DESIGN OPTIMIZATION OF OMNIDIRECTIONAL MIRROR OF AUTONOMOUS MOBILE ROBOT FOR SURVEILLANCE CAMERA COMPONENT USING QUALITY FUNCTION DEPLOYMEN METHOD

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ABSTRACT

Currently, the use of automation has become a useful tool to monitor manufacture in improving work efficiency and safety. One way the use of automation is applied in the monitoring process is the Autonomous Mobile Robot (AMR) which is often used to recognize objects with its camera sensors based on the direction of motion, position, and shape of the objects. However, conventional camera sensors on AMR have a limited point of view on the object. This problem can be solved by adding an omnidirectional mirror on the camera, which enables the camera to capture objects with a 360 degree view in one frame. However, the addition of omnidirectional mirror in general may lead to high cost production. Therefore, this study aims to design an omnidirectional mirror that is cost-effective and suitable to be integrated with the cameras. The design process of this study uses a Quality Function Deployment (QFD) approach to identify the best features related to the material and arrangement of the omnidirectional mirror's angle. The proposed result of the omnidirectional mirror design hopefully will capture a better and more optimal quality of the object at a lower cost. In practice, AMR added with omnidirectional mirror can raise the efficacy of the surveillance system by capturing clearer images. Consequently, the use of AMR can contribute further to various sectors in life, including manufacturing processes, home industries, traffic, and many more.

Keywords: *AMR, omnidirectional vision, direction determination, recognition.*

INTRODUCTION

In recent years, the use of automation has become predominant, which may help the surveillance system to improve work efficiency and safety in manufacturing sector (Kim et al. 1999). Autonomous Mobile Robot (AMR), as one of the application of automation, has become a useful tool for navigating in an environment without the need for physical or electro-mechanical guidance devices. With advances in technology, demands for AMR in various sectors such as industry, hospitals, institutions, agriculture and housing has increased tremendously because these tools can be assigned to supervise the work of an object, carry heavy objects, mission in searching for objects, etc. (Young et al. 1995).

AMR requires a sensor component to recognize an object in the surrounding environment. One of the main types of sensors on AMR is a camera sensor. In general, the process of capturing an image of an object uses a conventional camera lens system to capture field of view only one direction at a time (Neves et al. 2010). In practice, a weakness in the conventional camera sensors is that they have limited viewpoints which can be seen on the single image they capture (Lopez et al. 2012). Therefore, this camera system may be rather difficult to apply to a simple AMR system because the resulting point of view still does not meet the data requirement of the entire surrounding environment. One way to overcome this weakness is to add an omnidirectional mirror tool to the camera. In this case, the mirror is integrated into the camera to form a 360 degree angle view on a horizontal or visual plane that includes the surrounding environment. Therefore, the combination of omnidirectional mirror and camera sensors creates what is called as the omnidirectional camera. Furthermore, the omnidirectional camera works by directing a camera sensor towards a half-sphere mirror and placed perpendicularly which will function as a material handling AMR navigation process.

Specifically, omnidirectional mirrors have a variety of shapes, such as canonical, spherical, cylindrical, paraboloidal, ellipsoidal, and hyperboloidal. The shapes that are most often used are the spherical and paraboloidal because they have the ability to capture objects better than the other shapes. In addition, the design of the omnidirectional mirror also affects the image quality of the object. The design includes the material selection feature and adjustment of the convex angle in the mirror used. Therefore, the design of an omnidirectional mirror is very import to capture an image with an optimal quality at a 360 degree angle view.

Various attempts have been made by many researchers to get a wider camera viewpoint. Some previous researchers, such as Bruckstein and Richardson (2000) have created a design that uses 2 parabolic mirrors, of which one is convex and the other one is concave shaped, using glass material. Furthermore, Nayar (1999) created an omnidirectional mirror design using 2 mirrors with a conical shape. Meanwhile, Nalwa (1996) uses an arrangement of 4 triangular planar mirrors that are side by side in a pyramid arrangement with each camera under each mirror material. Peixoto (2000) found a system that uses a rotating camera to obtain an omnidirectional image by modeling the shape and characteristics of the mirror to capture objects more clearly at a certain distance.

By using an omnidirectional camera system, a wider point of view is obtained compared to using a conventional camera (Tarhan et al. 2011). However, the image obtained using the omnidirectional camera system is distorted because of its basic nature which present the entire surrounding images in one circular plane (Scotti et al. 2005). By knowing the nature of the omnidirectional camera's resulting image, this distortion can be corrected by changing the image into panoramic view. Hence, the image obtained can be processed more easily because it provides a 360 degree view of the environment around the sensor and is suitable for use in tracking straight lines, especially vertical lines. Therefore, the change from omnidirectional image to panoramic view is influenced by the change from Kartesian coordinates to Polar coordinates (Tan et al. 2014).

Based on the explanations above, the design of omnidirectional mirror is a major problem in this study because a not optimal design (based on features such as material and the angle of mirror convex) affect the image quality. In this case AMR's function in surveillance may become ineffective because the image captured has a low quality. Therefore, the aim of this study is to design an omnidirectional mirror that is cost-effective, by considering the features such as materials and the convex angle of the mirror. An optimal design is based on these two features, hence the omnidirectional mirror can be integrated with the AMR camera sensor so that it gets a more effective surveillance function due to higher quality of captured image.

In this study, the design of an omnidirectional mirror is carried out using the Quality Function Deployment (QFD) approach. This approach is appropriate because the QFD method is used for structured product planning and development that enables the development team to clearly determine the needs and desires of consumers, and evaluate each desired product or also the quality of products provided systematically in order to meet the wants and needs of consumers. In addition, the QFD approach has also been used by many researchers in various fields such as education, aviation, food products, and many more. Some benefits of using the QFD approach include increasing the competitiveness of products or services through continuous improvement in quality and productivity (Cheng and Melo, 2007). Also, the QFD method also gives benefit in increasing the product reliability and quality, communication, productivity, profits, customer satisfaction, and shorts time to market.

Similarly, Shanin and Zairi (2009) created a design in the quality of community web services. They considered features in the quality of satisfaction with service. Meanwhile, Dholakia and considered in increasing the quality of teaching and increasing the productivity of the teaching system using QFD. Furthermore, Benner et al. (2013) used the QFD method in applying the production chain process with aims to improve the food product quality (which does not only depend on the ingredients' quality). Therefore, the QFD approach is used in this study to design an omnidirectional mirror that considers the material selection features and the adjustment of mirror's convex angle that is integrated into the camera sensor.

Based on the design process using the QFD approach, this study contributes to designing new and cheaper omnidirectional mirror which have a better function of capturing a broader picture of objects. In addition, the use of omnidirectional mirror with QFD method can contribute more to various fields including manufacturing processes, home industry, traffic, and many more.

This study is arranged as follows. Section 2 presents the methodology for designing and manufacturing omnidirectional mirror. Section 3 illustrates the QFD function as a designing tool through data obtained and used as a basis for a picture of the design. Section 4 provides an overview of the potential results and analysis carried out by applying the QFD to the manufacture of the proposed omnidirectional mirror which is proposed as an example for industrial applications. And last, section 5 discusses the conclusion and provides suggestions for further researches.

RESEARCH METHOD

Based on the problems discussed in the previous section, this section explains in detail the methods for designing and manufacturing omnidirectional mirror based on the QFD approach. The methodology used in this study is shown in Figure 1 to assist in the process of data collection and processing.

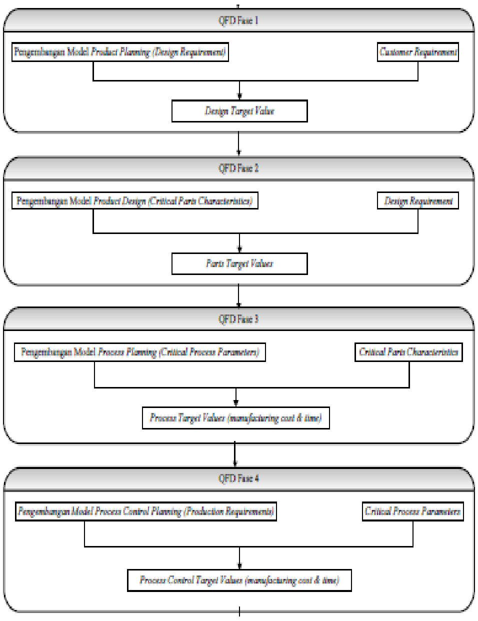


Figure 1. Research Method

Based on Figure 1, there are 4 phases of QFD that are proposed to solve the research problem. The phases are used to design omnidirectional mirrors that aim to improve the optimization of the catch of objects with low manufacturing costs. In general the phases describe the process of designing, manufacturing, to the end finish of the product. Hence, the 4 phases of QFD are explained as follows.

QFD – Phase 1
In this phase, a model is created that is able to identify the extent of customer expectations for the quality of an omnidirectional mirror product that is able to satisfy consumers, in terms on cost and quality. This identification step uses Customer Requirements (CRs) or Voice of Customers (VoC) with Design Requirements (DRs).

QFD – Phase 2
In this phase, a model of data analysis for required materials or components is made which can fulfill the design target value criteria in the first phase. It is done by translating the determination of Design Requirements (DRs) into Critical Parts Characteristics (PCs).

QFD – Phase 3
In this phase, modeling of the process parameters needed to produce materials or components produced from the target value parts in the second phase is carried out. In this case, Critical Process Parameters (PPs) are determined.

QFD – Phase 4
In this phase, a sequence of production processes model needs to be made to choose a strategic manufacturing decision from critical process parameters in the third phase. In this case, Production Requirements (PRs) are made.

Omnidirectional mirrors that use the QFD method starting from the design, manufacture, to finished results are based on customer requirements, and morphological charts that are inferred or converted into the House of Quality (HOQ) matrix. Furthermore, as a reference to achieve technical characteristics in accordance with the targets set**.**

RESULT & DISCUSSION

QFD Application In this part of the study, a quality function deployment was evaluated in the textile production industry of Turkey. In this application, customer requirements, customer significance level and technical characteristics were determined and scored with the experts and employee of all production industrial sectors (Omnidirectional Camera). Besides, a questionnaire was prepared for learning the opinions, perspectives of user about the sustainability of the lifecycle of Products. This step of the study was very important to gather data and also to assist in the implementation of the research. The research was focused on a quantitative perception by means of a questionnaire-based survey determining the evaluation of the Omnidirectional Camera. This survey was e-mailed to approximately a total of 10 user Omnidirectional Vision. the survey from the user omnidirectonal camera, with a 72% rate of response. The Technical characteristics include groupings identified according to the questionnaire on the environment which is focused on quality of product. These characteristics which were determined according to the survey questions and answers are shown in Figure 2

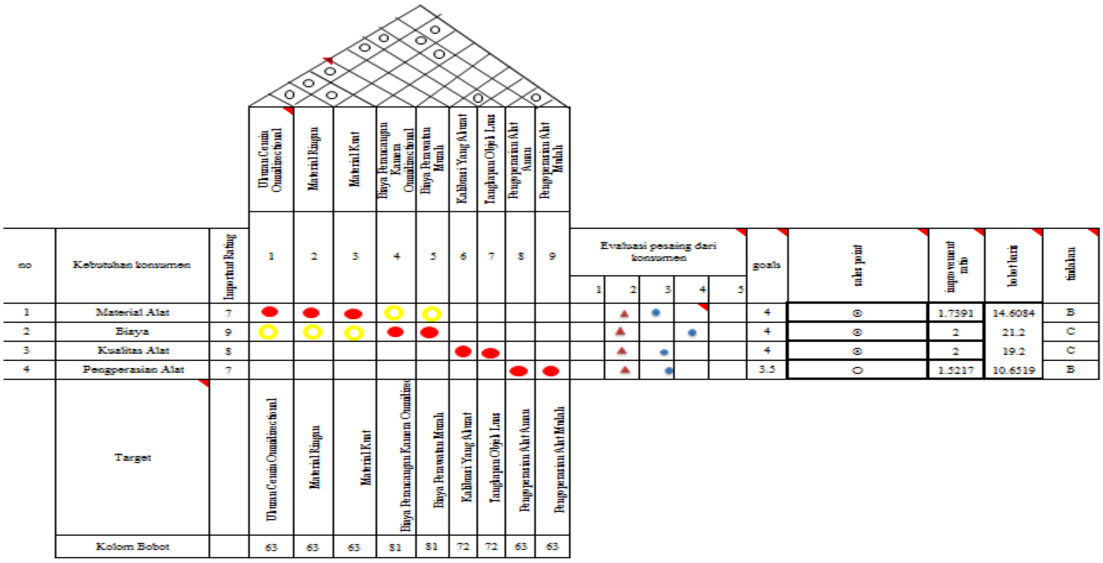
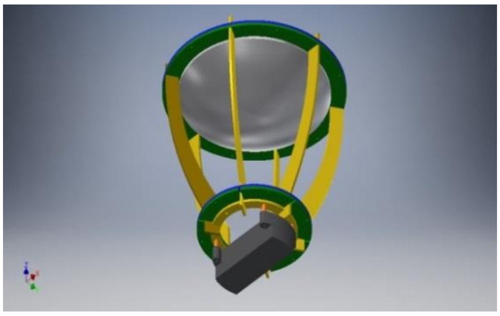


Figure 2. House Of Quality

The camera used by the author is Logitech c930e which has an open angle of 90 ° and a resolution of 1920 × 1080 pixels. Logitech c930e has an automatic focus. Therefore the focus of the camera is set using a software. The software used to adjust the focus is v4l2ucp. To get an omnidirectional image, the camera requires a tool in the form of a mirror, the design of the omnidirectional camera uses 1 hyperbolic mirror that is mounted perpendicularly. The results of the images obtained are capable of producing a 360 degree coverage area. Illustration of reflected light as in Figure 3



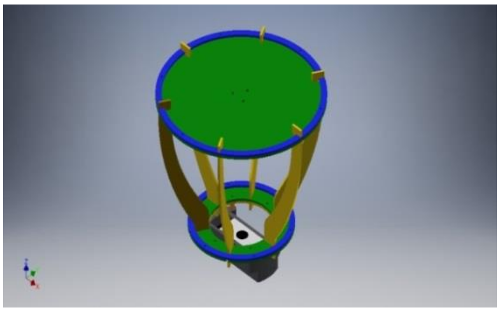


Figure 3. Omnidirectional Camera Design

The specifications are as follows:

- Video calling: 1280 x 720 pixels
- Video capture: up to 1280 x 720 pixels
- Photos: up to 8 megapixels
- USB 2.0 high speed
- Autofocus

`By placing it at a height of 200 mm from the omnidirectional mirror, the visibility expected by the researchers and the 360-degree vision radius was obtained. This makes it to be an advantage of omnidirectional mirrors in the implementation of object detection autonomously. Omnidirectional mirrors and cameras are placed in the middle of a room to get a comprehensive object capture from the room. The detailed shape and size of the omnedirectional camera according to the following specifications:

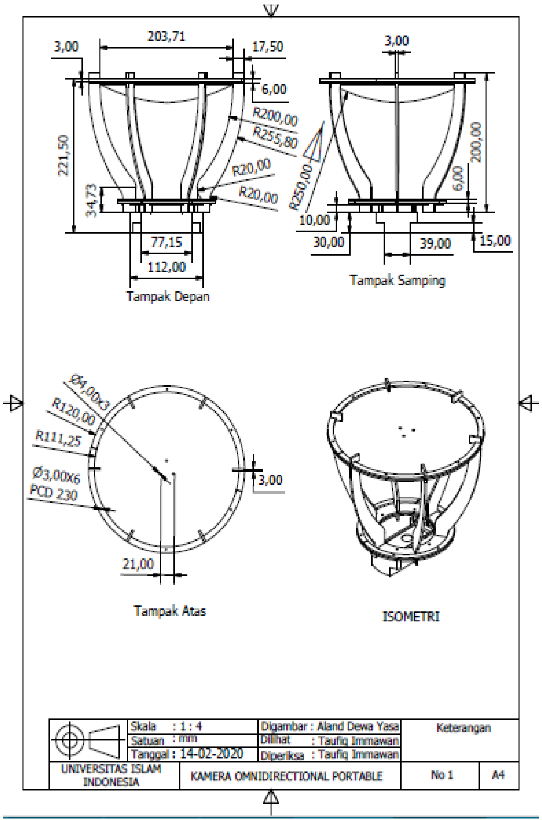


Figure 4. Omnidirectional Camera Design

The first step to calibrate the camera is to determine the frame that matches the mirror size of 500 pixels × 500 pixels. The purpose of this step is to have the frame only with an image that is reflected by a mirror. The camera used by the author is Logitech c930e which has an opening angle of 90 ° and a resolution of 1920 × 1080 pixels. To avoid the camera taking pictures outside the mirror, the authors reduce the camera resolution to 500 × 500. Then the authors use the v4l2ucp software to adjust the zoom (magnification) and focus the camera. Calibration on the camera omnidirectional system aims to get the coordinates according to the position of the object.

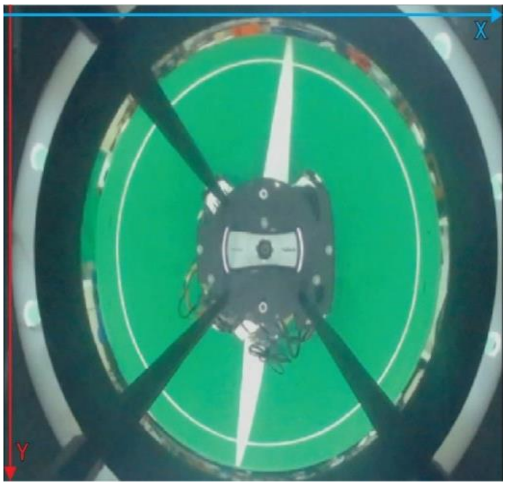


Figure 5. Camera Readout Before Calibration

The frame has a length (axis y) 500 pixels and width axis 500 pixels. Each axis is divided by 2 to get the middle value, so we get 250. The 250 value is the reference for calibration. To get the exact center point of 0 on the camera lens, the following equation is required:

$cx = x - 250$ $cy = -(y - 250)$

Information :

- x: camera reading value on the axis before calibration (pixels)
- y: camera reading value on the axis before calibration (pixels)
- cx: camera reading value on the x axis after calibration (pixels)
- cy: camera reading value on the y axis after calibration (pixels)

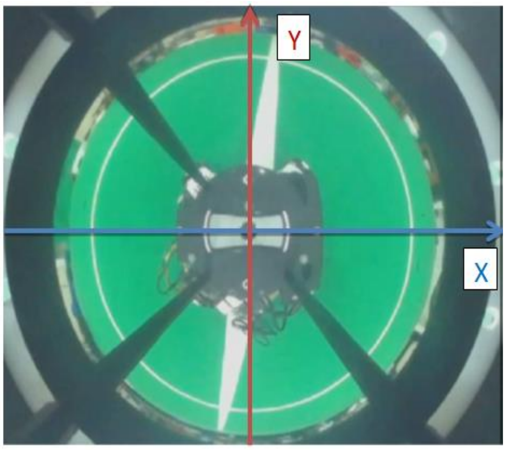


Figure 6. Camera Readout After Calibration

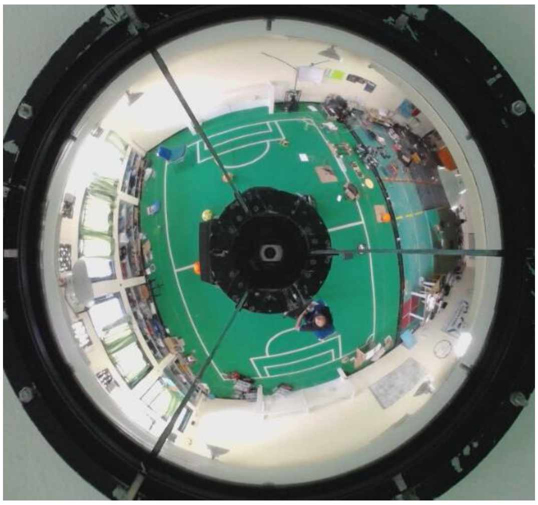


Figure 7. Camera Calibration

Before being calibrated the axis and y axis values are shown in Figure 4 In Figure 6, after being calibrated the values and axis values will have a value of 0 right on the camera lens.

Object detection testing aims to determine whether the camera can capture and identify the object. This can be seen in Figure 5, where there is the result of identifying the object detection system.

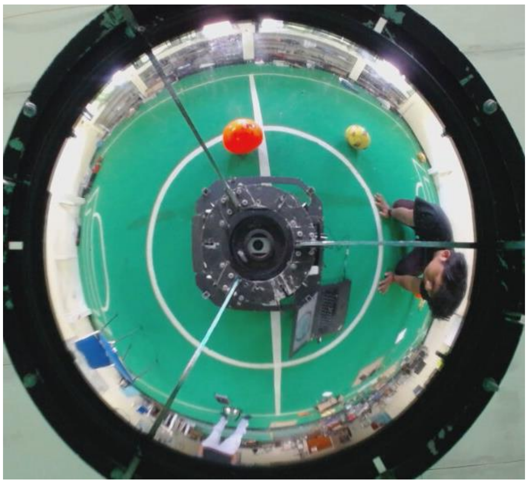


Figure 8. Object Identification

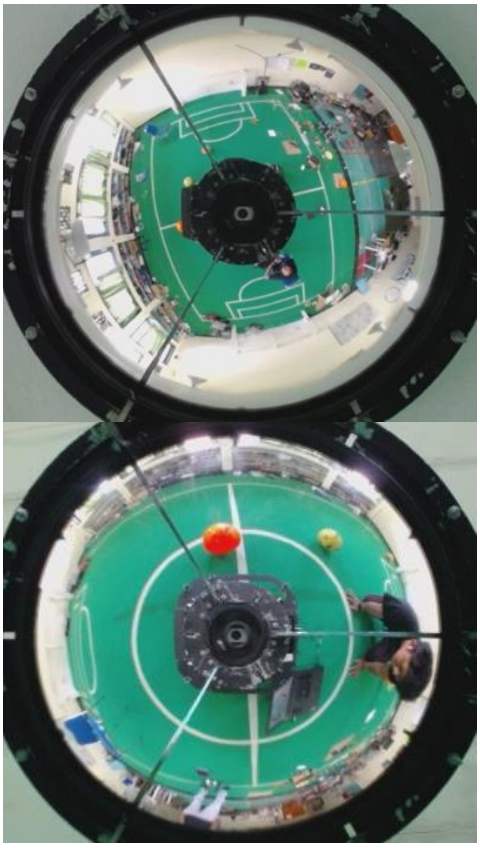
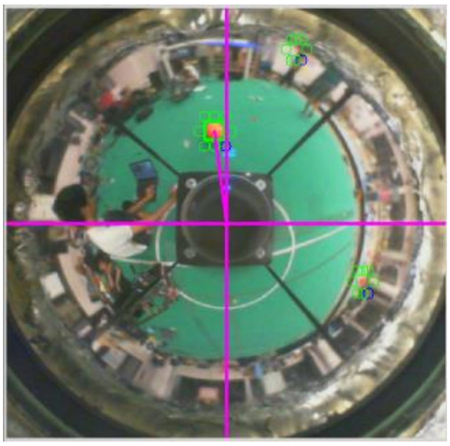


Figure 9. Object Identification Based on Distance

Figure 9 is an example of the objects' condition with a distance of $100cm$ from the robot. The data written is the highest value after 3 trials. Several factors may influence the detection results in Table 1, which include the intensity of light, shadow, distortion caused by mirrors, and the distance of the object at the distance which the omnidirectional camera capture. Each test was carried out 3 times with an average reading error of 0% or without errors (all detected).



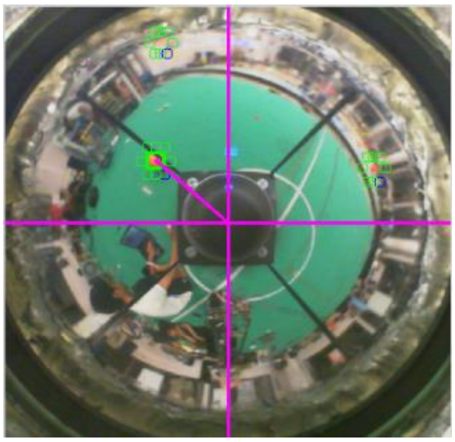


Figure 10. Detection of the ball in the field by robot rotation at a distance of 1 meter and 2 meters

Ball detection test based on distance. On Table I it can be seen that within a distance of 5 meters the ball is can still be detected properly.

Table 1 Testing The Ball Detection

Number	Distance (cm)	Result	
		Detected	Not Detected
1	25	✓	-
2	50	✓	-
3	75	✓	-
4	100	✓	-
5	125	✓	-
6	150	✓	-
7	175	✓	-
8	200	✓	-
9	225	✓	-
10	250	✓	-
11	275	✓	-
12	300	✓	-
13	325	✓	-
14	350	✓	-
15	375	✓	-
16	400	✓	-
17	425	✓	-
18	450	✓	-
19	475	✓	-
20	500	✓	-

CONCLUSION

From the analysis above, it can be concluded that the improvement of the existing research tool is proven to cause the object detection and calibration of the omnidirectional mirror to be more optimal. Coverage area for converting broad objects, ranges from 0 - 360 degrees. Based on these results, the authors conclude several things which are as follows:

1. There are 4 attributes used in QFD, which are tools' materials, cost, tools' quality, and tools' operation.
2. Obtain technical requirements and objectives for the design and development of omnidirectional mirrors obtained from people who are experts in using the tools.
3. Get an Omnidirectional Mirror tool virtual design that suits the needs of customers and people who are experts in using the tools.
4. Give a positive impact for the Omnidirectional Mirror process, which are:
   a. Cheaper tool costs.
   b. A more optimal results in terms of the object detection's scope and calibration results.
   c. Safe and easy when using the tools.

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