Landmark-based Automated Guided Vehicle Localization Algorithm for Warehouse Application

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ABSTRACT
Automated guided vehicle (AGV) is a solution for warehouse goods transportation, but robot localization is crucial for this application and existing methods are expensive. Therefore, in this paper, a low-cost landmark based AGV algorithm localization algorithm with single camera is proposed for warehouse application. The proposed algorithm includes the computer vision algorithm to recognize the landmark and estimate the distance between the landmark and AGV with single camera. Previous localization algorithm based on triangulation is using three landmarks for localization, the proposed localization algorithm uses only two landmarks which is based on concept of intersection of two circles. The landmarks in the scene were detected with Canny edge detection method and transformed back to straight square from skewed image with perspective transform to provide consistent landmark recognition result. The landmark then was recognized with Tesseract open source character recognition library and custom trained database. The performance of the proposed algorithm was evaluated using images captured by a single camera setup on a trolley and maneuvered through the library and laboratory at Universiti Sains Malaysia with landmarks. The recognition accuracy for landmark is 93.26% overall. The average error of the localization algorithm was 237.29mm and standard deviation 184.27mm. As a conclusion, landmark based AGV localization algorithm for warehouse application was successfully developed.

CCS Concepts
• Computing methodologies→Artificial intelligence→Computer vision;
• Computing methodologies→Artificial intelligence→Computer vision→Computer vision tasks→Vision for robotics;
• Computing methodologies→Artificial intelligence→Computer vision→Computer vision tasks→Scene understanding.

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Keywords
Landmark; Automated guided vehicle (AGV): Robot localization.

1. INTRODUCTION
With the tremendous evolution in industry, it can be observed that the involvement of automation in the industry has become greater and greater to cope with the high demand from the market. In industry, robotics and automation are widely used. From the manufacturing environment monitoring and control, product assembly process, to goods transfer in manufacturing warehouse, the contribution of automation cannot be neglected. The reason of implementing automation and robotics in industry is because the efficiency of the production can be greatly improved compared to traditional industry, which involves a lot of human interaction or in other words, labor dependent in the process. Traditional industry's process produces inconsistent results and lower performance in terms of efficiency, speed and cost compared to modern industry.

The main concern of this research is on the goods transfer process in manufacturing warehouse. As what have been mentioned, traditional industry is labor dependent. The goods in the warehouse are transported from one location to another location by labor manually, either with handheld or with forklift. This slows down the pace of the process, and mistake might occur during the process because of human error. Therefore, there is requirement of implementation of automation in this process for better performance. In the modern industry, labor or human interaction in goods transportation is minimized. Robots or Automated Guided Vehicles (AGV) carry the goods from one location to the desired destination in the warehouse.

AGV is a mobile robot which is well known in manufacturing plant, inventories of various industries and industry warehouse. It is normally implemented in industry as distribution system for logistics and handling of goods or materials used in industries[1]. Generally, AGVs must navigate in a guided environment. It can be guided by the landmarks or features in the maneuvering area. Since autonomous navigating task is the main requirement of the AGVs, therefore, self-localization or self-positioning is the crucial aspect for AGVs [1].

Self-localization is the ability to navigate autonomously in a certain environment and knowing its position along the process [2]. For AGVs in warehouse or industry, they need to be able to navigate to the desired location autonomously, and in order to perform this, firstly a very important information is required. This piece of information required is their own position in the environment. This is the reason why self-localization or robot localization plays the pivotal role in AGV. In general, AGV self-localization performance is contingent on the quality and amount of information that AGV acquires and utilizes. Self-localization's capability for AGVs is dependent on the following aspects:

i. The method for AGV to capture the key features of the environment [3]
ii. Various sources of information obtained to perform localization in the environment [3]
iii. The algorithm implemented to perform self-localization [3]

There are numerous methods for AGV to capture the key features of the environment. For example, sensors such as laser sensors [4], magnetic sensor [5], radio-frequency identification (RFID) [6] and vision sensor or camera [7] are widely used in industries to apprehend the notable features of the surrounding for localization [1]. With vision-based solution, the AGV works in a more flexible environment and has higher capability to adapt to an unfamiliar environment.

In order to do this, the algorithm needs to recognize the features or landmarks in the maneuvering area or around the warehouse. Artificial landmarks are commonly used in this field as they are easier to be detected compared to the natural landmarks or features in the maneuvering area [8]. Artificial landmarks are placed at the known location or coordinate in the maneuvering area. With the aids of landmarks, AGV needs to recognize the landmarks in the image capture and estimate the distance between the AGV and landmarks. Hence, a method is needed to estimate the depth or the distance between the AGV and the landmarks before moving on to the localization algorithm. To minimize the cost, monocular or single camera is preferred. Therefore, an algorithm to estimate with the distance between landmarks and AGV is required.

With the information of the landmarks, the position and orientation of the AGV in the warehouse environment is still unknown. Therefore, there is a requirement to come out an algorithm to process the information for the landmarks (e.g. landmarks' coordinate and distance). For AGV or mobile robot localization, the accuracy of the localization and the robustness on the algorithm to adapt environment change is a challenge.

2. RELATED WORK

There are numerous of researches about Automated Guided Vehicle (AGV) as the demand of automation in industrial logistics and transportation is increasing. Instead of just starting from the manufacturing system in the previous years, AGVs are also getting great involvement in repeating transportation tasks in other fields like warehouses, container terminal and external transportation system[9]. Therefore, researches about the improvement on AGV are kept going on in order to increase the efficiency of AGV in the industries. For AGV and mobile robot, localization and navigation are crucial problems, which have been studied by many researchers [7]. The accuracy of the of localization have direct impact on the navigation task performance and the overall efficiency of the AGV. Therefore, in this research, the focus is on localization algorithm. Few localization algorithms in previous researches will be discussed.

Before moving to localization algorithm, sensors are required to obtain environment information. For the AGV to localize itself, it is necessary to estimate its pose and position based on sensors information about the surrounding of the robot and environment [10]. In the previous researches and in the current industries, many types of sensors have been applied for AGV localization problem. For example, RFID, ultrasonic, laser range finder and others are utilized for AGV localization purpose [11], [12]. The use of sensors and methods for AGV in the previous research will be discussed in this chapter as well. Since camera with artificial landmarks are chosen as the methodology for AGV in this research, few visual methods to estimate distance between landmark and camera will be reviewed

2.1 Mobile Robot Localization

In the past decades, multiple approaches have been studied to solve the localization problem. Localization method can be classified into two groups, which are relative localization method and absolute localization method [13]. Both methods are discussed in the sections as follows.

2.1.1 Relative Localization

Relative localization is also called dead reckoning (DR) method. DR methods are used to calculate and estimate the total distance travelled, current position and orientation from initial pose or starting position [14]. There are two categories in dead-reckoning methods, which are odometry and inertial navigation [10].

Odometry is one of the most widely used navigation method for AGV or mobile robot positioning because of its good short-term accuracy, low cost, and high sampling rates. However, according to Borenstein et al. [8], the unbounded accumulation of errors for odometry is inevitable as its fundamental idea is the integration of incremental motion information over time. Orientation errors consequently causes large lateral position errors, which increases proportionally with distance travelled by the robot or AGV [8]. Odometry is based on simple equations that translates wheel revolutions into linear displacement. However, errors in translating the displacement will occurs in case of wheel slippage, the uneven floor surface and etc [8]. These errors can be classified into two types, which are systematic errors and non-systematic errors [15]. According to Borenstein and Feng [15], systematic errors are caused by the kinematic imperfection of the robot while non-systematic errors are mainly because of the interaction of floor and wheels of robot. For odometry, it is very important to have a quantitative measurement for odometry errors [8]. Without a well-defined measuring procedure for the quantification of odometry error, the result of calibration for mobile robot or AGV is poor and consequently, the odometrical accuracy is relatively low.

Inertial navigation uses accelerometers and gyroscopes to obtain the acceleration and rotation rate for localization [8]. Measurements from these two sensors are integrated to estimate the position of the mobile robot and according to Borenstein et al. [8], inertial navigation method has advantage that external references are not required. However, inertial navigation method needs to integrate rate data to estimate position, hence, tiny constant error might increase without bound after integration, and the inertial sensor data may drift with time. Thus, inertial navigation method or inertial sensors are not really efficient or appropriate to be deployed for long period localization task mobile robot [8].

As a nutshell, for relative localization or DR methods, the estimation error tends to accumulate over time and the error is getting more obvious if it is a long time localization task for AGV [16]. Hence, external sensors are required to provide external reference signals or information of environment for estimation error correction [17].

2.1.2 *Absolute Localization*

Absolute localization methods estimate the position and orientation of the robot by capturing the distinct features of a known environment [18]. Absolute position methods are reference-based, means these methods localize the robot by obtaining certain reference from the known environment. For example, in Seong et al. research [10], indistinguishable artificial landmarks were used as the references to yield the location of the mobile robot and reflectors were setup as artificial landmarks in an known environment in their research. According to Borenstein [8], there are five types of techniques for absolute localization, which are magnetic compasses, active beacons, global positioning system (GPS), landmark navigation and model matching.

Magnetic compasses allow the robot to know its absolute heading or orientation, however, it has a main disadvantage which is that the earth's magnetic field is often distorted near power lines or steel structures [8]. For this research, the scope is to develop a localization algorithm for AGV in manufacturing warehouse, which in manufacturing warehouse is often occupied with steel structure and power lines. Therefore, magnetic compasses are not suitable to be deployed in this case. Besides magnetic compasses, GPS is not selected in this project as GPS is meant for outdoor navigation [8]. The requirement of this project is to develop the AGV localization algorithm in indoor warehouse environment, therefore, GPS is not suitable.

Active beacons are one of the most common techniques or aids for mobile robot localization. Active beacons can be detected with ease and position information can be acquired with minimal processing [8]. However, even though this approach provides high sampling rate and high reliability, as a trade-off, its cost for installation and maintenance are also high. In this project, development cost is another concern and deploying beacons around the manufacturing warehouse is expensive. In previous research by Venet et al. [19], instead of deploying active beacons around the indoor environment, they only setup one active beacon which was composed of 3mW modulated laser(100MHz) in constant rotation on the wall of mobile robot's maneuvering area, and the receivers installed on the mobile robot. With this approach, the deployment cost was lowered. However, since it had only one beacon with rotating laser, that means, the detection speed was dependent on the laser rotating speed to complete one cycle, which could result in slow detection rate. Moreover, this only works while the AGV maneuvering area has no obstacle blocks the active beacon. In normal warehouse which consists of multiple racks, this approach is not suitable. Therefore, in this research, active beacons method is not selected.

Another method which is widely studied and commonly used in industrial for localization is using landmarks. Landmarks can be in any geometric shapes (e.g., triangle, circle, rectangle), or can be in any pattern (e.g., bar-codes, Quick Response codes). In the previous study by Taha et al. [20], bar-code artificial landmarks were used for mobile robot localization. Besides that, from another research by Zhang et al. [14], Quick Response (QR) code landmarks were placed at the ceiling of indoor in environment, and a camera which points to the ceiling was setup on mobile robot to perform AGV localization and navigation task. Landmarks have a known position on a known environment, which relatively enable the mobile robot to obtain its location or position in that known environment [8]. Landmarks must be designed with care so that landmarks can be easily detected and recognized. For instance, the color contrast of the landmarks need to be high enough relative to the environment [8]. Normally each landmark is unique, and each represents a location or coordinate of the mobile robot maneuvering area. There are two types of landmarks in general, which are natural landmarks and artificial landmarks. Natural landmarks are the distinct signatures from the environment itself such as the corner or edge, ceiling, doors, or surrounding objects [8]. Generally, camera with computer-vision algorithm is used to detect and recognize the landmarks and followed by localization algorithm. For natural landmarks, selection of features from the environment to be recognized is crucial as it determines the difficulty in feature description, detection, and matching and hence, the positioning accuracy is also affected [8]. In manufacturing warehouse environment, the racks and the surrounding are almost similar. Therefore, it is difficult to use natural landmarks in the warehouse environment as the features of environment are not unique. Artificial landmarks are specially designed markers that are placed in the environment or robot maneuvering are for the purpose of robot localization and navigation [8]. Artificial landmarks are easier to be detected compared to natural landmarks as they are designed with optimal contrast. Furthermore, since the size and shape of the artificial landmarks are known, with computer-vision processing, the geometric information of that landmark or the mobile robot can be calculated [8]. In previous studies, there are some cases where the researcher deployed QR code and Bar-code as artificial landmarks for localization purposes[4], [6], [21]. In Kobayashi's research [21], self-contained 2D landmark code was used for robot localization purpose. His proposed 2D code contained complete data set for localization (i.e. geometrical position, normal vector, physical size and shape). Figure 1. shows Kobayashi's proposed artificial landmark with self-contained information [21].

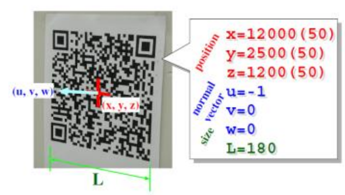

Figure 1. Self-contained 2D landmark code.

The main advantage of self-contained landmarks like what Kobayashi proposed is that, since the landmark itself already contained the position and information that needed for localization, extra database was not required to store the information of the landmark and extra training process for recognition was not necessary [21]. The localization was more effective compared to ordinary landmarks. In this research, artificial landmarks with computer-vision method is chosen because of its robustness and flexibility.

2.2 Mobile Robot Self-localization Approaches

There are numerous of researches have been carried out to enhance the mobile robot self-localization approaches and algorithm in terms of accuracy, robustness and efficiency (e.g., probabilistic map-based localization, triangulation approach, complex analysis method). The details of few localization approaches are discussed in the following section.

Trilateration technique is well-known in robot localization. It is a method of determining the position of an object based on simultaneous range measurements from three stations located at know sites [22]. It is not only used on robot localization, but also used in many fields such as aeronautics, kinematics, etc [22]. In robot localization, trilateration is used to determine the location of the robot with reference of at least three landmarks or beacons, depends on what sensor is used. Trilateration can be expressed as the problem finding the intersections of three spheres, or solving the following Equations [22]:

$$(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2 = l_1^2$$
$$(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2 = l_2^2$$
$$(x - x_3)^2 + (y - y_3)^2 + (z - z_3)^2 = l_3^2 \quad (1)$$

where

x_i, y_i, z_i (i = 1, 2, 3) are the coordinates of the landmarks/beacons

l_i (i = 1, 2, 3) are the distance measurements from the robot to the landmarks/beacons

Figure 2. shows the example of trilateration problem of robot localization with three landmarks.

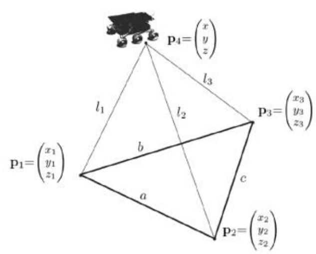

Figure 2. **Trilateration problem of robot localization with three landmarks.**

From Figure 2., the equations from equation 1 can be simplified to be two linear equations and one quadratic equation, which is illustrated in Equation 2 [22]:

$$(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2 = l_1^2 \quad x(x_2 - x_1) + y(y_2 - y_1) + z(z_2 - z_1) = \frac{l_1^2 + l_2^2 + a^2}{2} \, x(x_3 - x_1) + y(y_3 - y_1) + z(z_3 - z_1) = \frac{l_1^2 + l_3^2 + b^2}{2} \quad (2)$$

where

a = $\|p_2 - p_1\|$

b = $\|p_3 - p_1\|$

The equations can be further simplified by expressing the landmarks coordinates based on the specific coordinate system.

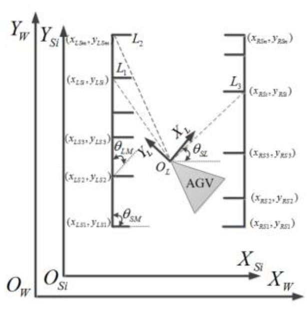

Figure 3. **Coordinate system of AGV with AGV's and landmarks' location.**

In the research of Gao et al. [23], trilateral technique was used to perform AGV self-localization. In their research, laser range finder was used to detect the landmarks placed in the mobile robot maneuvering area. The landmarks placement was optimized with heuristic algorithm, Genetic Algorithm (GA) so that the AGV can always detect at least three landmarks in the area [23]. Then, with the three landmarks detected and distances between the AGV and landmarks measured, triangulation or trilateral technique was implemented to determine the position of the AGV. Figure 3. illustrates the coordinate system used in Gao et al.'s research [23].

In their research, the Equation 2 was further simplified to Equation 3 based on their coordinate system.

$$\theta_{SL} = \theta_{SM} - \theta_{LM}$$
$$(x_{SL} - x_{S_{L1}})^2 + (y_{SL} - y_{S_{L1}})^2 = x_{L_{L1}}^2 + y_{L_{L1}}^2$$
$$(x_{SL} - x_{S_{L2}})^2 + (y_{SL} - y_{S_{L2}})^2 = x_{L_{L2}}^2 + y_{L_{L2}}^2 \quad (3)$$

By solving Equation 3, (x_{SL}, y_{SL}) can be calculated and the location can be estimated with Equation 4.

$$x_{WL} = x_{SL} - x_{WS}$$
$$y_{WL} = y_{SL} - y_{WS}$$
$$\theta_{WL} = \theta_{SL} \quad (4)$$

where x_{WL} and y_{WL} are the coordinate of the AGV, whereas θ_{WL} and θ_{SL} are the angle of the AGV to the landmarks (left and right). For this method, there is an obvious limitation, which is the camera on the mobile robot or AGV must detect or "see" at least three landmarks. Besides that, the coordinates of the landmarks in global map need to be known to estimate the position of the mobile robot in global coordinate. Moreover, the distance from each landmark to the mobile robot need to be known as well.

3. METHODOLOGY

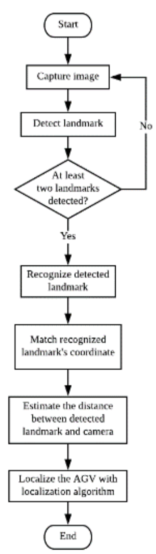

Figure 4. Flow chart of research methodology. landmark detection and recognition.

From the previous work by Gao et al. [23], improvement can be made by reducing the landmarks required to be detected from three to just two in this research. The high-level methodology of AGV localization algorithm are divided into three main parts. It begins with landmark detection and recognition, which includes the pre-processing of images to filter the unnecessary background and noise. Then, landmarks in the warehouse environment are detected and recognized with image segmentation method and Optical Character Recognition (OCR) method. With the detected and recognized landmarks, the distance of each detected landmarks is estimated. The method used in this part is using the similar triangle theorem on geometry of pinhole camera model. Then, with the information (e.g., coordinates of detected landmarks, distance of detected landmarks), the location of the camera or AGV can be estimated. The overall process is illustrated in Figure 4. with the presentation of flow chart.

Since it is to be a landmark based AGV localization. Therefore, before localization is done, the ability to detect and recognize the landmark is crucial. The environment at the warehouse is complicated, and same for library in USM engineering campus and mechatronics laboratory. Therefore, to avoid misrecognition of landmarks due to the environment background, landmarks need to be detected or segmented before recognition. The following section discusses the methodology used to segment out the landmarks and landmark recognition.

3.1 Landmark Detection and Segmentation

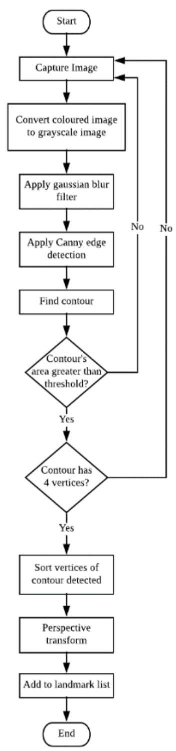

Figure 5. Flow chart of landmark detection.

There are many methods to detect or segment out the landmarks from the image captured by the camera. For example, template matching can be used to identify the landmarks in the image. However, the background can be too complicated. Therefore, there is high chance of mismatch of feature points of landmarks. Besides that, there are too many feature points captured from the background as well. Therefore, after several experiments of detecting the landmarks with template matching, decision was made to use edge detection because of the poor results compared to the edge detection method. It is because the landmark is intentionally designed to have maximum contrast, which is black pattern and symbol with white background. Therefore, the edge of the landmarks in the image can easily be detected. However, with edge detection method, not only the edges of the landmarks are detected, but all the edges from the complicated background is shown up as well. Therefore, after detecting all the edges in the image, additional process is still required to differentiate out the edges of landmarks, and the edges from the background. Figure 5. describes the overall process of detecting landmarks from the image.

3.2 Landmark Recognition

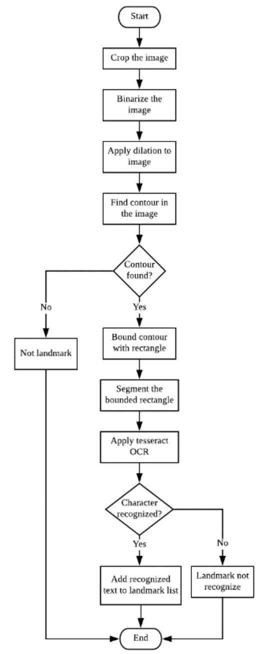

Figure 6. Flow chart of image recognition.

The segmented and transformed landmarks are to be recognized so that the global coordinate the landmarks can be determined for localization purpose. The symbol or the characters are located at the center of the landmark, therefore, in order to reduce the mismatch rate, the letters need to be segmented out and then recognized. Figure 6. shows the flowchart of landmark recognition.

In character recognition part, a classifier required to classify or recognize the characters in the image. In this project, Tesseract is used to recognize the characters in the landmark. Tesseract is one of the open-source OCR engines commonly used by developer [24]. Tesseract has its existing model data or trained data available, therefore, the trained data available can be applied directly to recognize the landmark. However, in the landmark design, two characters are not used in order to reduce the landmark mismatch rate, which are 'O' and 'Q'. Besides that, only capital letters are used in the landmark and numbers are not involved. Hence, there is a requirement to retrain the data instead of just using the available trained data provided by Tesseract. To train the data for tesseract, a third-party software is required. The third-party software used to retrain the data is "JTessBoxEditorFX".

3.3 Landmark Distance Estimation

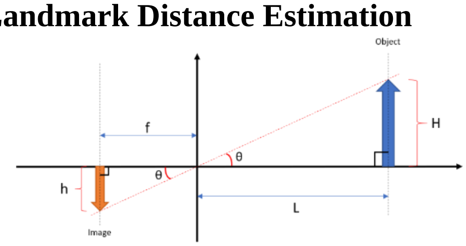

Figure 7. 2D pinhole camera model.

With the landmark recognized, the next piece of information that is required for AGV localization is the distance between the AGV or camera, and the landmarks. Since only single camera is used in this project, the common method used to estimate the distance like stereo-vision method cannot be applied. The method used to estimate the distance of the landmark is based on the pinhole camera model. The 2D pinhole camera model is shown in Figure 7.

where

H = Height of the landmark in real scene

L = Distance between camera and landmark in real scene

h = Height of the landmark in image in unit pixel

f = Focal length of camera in unit pixel

With similar triangle theorem, Equation 5 can be derived.

$$\frac{H}{L} = \frac{h}{f} \tag{5}$$

Height of the landmark is known which is 180mm. However, the focal length of the camera in pixel is unknown parameter initially and without knowing this parameter, it is impossible to estimate the distance between the camera and landmark, L by using Equation 5. Therefore, focal length of the camera in pixel has to be identified during calibration stage. In order to obtain the focal length of the camera in pixel, Equation 5 can be expressed as shown in Equation 6.

$$f = \frac{hL}{H} \tag{6}$$

Therefore, to calibrate or to calculate the focal length in pixel of the camera, f few images with known distance between landmark and camera, L were taken. For calibration, images were taken at eleven different distance between camera and landmark. Images were taken at distance of 0.75m, 1.0m, 1.25m, 1.5m, 1.75m, 2.0m, 2.25m, 2.5m, 2.75m and 3.0m. The known distance between the landmark and camera was measured by using measuring tape and its resolution is 1 mm.

Since the focal length of the camera is known during calibration, Equation 6 can be expressed as shown in Equation 7 to estimate the distance between the landmark and the camera.

$$L = \frac{k}{h} \tag{7}$$

where

k = H x f

The constant k can be calculated with known H and f during calibration. Therefore, only the height of landmark in image, h needs to be calculated to estimate the distance, L. In order to do that, the same process while calibrating the camera is used.

3.4 Localization

With the information (e.g., distance between landmarks and camera, detected landmarks and global coordinate of detected landmarks), the location of the AGV can be calculated. Instead of using triangulation which requires at least three landmarks detected to estimate the location, the proposed method only requires two landmarks to be detected to perform localization, of course, with trade-off and it will be discussed in the following section. Figure 8 describes the overall process of localizing the AGV with the information acquired.

At the beginning, two landmarks which are nearest to the camera are selected to estimate the location of the camera. The nearest landmarks are chosen because the further the landmarks, the greater the error during distance estimation. Hence, the error in localization is smaller if nearer landmarks are used. With the two landmarks selected, the next step is to estimate the possible locations of the AGV by using the concept of intersection of two circles.

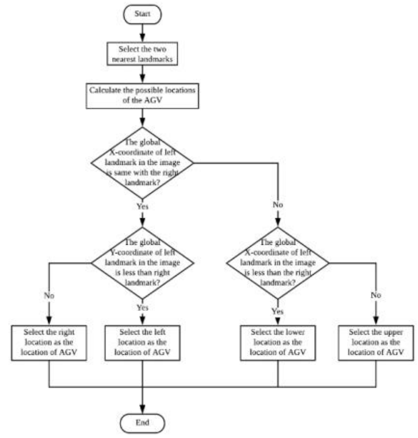

Figure 8. Flow chart of localization.

Consider the two selected landmarks as the center of two circles, and the distance between the two landmarks and AGV as the radius the circles respectively. Figure 9 illustrates two circles and their intersection points.

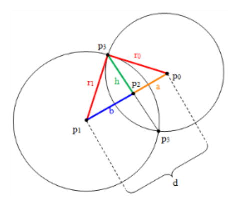

Figure 9. Concept of two circles.

From Figure 9, consider p_0 and p_1 are the locations of the two nearest landmarks detected, with coordinate (x_0, y_0) and (x_1, y_1) respectively. p_3 are the two possible locations of the AGV and p_2 is the intersection point of the line formed by two landmarks, and two possible positions of AGV. r_0 and r_1 are the radius of two circles, which represent the distance between the landmarks and the AGV. Then, by using Pythagoras' theorem, Equation 8 can be obtained.

$$h^2 = {r_0}^2 - a^2$$
$$h^2 = {r_1}^2 - b^2 \tag{8}$$

By using distance between two landmarks, $d = a + b$, a can be solved from Equation 9.

$$a = \frac{({r_0}^2 - {r_1}^2 + d^2)}{2d} \tag{9}$$

Since the a is solved, h can be solved from Equation 8. Then, the coordinate of point p_2 can be identified by using Equation 10.

$$x_2 = x_0 + \frac{a(x_1 - x_0)}{d}$$
$$y_2 = y_0 + \frac{a(y_1 - y_0)}{d} \tag{10}$$

With coordinate of p_3, distance between two landmarks, and h are known, the possible coordinates of the AGV can be estimated by using Equation 11.

$$x_3 = x_2 \pm \frac{h(x_1 - x_0)}{d}$$

$$y_3 = y_2 \mp \frac{h(y_1-y_0)}{d} \quad (11)$$

where x_3 and y_3 are the possible x and y coordinate of the intersection point of the circle, or the location of AGV.

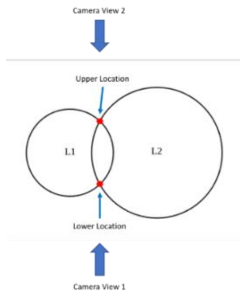

Figure 10. Scenario when both landmarks have different X-coordinate.

After obtaining the possible locations of the AGV, there is one last step to determine the exact location of the AGV from these two possible locations. The method to estimate the exact location of the AGV is through determining the direction of camera views or by observing where the landmarks are located.

There are two possible scenarios when determining the location of the AGV. Figure 10 and Figure 11 illustrates the two possible scenarios. Figure 10 displays the scenario when the two landmarks detected have the different x-coordinate and Figure 11 shows the scenario when two landmarks detected the same x-coordinate. The red dots represent the possible locations of the AGV or camera and the thick arrow is the direction of the camera heading. If the direction of the camera heading or orientation of the AGV heading is different, the landmarks will appear in different position in the image.

For Figure 10, for the case of the detected landmarks have different x-coordinate, the possible location of the AGV can be at lower or upper location. If the AGV is located at lower location, or the camera is heading forward, the landmark, L1 will appear at the left side of the image while the landmark L2 will appear at right side and vice versa if the AGV is at upper location. Therefore, the exact location of the AGV can be determined by checking which landmark is at the left side and which landmark is at the right side in the image. In case when the detected landmarks have same x-coordinate or both landmarks are at the same column, the possible location of the AGV will either at the right location or left location. By applying the same theory, the exact location of the AGV can be identified by determining which landmark is at left or right side in the image.

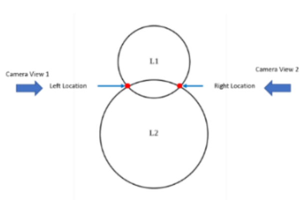

Figure 11. Scenario when both landmarks have same X-coordinate.

To sum up, if both landmarks have different x-coordinate, and if the landmark with smaller x-coordinate value is located at the left side in the image with the landmark has greater x-coordinate located at right side, then the exact location of the AGV is at the lower location from the two possible locations that have been estimated in previous step. The location of the AGV is at the upper location if vice versa. If the landmarks are located at the exact same column or having same x-coordinate, and if landmark with smaller x-coordinate is located left side in the image and with landmark with greater x-coordinate located at right side in the image, then the exact position of the AGV is at the left location. The AGV is located at the right for another case.

4. RESULTS AND DISCUSSION

The information required to localize the AGV (e.g., recognized landmarks, coordinate of the recognized landmarks and distance between AGV and the landmark) were obtained. 60 sample images were taken randomly in dedicated area of library and Mechatronics laboratory II in USM engineering campus respectively. The locations of the AGV or camera were estimated with distance estimation results obtained. The results are then compared with the results calculated by using measured distance.

Out of 60 samples data, total 22 cases were failed. From the other 38 cases, the average difference between the results estimated with algorithm and results obtained with measurement is 237.29mm. The main cause of failure in localization was due to the error in distance estimation. The distance estimated between landmark and camera was less than the real distance and during localization. Since method of intersection of two circles was used, the failure of localization occurred when no intersection point found. Figure 12. describes the scenario of the cause of failure.

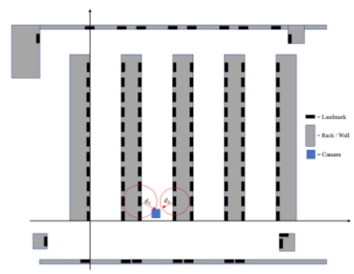

Figure 12. Scenario of failure of localization.

From Figure 12, d_1 and d_2 are the distance estimated between two landmarks respectively and those are the radius of two circles. d_2 is estimated wrongly and less than real distance value, therefore, there is no intersection point found between two circles.

Besides that, there were cases where the failure caused by misrecognition of landmark. Figure 13 shows one of the failures caused by misrecognition of failure.

Figure 13. Failure caused by misrecognition of landmark.

From Figure 13, landmark “CD” was recognized as “CIZ”. Since there is no “CIZ” landmark in the database, localization was not able to be done and as a result, failure was caused. There were few more cases that have the similar issue.

5. CONCLUSION

As a conclusion, the landmark-based automated guided vehicle localization solution for warehouse application has been developed with integration of landmark detection, recognition, landmark distance estimation and localization. The proposed landmark based AGV localization algorithm for warehouse application is able to localize the AGV with average error of ±250mm. The orientation of the AGV cannot be estimated by using the proposed algorithm as for now, the algorithm can only determine the coordinate of the AGV. The proposed solution is flexible to the changes of the layout of the environment by just editing the content in the map layout file (text file). Indeed, the performance of the proposed algorithm is not perfect and decent enough compared to the existing AGV localization solution with advance sensor. However, the cost of the proposed solution is lower than the existing solution in the market as only single camera is required. With improvement to the proposed solution, the solution can be implemented in the industry and enhance the efficiency of logistics in the industry.

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7. REFERENCES

[1] A. K. Kar, N. K. D., S. S. F. Nawaz, R. Chandola and N. K. Verma Automated Guided Vehicle Navigation with Obstacle Avoidannce in Normal and GUided Environments. *2016 11th International Conference on Industrial and Information Systems (ICIIS)*2016), pp. 77-82.

[2] Maniscalco, U., Infantino, I. and Manfre, A. Robust Mobile Robot Self-Localization by Soft Sensor Paradigm. *2017 IEEE International Symposium on Robotics and Intelligent Sensors (IRIS)*2017), 19-24.

[3] Olson, C. F. Probabilistic self-localization for mobile robots. IEEE *Transactions on Robotics and Automation*, 162000), 55-66.

[4] Markom, M. A., Adom, A. H., Shukor, S. A. A., Rahim, N. A., Tan, E. S. M. M. and Irawan, A. Scan matching and KNN classification for mobile robot localisation algorithm. *2017 IEEE 3rd International Symposium in Robotics and Manufacturing Automation (ROMA)*2017), 1-6.

[5] Chao, H., Zhongqing, F., Yupeng, R., Yueyue, C., Haixiang, L., Xiaodong, W. K. and Jianmeng, B. An efficient magnetic localization system for indoor planar mobile robot. *2015 34th Chinese Control Conference (CCC)*2015), 4899-4904.

[6] Sanpechuda, T. and Kovavisaruch, L. A review of RFID localization: Applications and techniques. *2008 5th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, 22008), 769-772.

[7] Biswas, J. and Veloso, M. Depth camera based indoor mobile robot localization and navigation. *2012 IEEE International Conference on Robotics and Automation*2012), 1697-1702.

[8] Borenstein, J., Everett, H. R., Feng, L. and Wehe, D. Mobile Robot Positioning: Sensors and Techniques. *Journal of Robotic System 1997*1997), 231-249.

[9] Hossain, S. G. M., Jamil, H., Ali, M. Y. and Haq, M. Z. Automated guided vehicles for industrial logistics - Development of intelligent prototypes using appropriate technology. *2010 The 2nd International Conference on Computer and Automation Engineering (ICCAE)*, 52010), 237-241.

[10] Seong, J., Kim, J. and Chung, W. Mobile robot localization using indistinguishable artificial landmarks. *2013 10th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI)*2013), 222-224.

[11] Joglekar, A., Joshi, D., Khemani, R., Nair, S. and Sahare, S. Depth Estimation Using Monocular Camera. *International Journal of Computer Science and Information Technologies (IJCSIT)*, 22011), 1758-1763.

[12] Wang, G. and Yang, K. A New Approach to Sensor Node Localization Using RSS Measurements in Wireless Sensor Networks. *IEEE Transactions on Wireless Communications*, 102011), 1389-1395.

[13] Font, J. M. and Batlle, J. A. Mobile Robot Localization. Revisiting the Triangulation Methods. *IFAC Proceedings Volumes*, 392006), 340 - 345.

[14] Zhang, H., Zhang, C., Yang, W. and Chen, C. Localization and navigation using QR code for mobile robot in indoor environment. *2015 IEEE International Conference* on Robotics and Biomimetics (ROBIO)2015), 2501-2506.

[15] Borenstein, J. and Feng, L. Measurement and correction of systematic odometry errors in mobile robots. *IEEE Transactions on Robotics and Automation*, 121996), 869-880.

[16] Park, H. R., Hyun, D. J., Yang, H. S. and Park, H. S. A dead reckoning sensor system and a tracking algorithm for mobile robot. *2009 ICCAS-SICE*2009), 5559-5563.

[17] Park, S. and Hashimoto, S. Indoor localization for autonomous mobile robot based on passive RFID. *2008 IEEE International Conference on Robotics and Biomimetics*2009), 1856-1861.

[18] Shan-shan, C., Wu-heng, Z. and Zhi-lin, F. Depth estimation via stereo vision using Birchfield's algorithm. *2011 IEEE 3rd International Conference on Communication Software and Networks*2011), 403-407.

[19] Venet, T., Capitaine, T., Hamzaoui, M. and Fazzino, F. One active beacon for an indoor absolute localization of a mobile vehicle. *Proceedings 2002 IEEE International Conference on Robotics and Automation (Cat. No.02CH37292)*, 12002), 1-6.

[20] Taha, Z., Mat-Jizat, J. A. and Ishak, I. Bar code detection using omnidirectional vision for automated guided vehicle navigation. *International Conference on Automatic Control and Artificial Intelligence (ACAI 2012)*2012), 589-592.

[21] Kobayashi, H. A new proposal for self-localization of mobile robot by self-contained 2D barcode landmark. *2012 Proceedings of SICE Annual Conference (SICE)*2012), 2080-2083.

[22] Lee, S. C., Choi, J. S. and Lee, D. Trilateration based multi-robot localization under anchor-less outdoor environment. *2012 7th International Conference on Computer Science Education (ICCSE)*2012), 958-961.

[23] Gao, X., Wang, J. and Chen, W. Land-mark Placement for Reliable Localization of Automatic Guided Vehicle in Warehouse Environment. *Proceedings of the 2015 IEEE Conference on Robotics and Biomimetics*2015), 1900-1905.

[24] Smith, R. An Overview of Tesseract OCR Engine. *Ninth International Conference on Document Analysis and Recognition (ICDAR 2007)*2017), 629-633