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A new hybrid stereovision-based distance-estimation approach for mobile robot platforms☆

Serdar SOLAK[a], Emine Doğru BOLAT[b,*]

[a] Kocaeli University Department of Informatics, Umuttepe Campus Izmit KOCAELI, Turkey
[b] Kocaeli University Faculty of Technology Biomedical Engineering, Umuttepe Campus Izmit KOCAELI, Turkey

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A B S T R A C T

In this paper, a new hybrid stereovision-based distance-estimation approach is proposed for indoor mobile robot platforms. To calculate the distances between the robot and object, triangulation method is used first. However, this technique is insufficient for objects located on the left or right side of the robot or the case of the stereo camera pair fixed to the robot with an angle down to the floor. Therefore, a new approach is proposed by adding a look-up table and curve-fitting methods to the triangulation technique. In this approach, the stereo camera pair is located on the robot with an angle down to the floor. In the experimental studies, an average accuracy rate of 97.69% is obtained. The Manhattan and Euclidean distances of objects that are not in the same line as the robot are also calculated. Average accuracy rates of 98.24% for Manhattan and 98.03% for Euclidean distances are achieved.

1. Introduction

For effective navigation by mobile robots in an environment, it is required to detect objects such as obstacles and the target successfully. Furthermore, it is essential that the various distances are known during the navigation of the robot. In the literature, different sensors, such as laser, sonar, camera and Kinect are used for distance estimation and mobile robot navigation [1].

Human beings can roughly estimate the sizes, dimensions and distances of objects. This is because human beings' vision is stereovision. The number of recent studies on distance estimation and motion planning of mobile robots concentrating on the stereovision technique is increasing. Being conscious of the dimensions of objects and determining the distances between the robot and objects are essential for the proper motion of a mobile robot. In this paper, a new low-cost stereovision-based distance-estimation approach is proposed for the navigation of mobile robots. During this navigation, it is fundamental for mobile robots to detect objects and determine the required distances. In this proposed approach, the Object Detection Process and the determination of the coordinates of the objects are performed first. Then, the distance-estimation process is achieved.

Several studies on stereovision-based distance estimation and obstacle detection are found in the literature. The triangulation technique resulting from the geometric structure of stereovision is commonly used in studies on distance estimation.

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* Corresponding author.
E-mail addresses: serdars@kocaeli.edu.tr (S. SOLAK), ebolat@kocaeli.edu.tr (E.D. BOLAT).

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In addition, the look-up table and hybrid methods are also employed. From a literature review, the studies on stereovision and distance estimation since 2009 are listed as follows.

In 2017, Yoo et al. proposed a distance-estimation method based on frequency analysis using a stereo camera. Disparities are calculated directly from the frequency-domain analysis. They stated that their method is convenient for real-time applications of autonomous vehicles and provides an improvement of up to 10% [2,3].

In 2016, a disparity estimation technique for stereovision system was proposed and realized on Field Programmable Gate Array (FPGA) [4]. In 2016, Ferreira et al. developed a stereovision-based real-time embedded system achieving object detection, calculation of its center of mass and restoration of the underwater images used for underwater robots [5]. In 2016, Li et al. suggested a stereovision-based three-dimensional (3-D) mapping system. A vehicle was used as a tracked robot navigating the environment with the proposed system and performed the 3-D mapping of the environment [6]. In 2016, Juang et al. studied detecting an object having different colors and a complex background. They also performed a study estimating the shape and depth of the object [7].

In 2015, Solak and Bolat proposed a stereovision-based model including only the triangulation technique for embedded systems. In this study, the case that the objects were in the same line as the stereo camera pair was used and an accuracy rate over 90% was achieved [8]. In 2015, Govindiya et al. performed a real-time distance estimation of the objects using stereovision, epipolar geometry and the triangulation method. The study was realized in the MATLAB environment [9]. In 2015, Hsu et al. proposed a stereo camera-based distance-estimation system having three stages, namely the object detection, segmentation and distance-estimation processes. A measurement error rate lower than 5% was obtained in their study [10]. In 2015, Rezaei et al. developed a safety distance warning system for drivers. The developed system can determine vehicles having short or long distances in day or night. Moreover, they observed that their algorithm also gave good results in different weather conditions [11].

In 2014, Manesatti et al. presented an algorithm determining the size of sheep using the stereovision technique. The triangulation technique was employed in their method and the algorithm was realized in MATLAB [12].

In 2013, Muhammed et al. measured the distances between objects and the cameras employing the triangulation technique and template matching. They simulated their algorithm in MATLAB using standard web cameras [13]. In 2013, Tran et al. proposed an infrared stereovision-based technique for long distances in ship navigation [8,14]. In 2013, Zhang et al. offered a stereovision-based distance measurement system using the correlation method [8,15]. In 2013, Patel et al. suggested a distance-estimation method using the triangulation technique. Their study, including camera calibration, object detection and the triangulation technique, was realized in the MATLAB environment [16].

In 2012, Mustafah et al. suggested a real-time stereovision-based algorithm for measuring the distances and sizes of objects [17]. In 2012, Lai et al. suggested a real-time binocular stereovision-based distance measurement system. After they used a Gaussian filter on the image taken from the cameras, they utilized an improved Sobel kernel. They realized their developed algorithm on a Digital Signal Processor/Basic Input-Output System (DSP/BIOS) system in real time [8,18].

In 2011, Bhowmick et al. proposed an algorithm determining the distance between a sensed pedestrian and a vehicle using the stereovision technique [19]. In 2011, Kyto et al. compared the measured resolution of the depth values of the stereoscopic vision system with the sensed values. Although the focal length and baseline had the same influences, it was observed that the focal length possessed more influence, depending on the calibration process [20]. In 2011, Leo et al. suggested an applicable method confirming the standards for stereo camera calibration [21].

In 2009, Ozgunduz et al. proposed a stereovision-based obstacle recognition and avoidance system for autonomous vehicles. In their study, the distances between the obstacles and the cameras were calculated using the look-up table method [22].

In this paper, the projection of the object on the image plane and the coordinates are calculated utilizing the triangulation technique. For an accurate distance estimation of the related object and to decrease the error rate, multiple measurements of disparities from different points of the object are taken and an average measurement value is obtained. In addition, the disparities between the stereo camera pair and the objects are measured using the triangulation technique. Then, a look-up table including these disparity values and real distances is created. A relation between the disparity values and the corresponding average real distances is provided. The equation of this relation is obtained employing a curve-fitting technique. It is an exponential function and the coefficients of this function are obtained utilizing the least-squares technique. This function is beneficial for measuring the distances. Moreover, the objects may be located on the left or right of the robot. In this case, the Manhattan and Euclidean distances are also calculated.

In various studies up to this time, the triangulation technique has been used. However, it has some deficiencies, giving incorrect results in the case of stereo cameras having an angle down to the floor or when the object is on the left or right of the stereo cameras. Our proposed method contributes to the literature, eliminating these deficiencies of the triangulation technique. The triangulation technique is improved by adding the look-up table and curve-fitting method to the developed model. This approach gives more accurate results of distance estimation under various cases.

The studies simulated in programs such as MATLAB, which are expensive tools, having a license problem and requiring a Personal Computer (PC) or laptop, are not a practical and applicable solution for embedded systems. For adapting the MATLAB code to the embedded system, extra time and effort are also required. Some studies realize their algorithms in MATLAB communicating with the system, needing a PC or laptop, increasing the cost. In this study, open source software and hardware tools, BeagleBoard-xM, Open Source Computer Vision (OpenCV) and C are used, proposing a new low-cost distance-estimation model. The processing time for the object detection and distance-estimation processes takes about 41 ms. Real-