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Development of aFree-Navigation Mobile Robot System Based on a Digital Image Processing Methodology

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Abstract

This paper presents the development of an image processing methodology as a scanning technique with the ability to detect static and dynamic objects in the environment of a mobile robot. The aim of the proposed methodology was to achieve free-navigation of the mobile robot. Digital cameras were thus used to explore the area around the robots as part of robot control system. A Kinect device using the proposed algorithm was thus used gain information about adjacent objects, such as their size, location, and colour. The percentage error in objects location and dimensions was less than 1.65% based on the experimental results.

Keywords: Image Processing Methodology; Kinect Device; Mobile Robot; Free-Navigation.

1. Introduction

Due to the development of mobile robots control systems in the attempt to reach an autonomous state of motion studying the available choices of controller system components for best performance is of interest. In the last decade, the performance and robustness of mobile robot control systems has been improved in terms of solving navigation problems, yet acquiring environmental knowledge remainsone of the most important tasks of control system in order to deal with path planning and execution activates. Several types of sensors are used as detectors to allow mobile robots to obtain information about their environments. These can be classified as passive and active sensors. The information from these sensors is applied in the mobile robot control systems to re-plan collision-free path activity.The use of a laser sensor as one of these detectors was presented in **[1]**, with laser and digital camera devices submitted in **[2]**. Sonar sensors were proposed in **[3]**, and ultrasonic sensors submitted in **[4]**. Radio frequency waves were presented in **[5]**, and different types of digital cameras were also used as effective robot sensors. Here, image processing was implemented to analyse the data from a mobile robot environment based on images from various types of cameras which were applied and erected in different ways. In **[6]**, an overhead camera, which was erected above the area of traverse, was used to collect information about the environment, robot, obstacles, and goal positions at all times. An omni-directional vision type camera was erected on a mobile robot in **[7]** for dynamic object tracking, and the desired coordinates for the mobile robot obtained from image processing. A web camera was used to identify objects in the robot environment, and the image processing used as part of a control system for a mobile robot to follow a movable part in **[8]**; throughout this process, the image was compared with stored images to allow the robot to move forward to the desired location; IR was thus used to detect obstacles to avoid collision. Digital Video Camera was used as attitude estimator to supply information about robot direction in trajectory tracking for a feedback controller in **[9]**. The depths of the objects relative to the robots formed one of the most important parameters, which was needed to determine the path of the mobile robot in the unknown environment.The Kinect device is a new technique that was presented by **[10]**, which measures the objects' depths. In that paper, it was shown that the error in the recorded depth was dependent on the location of the object in front of the Kinect device. The error ranged from a few millimetres up to four cm at the full range of the device. A stereo vision technique also was used to define the obstacles' location and to measure the distance from the mobile robot. Two cameras were used in **[11]** that were erected parallel at a fixed distance to obtain stereoscopic output images.Triangulation was applied to compute object location relative to the cameras based on position in the images and the specification of the cameras and their locations.

In this paper, further digital image processing is applied to obtain information about the robot environment. A proposed algorithm is used in conjunction with the Kinect device to scan the environment and obtain detailed information of the objects around the robot, including their position, size, location, velocity, and colour.

2. Object Detecting

Image processing was applied to obtain information about the mobile robot's environment. A digital image can be represented by a two-dimensional function f(x, y) which represents the intensity of an image at a given location.When the digital image is analysed using a computer, this process is called digital image processing **[12]**. Each digital image can thus be represented by a two dimensions matrix with M rows and N columns. Each element is specified as the intensity of the image at that location. These elements, which have particular locations and values, are called picture elements or pixels, and they are

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proportional to the source illumination and the amount of illumination reflected by the objects.In general, digital images can be classified into four groups **[13]**:

1. Grayscale image.
2. Binary image.
3. Indexed image
4. RGB image.

To gain information about an object, it's edges must be specified. In an object image, there is a subset of pixels that represents the object. In this region, there is a set of pixels with at least one neighbouring pixel not within that subset of pixels. The boundary of the region is defined by this set of pixels.In these edge regions, there are discontinuities in the image intensity values. This type of discontinuity can be discovered by examining derivatives of the image function f(x, y).

The vector which determines the first-order derivative, as seen in **[13]**, is

$$\boldsymbol{\nabla f} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The magnitude of this vector is thus

$$\nabla f = \left[(\partial f/\partial x)^2 + (\partial f/\partial y)^2\right]^{\frac{1}{2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

and the second-order derivative is in the form

$$\nabla^2 f(x,y) = \frac{\partial^2 f(x,y)}{\partial x^2} + \frac{\partial^2 f(x,y)}{\partial y^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

The derivatives are zero in areas of constant intensity, and the magnitude values are dependent on the intensity variation. The edges in an image can be detected based on the greatest value of the first derivative in a given threshold. The second-order derivative can also be utilised to detect those edge locations which are in the zone of zero intersection of the edges in two directions. These edges are places in the image in the zone with a higher intensity value gradient. Using the first derivative, the edge region can be defined as the place with the highest value of this derivative; using the second derivative, it is the place with zero value. The edges of images can thus be detected by using one of these two criteria, and several estimators can be used for edges detection. These include the

a. Sobel edge detector
b. Prewitt edge detector
c. Roberts edge detector
d. Laplacian of a Gaussian detector
e. Zero crossings detector
f. Canny edge detector

The first derivative is used for the first three methods.The main difference between them is the type of mask used to digitally approximate the derivatives in the x and y direction of the image. The second derivative for the Gaussian function is used for the Laplacian of Gaussian and Zero crossing detectors. In the final two detectors listed, the Gaussian function is used as a smoothing filter then the second derivative for the function is computed. With the Canny method, a Gaussian filter is used and the local gradient (∇f) for each point is computed per equation (1). The local maximum value of the gradient represents the location of the edge point. Tracking along the computed edge points after setting all other points to zero produces a fine line. Then two thresholds are used to detect the image edges **[14]**. The Canny method is widely used in image processing because it is the preferred operator for edge detection **[15]**. In this work, an algorithm is thus proposed to determine obstacles locations, dimensions, and velocities, when the obstacles are in motion based on data from a Kinect device used as motion detector for a wheeled mobile robot.

The steps of the proposed algorithm are:

- When the system starts, colour image frames and depth image frames are received at a rate of thirty frames per second.
- Two frames from each sensor are force recorded, and the time period between them is also recorded.
- For each depth image frame, a three dimensional matrix is developed from the xyd cloud points produced by the streamed depth frames in comparison with the fixed one.
- The distances between any obstacles and the Kinect are recorded.
- The recorded colour image frame is converted to grayscale form with the same luminance in order to prepare the image for edge detection.
- A filter is used on the gray scale image to reduce noise, and it is then converted to a binary image by replacing all pixels of luminance greater than 0.5 with ones and all others with zero values.
- A small rectangle is determined that includes each object. The centre of this region and its outer coordinates are specified.
- A calibration procedure is done to compute the location of any object relative to the Kinect device's local coordinates, which are also the robot's coordinates. The calibration process begins by reading

the location of the centre and edges of the object from the binary image frame for different depths, and then the relationship between the position and the dimensions in two directions and the pixels locations in the binary images is calculated. A third-degree polynomial equation is used to fit the data withinthe calibration process.

- If the locations of the centres of the two frames are the same, the obstacle is in static state and its dimensions and position relative to the robot becomes known.
- For dynamic obstacles, the dimensions will be computed, and the speed of the object, which is assumed to be constant, and its direction can then be calculated by recording the position of the object centre point in the x-direction (left or right relative to the device) and d-direction (perpendicular distance) when the period of recorded frames starts and finishes. From the change of position of the centre in the x and d directions, the object velocity can be calculated as a vector summation result of x and d directions.

Where any object is presentin the robot environment, after using the proposed image processing algorithm to obtain the object's data (dimensions and location), the track in the obstacle area will be modified to avoid collision.

3. Experimental Results:

The Kinect device was used as motion detector for the mobile robot as is shown in figure (1). The output frames of the device are 480×640 pixel resolutions and thirty frames per second. In order to employ the Kinect device with the MATLAB toolbox, a computer installation process was required to obtain depth and RGB images. The process included **[16]**

1. The installation of SDK v. 1.8, a Windows toolkit.
2. The installation of the Windows support package for Kinect.

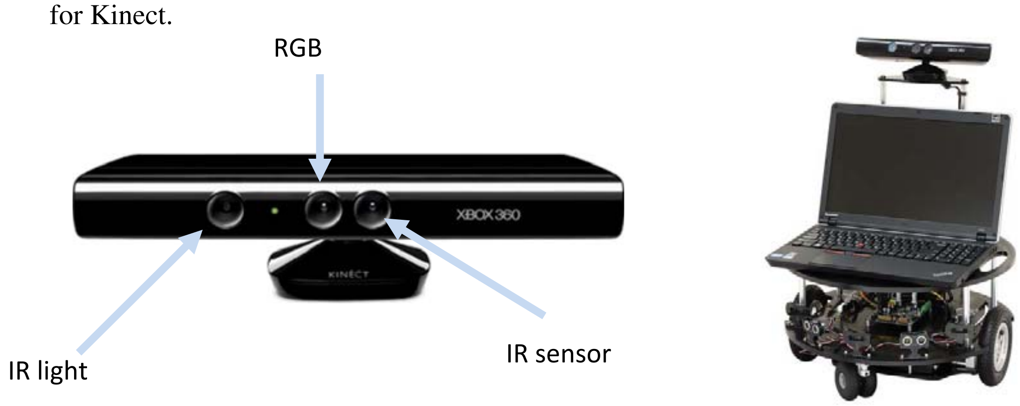

Figure (1): Kinect device with mobile robot.

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A MATLAB program was required for the proposed algorithm as this was used to detect the obstacles and to define their dimensions and velocities. The program can be also used to detect obstacles with a desired colour. The proposed algorithm includes the possibility of discrimination dependent on the obstacle colour in addition to the determination of its location relative to the Kinect device and the computation of its dimensions from the digital image data. To clarify the effectiveness of the algorithm in objects detection using the Kinect device and MATLAB program, static objects with different colours were applied and the blue objects selected to be detected. The results of the application were as follows:

Initially, a color image (RGB), as in figure (2), was received from the Kinect device when the program was started. Different objects were shown in the colour image. The colour image frame is represented by three 640 x 480 matrices, one for each primary colour (R, G, and B). Blue colour objects were selected for the test. After the digital image was received, it was transformed to a grayscale image, as in figure (3.A) with integer value elements ranging from (0 to 225). As seen in the plate, the digital image contained only the details of those objects with the blue colour as selected. The grayscale image with high noise required further processed for clarity, however, to reduce the noise, a filter was applied to clarify the image features then. The digital image was clarified as in figure (3.B), this sharper grayscale digital image was then converted to a binary image, presented by a matrix of values zero or one for each element, removing all non-essential details. A threshold for pixel luminance was used in which values higher than 0.5 were converted to ones and all other values to zero, so the image appearedas in figure (3.C). The positions of the corners of the binary digital image in the 480× 640 image matrix were recorded and the dimensions and the locations of objects computed from those positions in the matrix. To verify the effectiveness of the proposed algorithm in terms of determining the objects' dimensions, a comparison was made between the real position and the dimensions of the blue objects existing alongside the other rectangular shapes with deferent colours as shown in figure (4). The real distance between the Kinect and the blue rectangular shape face was about 108.3 cm, and the object was 12 cm in face length and less than 9 cm in height, as shown in figure (5).

Figure (2): RGB image captured by Kinect

A.

B.

C.

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Figure (3): (A) Grayscale digital image (B) Grayscale after filtering process,
(C) Binary digital image.

Figure (4): True position of the three colour objects.

Figure (5): Objects face images.

In terms of position data, the centre point of the object body, as shown in figure (6), deviated slightly more than 3 cm towards the left of the line passing through the centre point of the Kinect device, which was presented as the y coordinate of the area plane. The result of the running a program to compute the position and the dimensions of the desired object in blue were read from the output of the program seen in figure (7). From these results, it can be observed that the real dimensions closely matched the program output and the error in the object length, as an example, represented only 1.633% of the real dimensions. This percentage of error is sufficient for re-planning activity within the proposed controller to allow a mobile robot to proceed according obstacles' locations and dimensions.

Figure (6): Object centre point position

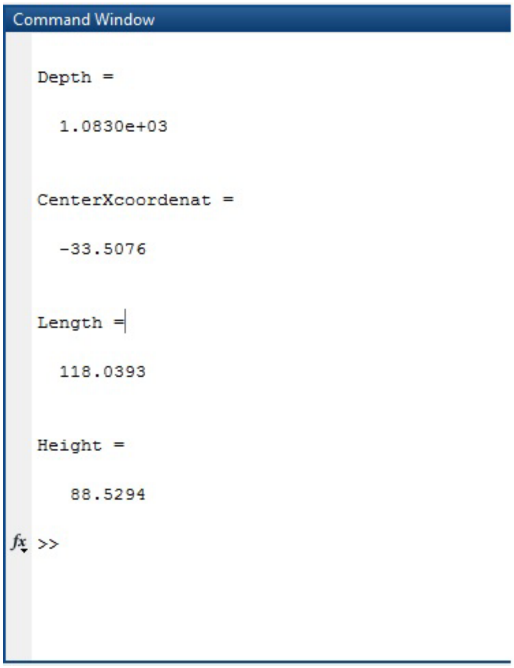

Figure (7): Obstacles detecting program results.

4. Conclusions

An image processing technique to be used as a detecting option for static or dynamic obstacles in mobile robot control systems was presented in this paper. A Kinect device was used as a detecting sensor, with a proposed algorithm used to specify the position, dimensions and velocity of objects surrounding a mobile robot. The experimental results verified the effectiveness and the capability of the presented technique with a percentage error in terms of objects location and dimensions of less than 1.65% . The proposed algorithm was also applied to discriminate objects colours for some applications.

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