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Method for Measuring Distances based on the Conjunction of Radar and Vision Sensors

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This paper proposes the method of measuring distances and improving the accuracy based on the information obtained from both a radar sensor and a vision sensor (camera). In experiment, the region of interest (ROI) was used for object detection and the distances for measurement were divided into sections and the learning of the actual distances applied to the image data. When any object's motion was detected through filtering in the ROI section, the coordinate for the bottom of the object was received based on the learned data and the distance from the coordinate was calculated. Moreover, raw data of the radar sensor was used for learning background data during a certain time and the existence of object's motion was determined by way of subtraction of the background data from the current data. When any motion of object was detected, the distance to the initial value in the relevant section was calculated. To improve the accuracy of distance measurement based on the conjunction of both sensors, the distances were divided into three sections: close distances (below 2m), middle distances (2m~7m) and long distances (beyond 7m). In conclusion, for close distance measurement, it is desirable to use a vision sensor since it is not possible to detect close distances by using a radar sensor. For middle distance measurement, it is desirable to correct the data of the vision sensor and use the average between the corrected data of the vision sensor and the data of the radar sensor. In case of middle distances, using both sensors decreased the distance measurement error by approximately 4cm, compared to using a radar sensor. For long distances, it is desirable to use a radar sensor for distance measurement since the data of radar sensor is more accurate than the data obtained from the conjunction of both sensors.

Keywords: radar sensor; vision sensor; distance; object detection; camera

I. INTRODUCTION

Recently, the methods and technologies for recognizing and detecting a certain moving object in real time have been proposed and applied to industries. The ultimate purpose of the computer vision is for computer to implement all the functions that human eyes have (Lee *et al.*, 2009; Jeon *et al.*, 2014; Jang, 2018). There are three important functions of the human vision system: first, it is to recognize an object in three-dimensional space; second, it is to track the recognized object; and third, it is to measure the distance to a target. Object recognition refers to the process by which a person recognizes the object at a certain distance to the extent he can recognize it. This may be a fixed object or a moving object. Object tracking refers to the process by which he determines the direction to which the recognized object moves, the height, etc. Distance measurement refers to the process by which he recognizes the distance to a certain target based on his experience and helps him make a decision on the subsequent behavior. Application of those characteristics to the computer vision enables various internet of things (IoT) including autonomous vehicles, monitoring systems and home automation (Seo, 2017).

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There are various types of distance measurement sensors including laser, infrared, ultrasonic and radar sensors. Therefore, using several sensors enable to measure the distance information as well as the location information. A system containing sensors transfers the recognized data to its control part which uses the transferred data to calculate the distance through algorithms and then transforms the result into a certain format so that users may understand it. However, since the aforementioned sensors using wavelength detect information based on the signals emitted by the sensors, they cannot provide visual factors. Moreover, since the sensors may determine the existence of an object only within the coverage range of the sensors, users' needs are not satisfied in many cases (Jeon *et al.*, 2014; Kim, 2017). Embedded in the internet of things devices, a system using sensors collects and exchanges various data from various devices (Choi & Koh, 2017). In order to improve the foregoing problems, a distance sensor is only used to measure distances and then fused with a vision sensor to provide visual data of the surrounding objects at the measured distance.

In this paper, after detecting an object and measuring the distance (i) by removing background with a vision sensor and (ii) by using electromagnetic waves of a radar sensor, the detected distance was corrected according to the results of the two methods. This paper is to verify the accuracy of distance measurement based on the respective experiment results and to improve the accuracy of measurement by dividing the distances into three sections and giving sensor weighting for each section. Chapter II explains the characteristics of the respective distance measurement sensors: laser, infrared, ultrasonic and radar sensors. Chapter III describes an experiment in which distance measurement algorithms are implemented by using radar and vision sensors and Chapter IV proposes a distance measurement algorithm using the fusion of radar sensor and vision sensor. Chapter V presents the experiment results for the proposed algorithm and Chapter VI provides the conclusion.

II. RELEVANT STUDIES

A. Types and Characteristics of Distance Measurement Sensors

There are various types of distance measurement sensors, including laser, infrared, ultrasonic and radar sensors (Jang & Jung, 2018). An ultrasonic sensor measures distances by using sound waves in the inaudible frequency range, instead of the audible one. Sound waves are transmitted through the vibrations of air and thus, it would be difficult to make an accurate measurement with that sensor, depending on wind, temperature and existence of another object in the direction to be transmitted. An infrared sensor makes a measurement by using a visible light range, instead of an invisible one. It is a weak point of the infrared sensor that if it is used outside or in a place where there are various temperature changes, the accuracy of measurement is lowered.

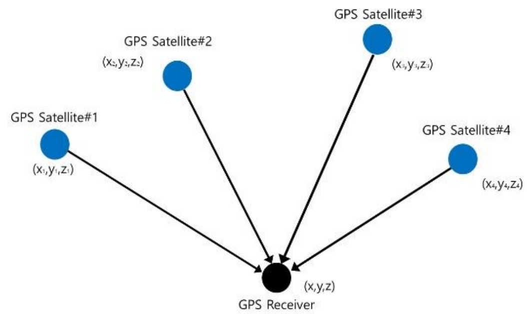

Figure 1. Positioning Principle of GPS

Moreover, GPS may be used to measure the moving distances of an object. Based on GPS, both of distances and locations can be detected. GPS, a global positioning system, receives the signals from three or four satellites via its sensor, as shown in Figure 1, to locate the GPS terminal. When the location information of the satellites is sent to the receiver, the receiver measures its location by using the difference between the time when signals were sent from the satellites and the time when the signals were received by the receiver.

GPS is most commonly used for smartphones and navigations. Smartphones and navigations measure distances based on the changes of user's location. However, if there are obstacles such as buildings and trees around users, the accuracy of location is lowered since GPS signals are sent from satellites.

B. Principle of Radar Sensors

Radar sensors radiate electromagnetic waves to send signals and when the sent signals are met and reflected by an object, the reflected signals return to the sensor receiver. The sensors measure location, speed, distance, etc. by measuring the time when the signals are sent and the time when the reflected signals return. Figure 2 shows the overall principle. The radar sensors may be technically classified into pulse and continuous wave types (Jang, 2016).

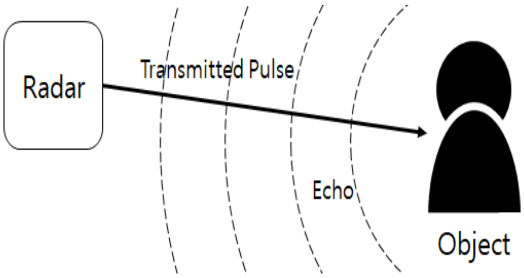

Figure 2. Principle of Radar Sensors

1) *Pulse Radar:* It radiates pulses for a short time and measures the relative speed and distance between an object and the sensor by calculating the frequency and time taken by a pulse to travel to an object and back to the sensor. Even though the radar radiates pulses, the respective frequencies of the pulses reflected by two adjacent objects have different sizes or forms, depending on the speed of each object. Moreover, when pulse radar radiates toward a fixed object, the change in frequency resulting from the time when the reflected pulses return becomes zero and thus, it can distinguish a fixed object as well.

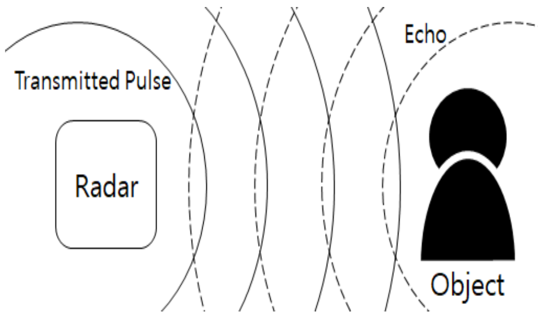

Figure 3. Principle of Continuous Wave Radars

2) *Continuous Wave Radar:* A continuous wave radar (CW) radiates electromagnetic waves continuously to measure the reflected waves. It may measure the relative speed and direction of the object but not the distance. Figure 3 shows the principle of CW. There is a frequency modulated continuous wave radar (FMCW) which has been developed for modulating frequencies to detect distances, so it is possible to overcome the weak point of CW. FMCW can be deemed as a combination of the existing CW and the concept of frequency modulation.

C. Object Detection through Image Data

Image data refers to images saved through cameras. There have been many studies on the object detection methods using images. Among such methods, the background subtraction technique and the Gaussian Mixture Model (GMM) are most popular. Each of them uses a fixed camera and has little capability to change the point of view of the camera. However, they are remarkably adaptable to a single point of view.

$$G = \frac{R+G+B}{3} \quad (1)$$

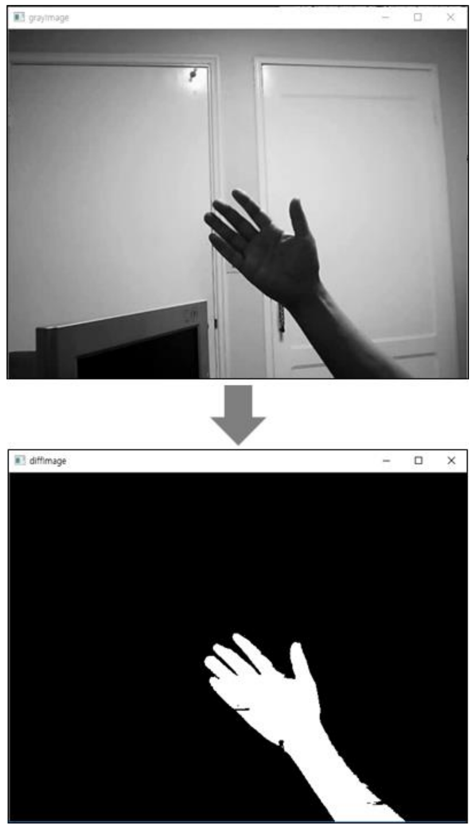

Figure 4. Example of Object Detection using the Background Subtraction Technique

1) *Background Subtraction Technique:* It is a method of detecting an object based on the separation between foreground and background by using the difference between pixel values in image. This technique sets a part, when there is no difference between the previous frame and the current frame, as the background and another part is determined when there is any difference, as foreground (Kim, 2017; Kim *et al.*, 2011) . First of all, the background subtraction technique uses

Equation 1 to convert a color image to black and white. The purpose of converting to the black and white image is to reduce the amount of computation to increase the processing speed. After such conversion, the difference between the previous frame and the current frame is calculated. An object can be detected by setting a pixel value as white color if the pixel value changes beyond a certain level in the frame or as black color if it changes below a certain level. Figure 4 shows an example of object detection using the background subtraction technique.

2) Gaussian Mixture Model: The Gaussian Mixture Model is an algorithm where a number of the Gaussian distributions are mixed. It shows excellent performance in relation to lighting variation, denoising and foreground extraction. The Gaussian Mixture Model algorithm refers to the method of modelling the distribution density with the probability density function (Kim *et al.*, 2011; Lee *et al.*, 2007; Lee & Chung, 2010; Parekh *et al.*, 2014; Olufunminiyi & Olufade, 2014; Miezianko & Pokrajac, 2008; Chavda & Dhameja, 2017). However, the external environment changes over the time and brightness changes gradually. Therefore, in order to make its modelling available, a number of the Gaussian distributions are used.

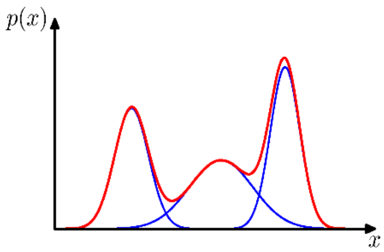

Figure 5. Gaussian mixture distribution

If there is any value which is not in the Gaussian distribution when an object moves, it is recognized and detected as the foreground. Figure 5 shows the Gaussian mixture distribution.

III. DESIGN OF DISTANCE MEASUREMENT ALGORITHMS

The distance measurement algorithms are designed using a radar sensor and a camera. For a radar sensor, the IR-UWB radar sensor is used to design distance measurement algorithm by using the sensor values for the divided sections. For a vision sensor, the background subtraction technique is used to detect an object and design distance measurement algorithm by using a reference value.

A. Distance Measurement Algorithm Using a Radar Sensor

A radar sensor determines that there is an object in the range if the sensor data increase beyond a reference value and then, it calculates the distance based on the location of the x-coordinate for the increased data.

1) *Composition of Hardware:* The IR-UWB sensor uses the Xethru X4M03 module of Novelda based in Norway. The operating principle of the module is shown as Figure 6. The detection distance of the radar sensor covers up to 10m. Its specification can be seen in Table 1. The vertical FOV is 7° and the horizontal FOV is 130° which is as shown in Figure 7. The x-axis for radar sensor data consists of total 1536 sequences. It can be seen that when an object moves, the x-axis becomes proportional to the distance between the sensor and the object and the y-axis becomes inversely proportional to the object size. In other words, if using a same-sized object, the closer the distance is, the bigger the value of y is, whereas the farther the distance is, the smaller the value of y is. Accordingly, existence of an object can be determined based on the different threshold values set for detecting an object.

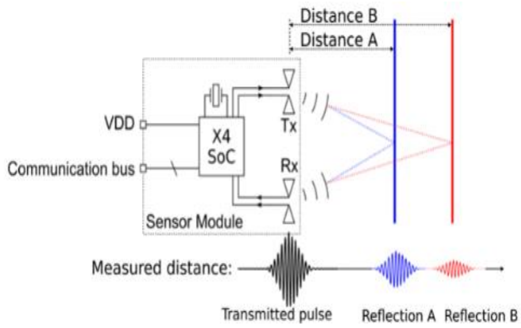

Figure 6. Basic Concept of the X4M03 Radar

Table 1. Specification of the X4M03 Sensor

Item	Coverage Range
Detection Distance	~10m
Cycle Time	30(fps)
Vertical FOV	7°
Horizontal FOV	130°

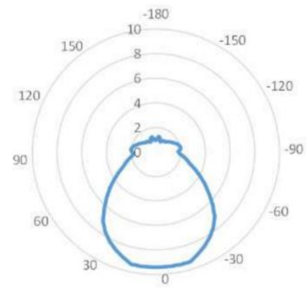

Figure 7. Basic Concept of the X4M03 Radar

2) *Design of Distance Measurement Algorithms:* The distance measurement algorithms can operate only when an object is detected within the coverage range. Thus, the distance can be detected only after an object is detected. Object detection is to detect an object based on the phenomenon where the value of y increases at the location of the object in the coverage range of the sensor, if any, as can be seen in Figure 8. At this time, the x-axis is divided into sections to reduce the amount of computation and to proceed without delay. This paper proposes 6 for the number of x elements per section and 256 for the total length.

$$L = TL / n_x \tag{2}$$

For Equation 2, L stands for length for each x-coordinate and TL, total length that the sensor can measure. n_x stands for the total number of x-coordinates.

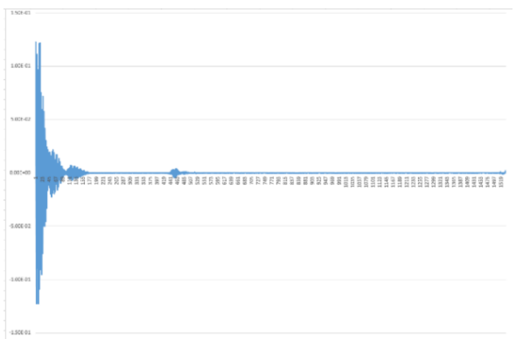

Figure 8. When an object is detected at the distance of 3m from the sensor

The result of calculation of the length for each x-coordinate using Equation 2. is approximately 0.65m.

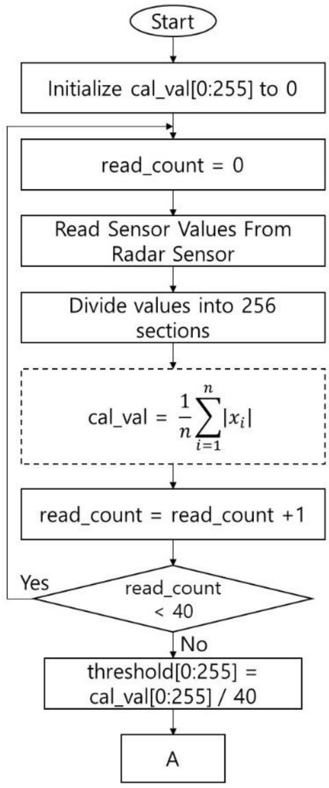

Figure 9. Setting of Background Data

The object detection algorithms are shown in Figure 9 and Figure 10. The sensor receives surrounding environmental data first 40 times after operating as shown in Figure 10 and collects the background data using the average value filter as shown in Equation 3. Figure 10 indicates that the existence of object is determined based on the comparison between average value of the data received 20 times after setting the background data and the initial background value multiplied by the correction value. When an object is detected, the distance between the object and the sensor is calculated using Equation 3. based on the relevant section number.

$$cal\_val = \frac{1}{n}\sum_{i=1}^{n}|x_i| \tag{3}$$

The correction value for each section is set as follows: 2.9 times for section 0 to 101(approximately 4m or less); 2.6 times for section 102 to 203(approximately 8m or less); and 1.1 times for section 204 to 255. The background signal data for the close distance of the initial section 0 to 101 are huge due to the transmitted pulse as shown in in Figure 6. Moreover, from a human perspective, the detection area is large enough for a man to be included and thus, the size of the measured data becomes big.

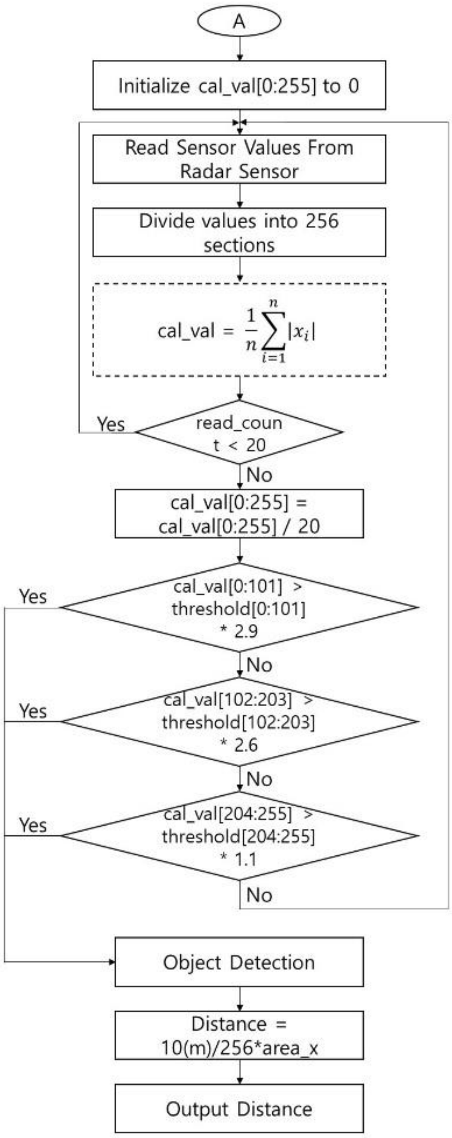

Figure 10. Object Detection and Distance Calculation Algorithm

$$distance = 10m/256 * area\_x \qquad (4)$$

For Equation 4, distance refers to the distance from the sensor to the object, area_x refers to the section no. where the object is detected and 10m/256 refers to the length for each section.

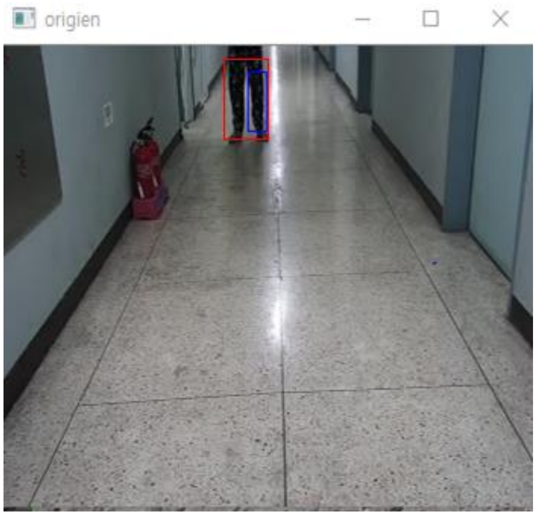

Figure 11. Image Applied with Labelling

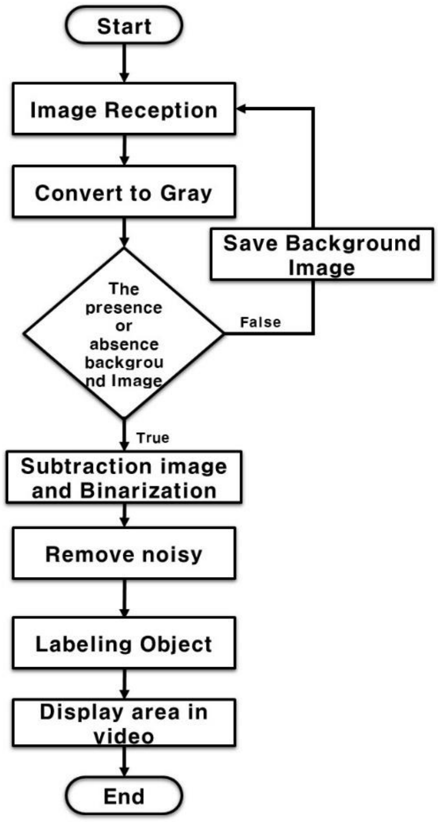

Figure 12. Motion Detection Algorithm using Background Subtraction Technique

B. Distance Measurement Algorithm Using a Vision Sensor

1) *Motion Detection Using the Background Subtraction Technique:* The background subtraction technique is a method by which the foreground may be extracted conveniently if there is no motion or many changes in image. The first frame data are used as the background image. The color image for the

background is converted to black and white by using Equation 1. Filtering applies to the converted image to remove noises. After then, the next frame data are converted to black and white. Using the background images and the subtraction technique, the difference between backgrounds is calculated. Based on the difference, a threshold is set for binarization. Small noises are removed from the binarized image by the opening computation. After removing noises, labelling is necessarily applied to the masked area. Labeling is a method of grouping pixels which fall under the same area. When labeling is completed, the marking of area is finally performed so as to enable the location of object to be seen in the image. In relation to the marking of area, it can be performed according to the outline of the relevant object; or the nearest pixels can be marked with a quadrangle. In this paper, marking with a quadrangle has been chosen. Figure 11 shows the image where labelling is applied and Figure 12 indicates the motion detection algorithm using the background subtraction technique.

$$Q = (Dis[i-1] - Dis[i]) / distance$$
$$OD = (vd + (i * distance)) - ((Y - Dis[i]) / Q) \tag{5}$$

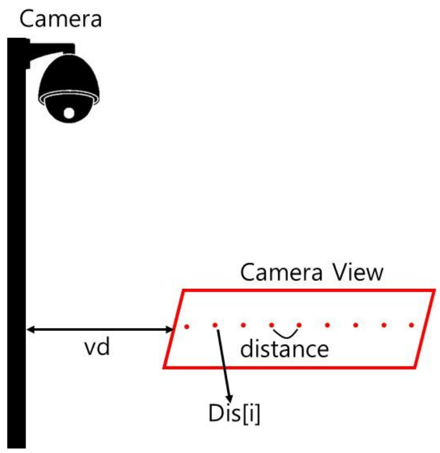

Figure 13. Distance Measurement using a Camera

2) *Distance Learning and Measurement Algorithm:* In order to measure the distance from the detected object to the camera, the user needs to mark each point at a certain distance within the coverage range of the camera and to make the relevant distances learned. The learned data are set as coordinates as shown Figure 13. The length between dots is 95cm and the total length from the first dot to the last one is 9.5m. VD as shown in Figure 13 and Equation 5 refers to the distance between the point where the camera is installed to the other point where an object is first detected in the range of the camera's vision. Dis[i] refers to the y-coordinate for dot number i. OD refers to the distance from the camera to the object. Q refers to the distance for each y-coordinate in the relevant section. Distance refers to the actual distance between dots. Base on those data, the algorithm has been implemented as shown in Figure 14. In order to verify whether the coordinates have been properly marked, if assuming that an object exists at the point where the mouse click occurred based on the Mouse Event, it has been confirmed that the actually measured distance (172cm) has come close to the distance to the point where the click occurred (178cm). However, errors occurred across the overall distance measurements and accordingly, the measurements have been corrected based on the reference value set as the minimum error.

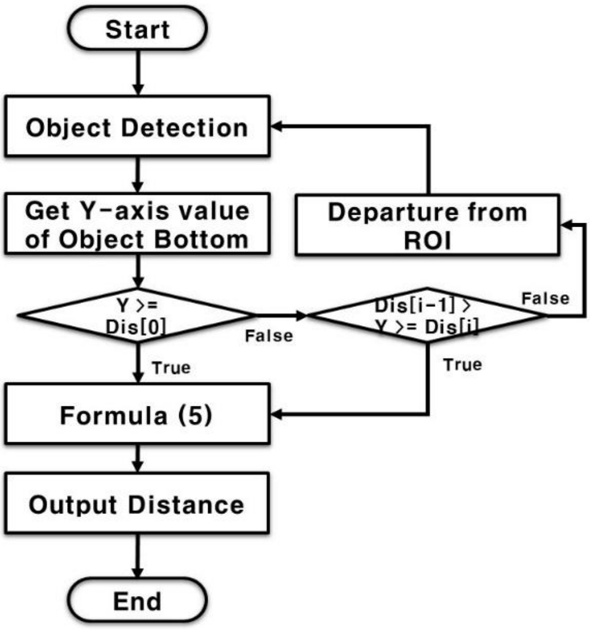

Figure 14. Distance Measurement Algorithm for Cameras

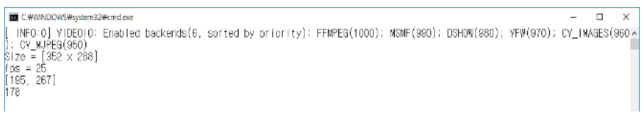

Figure 15. Measurement Result for a Short Distance

IV. IMPLEMENTATION OF DISTANCE MEASUREMENT ALGORITHMS AND EXPERIEMNT RESULTS

A. Implementation of Distance Measurement Algorithms and Experiment Results

In order to measure distances using a radar sensor, the experiment environment has been arranged as shown in Figure 16. After installing a radar sensor at a distance of 1m from the bottom, an immovable object was placed in the coverage range of the sensor for at least 2 seconds after operating the program containing the algorithm. The program saved the data received for 2 seconds as the threshold value as can be seen in Figure 9.

To verify the accuracy of the distance measurement of the radar sensor, the experiment was repeated, ignoring the motion data for the first 1~2 seconds when an object entered and stood for 20 seconds in such area as marked at a distance of 3m, 5m, 7m or 9m. The experiment result for each distance may be shown in Figure 17 and explained in Table 2.

While doing the experiment with the radar sensor, the errors were from 0m to +0.14m, indicating that the experiment result had the average of +0.07m farther than the actual distance. It was analyzed that such errors may occur because there were minor motions as the man subject to detection breathes or speaks rather than to stay completely immovable.

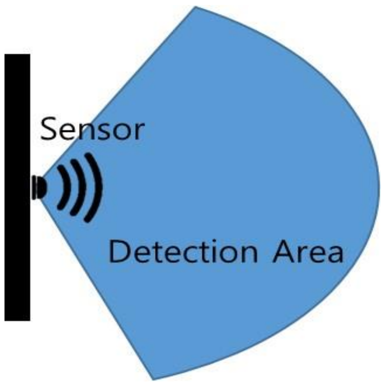

Figure 16. Radar Sensor Experiment

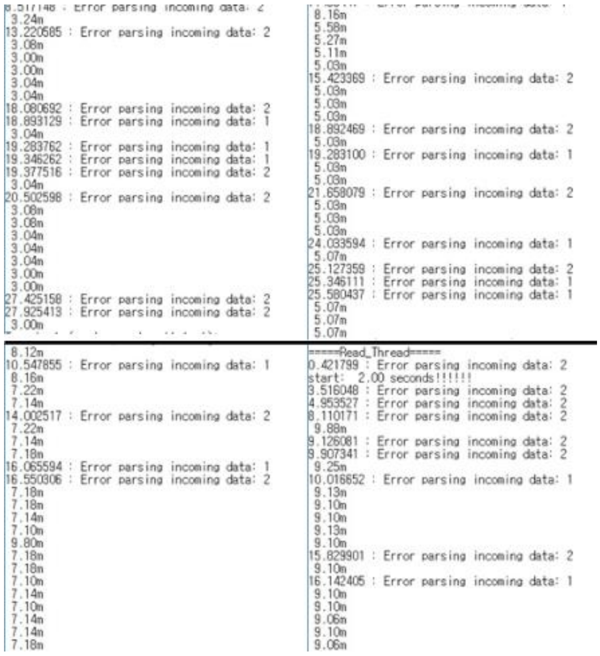

Figure 17. Screenshot of Result of Distance Measurement using the Radar Sensor

B. Distance Measurement Experiment Using a Vision Sensor and Result thereof

In order to measure distances using a vision sensor, the experiment environment has been arranged as shown in Figure 13. After installing a camera at a distance of 1m from the bottom, image information was received from the program containing the algorithm and an object was detected. Then the output of the distance information can be shown in Figure 18 and explained in Table 3. The reason why the camera was installed at a distance of 1m from the bottom is that the height of an automotive front camera was based.

Like the radar sensor experiment, it was repeated for each distance as follows: the object stands by out of the ROI before the experiment; once the experiment begins, an object enters and stays at the relevant distance of the ROI for 5 seconds.

When taking the experiment with the vision sensor, the errors were from -0.01m to -0.35m. This was because the coordinates were manually input for distance learning before detecting the object. It was analyzed that even though an object was detected, it was not the actual foot of the object but its shadow or the coordinate corresponding to the blurred part resulting from discarding noises.

Table 2. Screenshot of Result of Distance Measurement Using the Radar Sensor

Distance / count	3m	5m	7m	9m
1	3.00	5.07	7.10	9.06
2	3.04	5.07	7.10	9.06
3	3.04	5.07	7.10	9.06
4	3.04	5.07	7.10	9.06
5	3.08	5.07	7.14	9.06
6	3.08	5.03	7.14	9.10
7	3.08	5.03	7.14	9.10
8	3.04	5.07	7.02	9.10
9	3.04	5.11	7.02	9.13
10	3.00	5.07	7.02	9.06
Average Error	0.04	0.07	0.09	0.08
Max Error	+0.08	+0.11	+0.14	+0.13

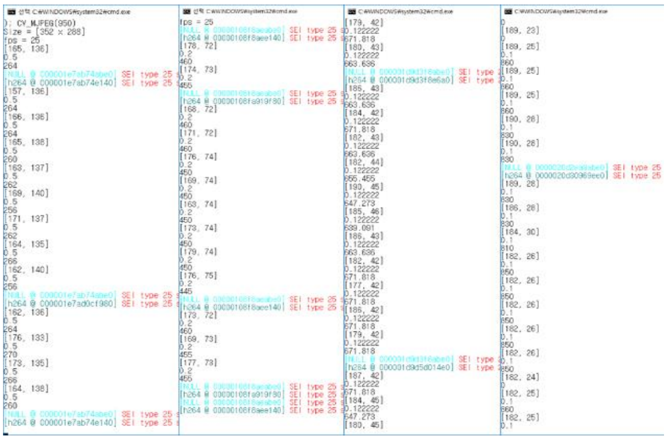

Figure 18. Screenshot of Result of Distance Measurement using the Vision Sensor

Table 3. Result of Distances Measurement by the Vision Sensor

Distance / count	1m	2m	3m	5m	7m	9m
1	0.91	1.89	3.00	5.07	7.10	9.06
2	0.97	1.94	3.04	5.07	7.10	9.06
3	0.97	1.94	3.04	5.07	7.10	9.06
4	0.96	1.94	3.04	5.07	7.10	9.06
5	0.90	1.96	3.08	5.07	7.14	9.06
6	0.94	1.97	3.08	5.03	7.14	9.10
7	0.97	1.97	3.08	5.03	7.14	9.10
8	0.96	1.96	3.04	5.07	7.02	9.10
9	0.96	1.94	3.04	5.11	7.02	9.13
10	0.96	1.97	3.00	5.07	7.02	9.06
Average Error	0.05	0.05	0.04	0.07	0.09	0.08
Max Error	-0.10	-0.11	+0.08	+0.11	+0.14	+0.13

V. METHOD FOR IMPROVING THE ACCURACY OF DISTANCE MEASUREMENT

A. Comparison of Accuracy of Distance Measurement

Table 4 describes the respective maximum errors of the distance measurement by the vision sensor and the radar sensor. The overall distances measured by the radar sensor are a little longer than the reference value, whereas those by the vision sensor are shorter and the range of errors is wider. Moreover, in case of the vision sensor, the farther the distance is, the shorter the travel distance for each pixel is.

Table 4. Maximum Distance Measurement Errors by Sensor

Distance / Sensor	1m	2m	3m	5m	7m	9m
Radar	-	-	0.08	0.11	0.14	0.13
Vision	-0.10	-0.11	-0.09	-0.20	-0.18	-0.35

B. Method of Improving the Accuracy of Distance Measurement

In order to improve the accuracy of the vision sensor, the data learning for each certain distance may be repeated to increase the accuracy of the reference distance. In addition, the accuracy may be also improved by decreasing or increasing the coverage area of the vision sensor as much as the difference between the radar sensor and the existing vision sensor for the length of each pixel in each section.

Table 5. Result of Accuracy Improvement Experiment

Distance / count	1m	2m	3m	5m	7m	9m
1	0.96	1.94	2.99	5.01	7.06	9.02
2	0.97	1.94	3.01	4.98	7.06	9.02
3	0.96	1.94	2.99	5.01	7.06	9.02
4	0.93	1.96	3.00	5.01	7.10	9.02
5	0.93	1.94	3.04	4.96	7.10	9.06
6	0.96	1.96	2.99	4.91	7.10	9.14
7	0.96	1.96	3.03	4.99	7.02	9.06
8	0.96	1.97	3.04	4.98	7.02	9.10
9	0.93	1.96	3.02	5.00	7.06	9.02
10	0.95	1.96	2.97	4.98	7.02	9.02
Average Error	0.05	0.05	0.02	0.02	0.06	0.05
Max Error	-0.07	-0.06	+0.04	-0.09	+0.10	+0.14

If the image quality of the vision sensor increases, the number of pixels in a certain section also increases and thus, it is expected that the accuracy of distance measurement will increase. However, since object detection increases the burden of computation, the availability of the real-time processing depends on the characteristic of the PC.

Due to those problems, this paper proposes the method of improving the accuracy of distance measurement as follows: when an object is detected by the vision sensor, the distance data of the object are aggregated and the average data is accumulatively saved. The accumulated distance data and the radar sensor's data are compared. In case the object is detected as being in a close distance (below 2m), the vision sensor's data is used to measure the distance; In case the object is in a middle distance (2m~7m), the average between the vision sensor's data and the radar sensor's data is used; and if in a long distance (beyond 7m), the radar sensor is used.

Table 5 shows the result of the distance measurement based on the proposed method. The maximum error for the close distances is -0.07m; for the middle distances, -0.09m; and for the long distances, +0.14m. Moreover, when measuring the distances to the detected object, there were some cases where the measurement results of the two sensors were different. It was because of the wrong detection of the sensors. In order to reduce such wrong detection, when the difference between the distance measurement results of both sensors was beyond a certain level, it was not deemed as the same object but another object.

VI. CONCLUSION

This paper studies how to improve the accuracy of distance measurement based on the conjunction of radar and vision sensors. In case of the radar sensor, there is no problem with the accuracy for a single object in the sensor's range. However, the radar sensor has a weak point in the presence of there are nearby objects (e.g., iron doors or walls) indoors and the relevant object is at the same distance as the nearby objects, it may not be detected. In case of the vision sensor, it has a weak point that its accuracy may be reduced, depending on external stimuli such as weather, illuminance and wobble.

In this paper, when the object was detected by the vision sensor and the distance from the object to the vision sensor was measured, the accuracy of the result was lower compared to that of the radar sensor. This is deemed that the accuracy may change depending on variables such as lighting and the difference between the heights of the object and the camera. Moreover, there were cases where an object was wrongly detected as being at a distance of 9.8m even though it was actually at a distance of 7m. Therefore, such wrong detection increased at close distances within 1.5m because of the reflected pulses and output power.

While measuring distances, we attempted to prevent such wrong detection of the radar sensor by weighing the camera for the close distances and by weighing the radar sensor which is less affected by the surrounding environment for the other distances. In case of middle distances, using both sensors decreased the distance measurement error by approximately 4cm, compared to using a radar sensor.

Experiments based on the assumption that the image quality of vision sensor may be enhanced turned out that the accuracy of distance measurement would increase since there are more pixels in the same section. If using both radar and vision sensors, the available applications may include autonomous vehicles, advanced driver assistance systems (ADAS), collision avoidance systems, etc.

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