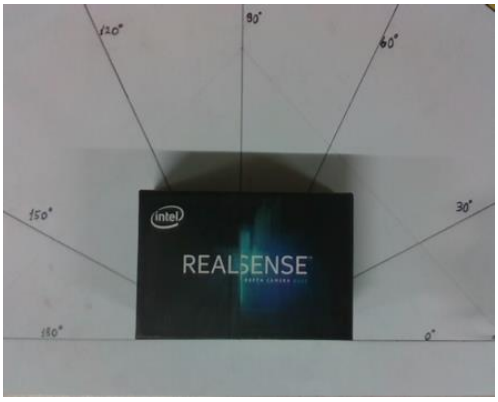

Figure 2. The normal image taken from camera

Figure 3. The image taken from camera and threshold applied

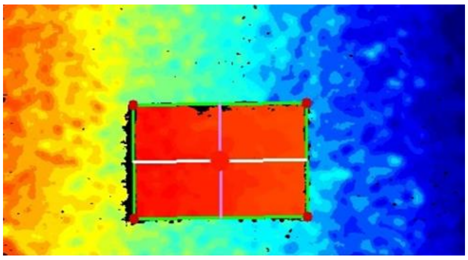

Figure 4. Corner point and edge detection product

Morphological processing was applied to remove the noise in the obtained images. Among the objects obtained as white on a black background, the objects were contoured in order to detect the objects of the desired size, and the objects below the determined value were not filtered and processed. Finally, the image of the object to be measured was obtained as in Figure 4 and the corner points were determined.

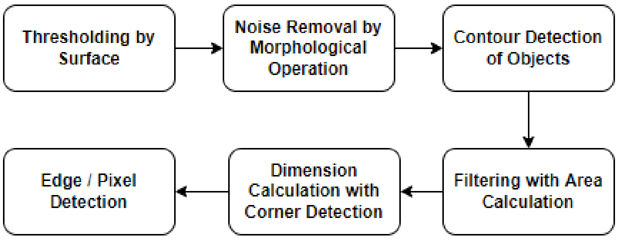

Figure 5. Image processing, filtering and size detection flowchart of the object

The edge lengths of the object are extracted using the corner points. The extracted edge lengths were measured as the number of pixels. In Section 2.3, the side lengths of the object, which are measured from different distances, are expressed as pixel edge length ratios in a table. In addition, in Figure 5 you can see the image processing filtering and size detection flowchart of the object.

2.3. Mathematical Model Extraction

With the depth camera, the distance of the object from the camera can be found. However, some mathematical operations are required to find the true lengths of the sides of the object. The object whose dimensions are to be measured is expressed with a different number of pixels inversely proportional to its distance from the camera. For example, when an object is close to the camera, it is represented by more pixels than when it is far from the camera. This relationship was expressed with a mathematical equation and the conversion of the pixel number to the length was carried out. In order to create the relationship equation, a rectangular object with known dimensions was viewed at different distances to the camera, and a data set was created. This dataset contains the ratio of the distance of the object to the camera and the number of pixels representing the edges to the actual edge length. Table 1 shows the data set.

The relationship between the distance of the object from the camera and the number of pixels representing the edge length is a non-linear relationship. This non-linear relationship can be observed better when the obtained data set is graphically expressed as shown in Figure 6. The x-axis in the graph represents the distance from the camera (cm) and the y-axis represents the ratio of pixels to the edge length.

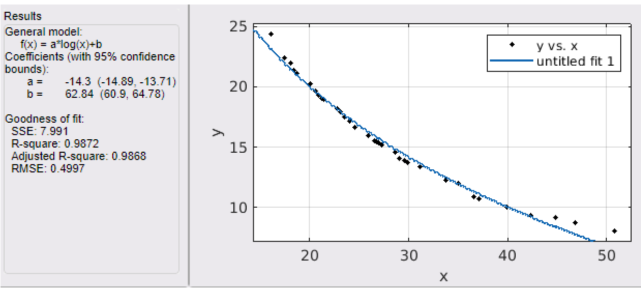

Figure 6. Distance logarithmic relation of object

$$ratio = a.\log d_{camToObject} + b \quad (1)$$

$$l_{real} = \frac{l_{piksel}}{ratio} \quad (2)$$

Curve Fitting Toolbox tool provided by MATLAB program was used for curve fitting. By choosing the logarithmic function that best represents the data set (Equation 1), the unknown coefficients of the function were calculated by the program. The x-axis of the graph in Figure 6 represents $camToObject$ and the y-axis represents $ratio$. These values were obtained as $a = -14.3$ and $b = 62.84$. In Equation 1, $d_{camToObject}$ (cm) is the distance of the object from the camera, and $rate$ (pixels/cm) is the number of pixels per millimeter on the object. Using Equation 1 as in Equation 2, l_{pixel}(pixel) and actual length of the object in centimeters l_{real}(cm) are obtained from the number of pixels representing the edge of the object. With this method used, the edge lengths of rectangular objects of different sizes can be measured without the need for any reference object whose dimensions are known on the image. Thanks to this obtained logarithmic relation, the dimensions of the object can be determined regardless of distance.

2.4. Size Detection with Mathematical Model

With the depth camera, the height of the object is determined by measuring the distance of the camera to the object and the ground where the object is located. The edge lengths obtained from the camera image are in pixels. Using Equation 1 and Equation 2, the edge lengths obtained in pixels are converted to lengths in centimeters. The volume of a rectangular object whose base sides and height are known is calculated in this way. Figure 7 shows a sample whose 3D dimensions were calculated.

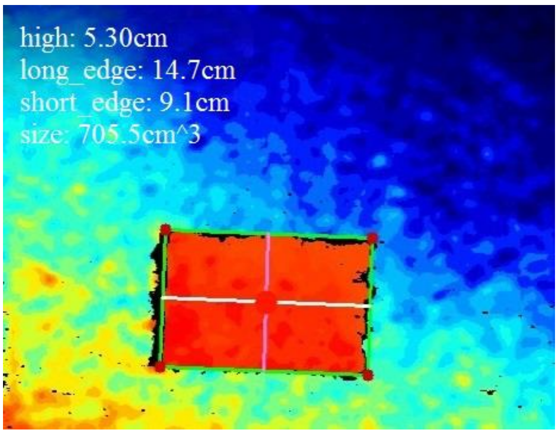

Figure 7. Sample product image with 3D dimension calculated

Table 1. Distance-dependent edge-to-pixel ratio of object

Distance (cm)	Pixel/Edge _a (pixel/mm)	Pixel/Edge _b (pixel/mm)
16,1	24,35714	24
17,5	22,42857	22,44444
18,1	22	21,77778
18,4	21,35714	21,33333
18,7	21,14286	21,11111
20,1	20,28571	19,77778
20,6	19,64286	19
20,9	19,28571	18,77778
21,2	19,07143	18,55556
21,4	18,92857	18,33333
22,8	18,21429	17,44444
23,1	17,92857	17,11111
23,5	17,5	17
24	17,14286	16,66667
24,6	16,64286	15,88889
25,9	16	15,33333
26,6	15,5	14,94444
26,8	15,42857	14,88889
27	15,35714	14,77778
27,3	15,21429	14,33333
28,6	14,57143	13,88889
29,1	14,07143	13,66667
29,6	13,92857	13,44444
29,9	13,71429	13,11111
31,2	13,35714	13,22222
33,8	12,28571	12,22222
35	12	11,77778
36,6	10,92857	11,22222
37,1	10,71429	11
39,9	10	10
42,3	9,357143	9,444444
44,9	9,142857	9,333333
46,8	8,714286	8,666667
50,8	8,071429	8

2.5. Angle Calculation with Mathematical Model

In this section, the measurement of the orientation angle of the detected rectangular object is explained. A white line in Figure 8 has been added to the camera image for correct mounting of the camera on the conveyor. This line is parallel to the horizontal axis of the image frame. The lower left corner of each frame obtained from the camera is accepted as the origin of the coordinate system, its vertical edge is its ordinate and its horizontal edge is its abscissa. Corner coordinates of the contour representing the object are determined by reference to this coordinate system. The orientation angle of the object is calculated by using the coordinates of the long edge from the side edges obtained in Section 2.2.

$$\Theta = \tan^{-1}\left(\frac{y_2 - y_1}{x_2 - x_1}\right) \quad (3)$$

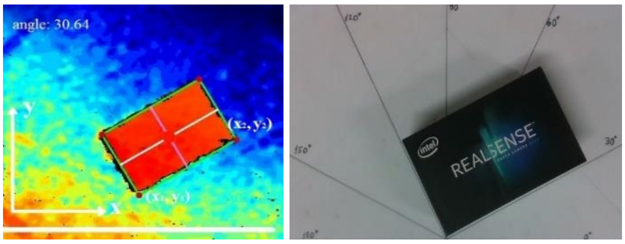

Figure 8. Angle detection object and its normal image

3. EXPERIMENTAL RESULTS

The mathematical model developed for the size and angle detection of objects was tested on 6 different objects. Table 2 shows the actual dimensions of these objects and the dimensions obtained as a result of the developed method. Figure 9, Figure 10, Figure 11, Figure 12, Figure 13, Figure 14 show the objects whose size and angle measurements were made using the depth camera and the developed method. A virtual line was created on the screen where the image is taken. The angle of the object was determined by measuring the angle made by the (+)x side of the long side of the object with the imaginary line. For example, when the sample-1 given in Figure 9 is examined; the long side (edge_a) is 14.3 cm, the short side (edge_b) is 9.1 cm, the height is 5.2 cm, and the standing angle on the surface is 0 degrees. When the measurement is carried out with the developed method; It is seen that the long side (edge_a) is 14.4 cm, the short side (edge_b) is 8.9 cm, the height is 5.4 cm, and the stance angle on the surface is 0 degrees. When the results obtained are taken into consideration, it has been observed that the measurement is made with an accuracy of 99.3% in long edge detection, 97.8% in short edge detection, 96.15% in height detection and 100% in angle detection. Figure 9, Figure 10, Figure 11, Figure 12, Figure 13, Figure 14 of the samples whose dimensions are given in Table 2 are shown. These pictures represent the objects in which size and angle measurements are made using the depth camera and the developed method.

Table 2. Distance-dependent edge-to-pixel ratio of object

		Sample Dimensions and Angle Measurements				
		Edge_a (cm)	Edge_b (cm)	Height (cm)	Angle (cm)	Size (cm^3)
Samples	1	14.3	9.1	5.2	0	676.676
	2	14.6	5.9	7.2	30	599.184
	3	5.9	6.7	4.6	60	181.838
	4	8.2	16.7	3.7	90	506.678
	5	7.5	10.1	4.8	120	363.6
	6	11.1	9.2	7	150	714.84
		Results of The Measurement with Proposed Method				
		Edge_a (cm)	Edge_b (cm)	Height (cm)	Angle (cm)	Size (cm^3)
Samples	1	14.4	8.9	5.4	0	690.7
	2	14.9	6.2	7.2	30.18	665.7
	3	6	6.8	4.6	61.2	187.3
	4	8.3	16.1	3.8	90	510.6
	5	7.5	10.2	4.9	120.66	372.4
	6	11.4	9.3	7.2	150.95	758.5

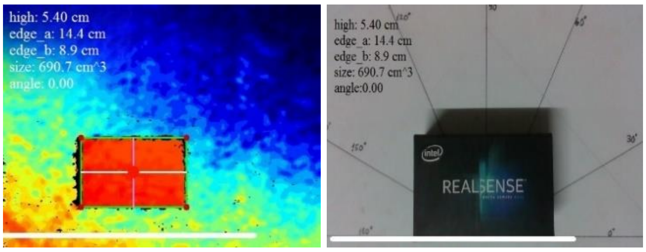

Figure 9. Sample-1 dimension and angle calculation

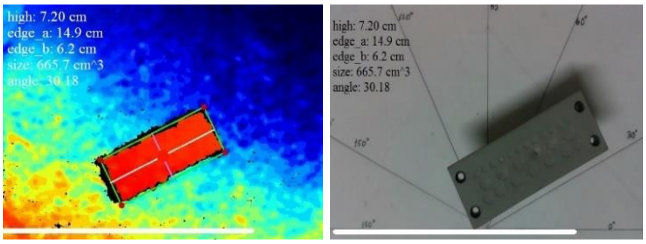

Figure 10. Sample-2 dimension and angle calculation

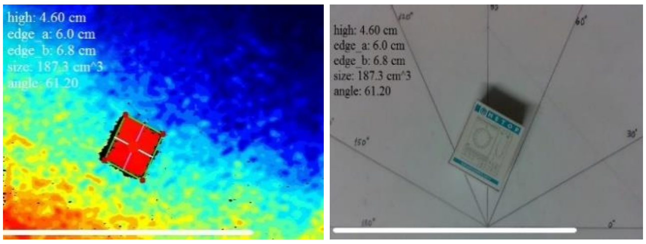

Figure 11. Sample-3 dimension and angle calculation

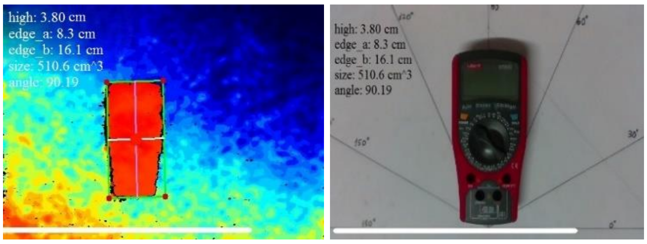

Figure 12. Sample-4 dimension and angle calculation

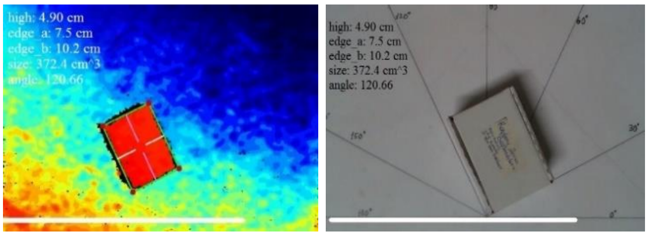

Figure 13. Sample-5 dimension and angle calculation

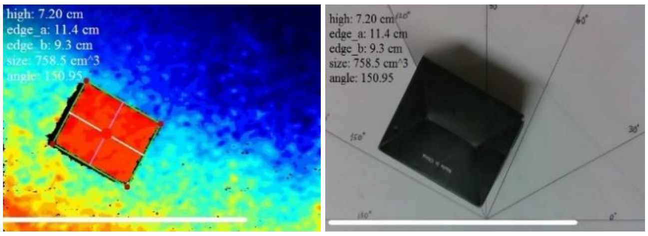

Figure 14. Sample-6 dimension and angle calculation

4. CONCLUSION

Two methods are generally used to calculate the size of objects. In the first method, a reference object of known dimensions is placed next to the object to be measured. The lengths of the edges are determined by proportioning the object to be measured and the reference object. However, since the number of pixels increases with the approach of objects at different heights to the camera, the proportional study with the reference object begins to not give accurate results. In a second method, two depth cameras are pointed at the object at different angles. The edges of the object can be measured from the intersection areas. However, the large number of cameras affects the cost. With the method we developed, size and angle calculations of objects of different sizes were made without the need for a reference object and additional cameras. In this way, a system that is low cost and flexible in terms of object dimensions and does not require color separation has been developed. This developed system has also been applied to lines industrially and is currently in use. In this way, both academic and industrial gains were achieved with the study.

Author contributions: Concept – İ.P, F.Ç, B.G, R.G; Data Collection &/or Processing – R.G, S.E, F.G; Literature Search – M.Y, B.G, F.G, S.E; Writing – F.Ç, M.Y, F.G, B.G; Software and Hardware Development – R.G, S.E, F.G, M.Y.
Conflict of Interest: This study was obtained from TUBITAK-2244 project named "Design, Development and Realization of Autonomous Storage and Logistics Management System" numbered "118C142".
Financial Disclosure: The products used in this study and other expenses were funded by OPTİMAK STU.

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