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An improved sensor framework of mono-cam based laser rangefinder

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ABSTRACT

Monocular camera based laser rangefinder is an economical strategy for retrieving the distance data. It is released from a burden of buying the expensive laser scanning sensor. In this paper, we proposed an improved framework for application on the mobile robots. This framework addressed the disadvantages in the original design. We chose the carpentry board instead of the cardboard to enhance the mechanical strength, and applied the curve fitting technology to compensate for the distance computational error induced by the lens distortion. Experiments on the mobile robots evaluated the performance of the proposed sensor framework. The results show that the improved mechanical structure can avoid the motion vibration of the mobile robot and curve fitting method can decrease the computational error especially for the case that the distance between sensor and object is much larger.

1. Introduction

Perception of the world is an important ability for autonomous mobile robots. They interpret the environments from various sensors for the purposes of map building, localization and navigation tasks. As one of the popular sensors, laser rangefinder which uses a laser beam to determine the distance (or depth) to an object has been widely used in robotics area. It has advantages of high precision and wide detectable range. However, these laser products are very expensive, for example the SICK LMS200 laser scanning system is about $5500 with educational discount, and especially the price of the 3D laser scanning rangefinder is much higher. There seems to be very little innovation on bringing the cost of these systems down to the users on hobbyist or experimenter level. Therefore by applying other sensors researchers developed several alternate methods to simulate the performance of distance detection of laser rangefinder under a limited budget.

The vision system is the one to be considered as a useful sensor for retrieving the distance information. Stereo camera allows the camera to simulate human binocular vision, and therefore gives it the ability to capture three-dimensional images and retrieve the depth or distance data easily. The stereo camera is not as expensive as a laser and widely uses in mobile robots for implementing various autonomous abilities [1,2]. Although the price of a typical stereo camera (around $2000 for Bumblebee 2 stereo camera) is much lower than the laser, it is still unaffordable for low-cost, efficient consumer.

In comparison with stereo camera, monocular camera including the popular web camera is a cheaper device and it has been treated as a major sensor in many robotics research works. However it is a challenge task to get the depth or distance from the monocular camera. Hence variant of technologies are developed to extract the depth from the monocular sensor data. The pioneer work was from Davison's real time Monocular SLAM algorithm [3,4], where the depth information was extracted by a unified inverse depth parameterization (IDP) algorithm without any delayed initialization procedure. Also the improved IDP algorithms [5,6] were proposed to address the redundant problem of the feature initialization in IDP. Murphey et al. designed a DepthFinder model [7] to calculate the distance from at least two frames of images, in which the monocular camera was moved to simulate a stereo vision system. The errors of this model, however, were serious when the camera motion was unparallel, that is, the ambiguity of image points affected the accuracy. Without moving the monocular camera, a virtual range finder [8] suggested applying the camera to capture the image of interested landmarks on the flat-floor, and estimating the distances from these landmarks by camera calibration parameters and external installation information. The drawback of the virtual range finder is that the landmarks have to be limited on the ground floor. Another low-cost way is to integrate a monocular camera and laser projector. For example in the research work [9] a compact, planar laser distance sensor based on monocular CMOS camera and laser point sensor module was presented. It is an implementation of scanning laser and has capabilities of 3 cm accuracy out to 6 m, 10 Hz acquisition, and 1 degree resolution over a full 360 degree scan. The scanning configuration was driven by a motor. A challenge of this scanning laser is on the angular synchronization. Without considering the scanning, a straightforward incorporation of a web camera and a laser projector was depicted in [10]. They

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were mounted by a cardboard and aligned in the same plane. In this system, the laser projector emitted a beam to the object and there will be a lightest spot on the object. The web camera captured the image of the spotlight and the distance was calculated according to the image information and the calibrated data of the camera. This webcam based system has simple implementation and lower cost. This idea is also borrowed to develop the movement behavior interpretation system for the presentation [11].

However the problems in the original webcam based system [10] are that the mechanical structure has less strength since the camera and laser projector are only combined by a piece of cardboard, and the accuracy of the distance computation decreased when the object was far from camera. To address these disadvantages above, Portugal-Zambrano and Mena-Chalco developed an improved camera calibration technique to perform a correction of distance computation [12]. In that work the sensor framework was heave, and the calibration procedure was carried out in Y'CbCr scale of colors which adds an extra computational procedure. In our opinion, it is not necessary to transform the RGB scale to Y'CbCr scale. The computational accuracy can be improved in RGB scale of colors. In this paper, considering the issue of low cost for users with limited budget, we proposed an improved webcam based laser rangefinder system and named it as mono-cam based laser rangefinder sensor framework to make a distinction. We chose the carpentry board as the sensor base instead of the cardboard to enhance the mechanical strength. For the distance correction, the curve fitting technology was applied to improve the computational precision. The cost of our proposed sensor framework is around $6 which is lower than $30 cost of [9].

The rest of this paper is organizes as follows: in Section 2 the measuring principle of mono-cam based laser rangefinder is represented. After review of the disadvantages of the webcam based laser rangefinder in Section 3, the improved mechanical structure of the sensor base and the curve fitting technology are presented. In Sections 4 and 5, the experimental conditions, results and discussion are described. The paper is concluded in Section 6.

2. Measuring principle of mono-cam based laser rangefinder

To make this paper self contained, the triangulation principle of calculating the distance is briefly reviewed in this section. As is shown in Fig. 1, the monocular camera is treated as a pinhole model. It is exactly installed over the laser projector so that the lens center of the camera is aligned with the optical axis of the laser. The height between the lens center and optical axis is h. Since the laser beam is parallel to the optical axis of the camera and can be focused to a very tiny brightest spot on the object, it is easy for camera to capture the spotlight at the focal plane. According to the triangulation principle, the distance from the laser to the object is calculated by

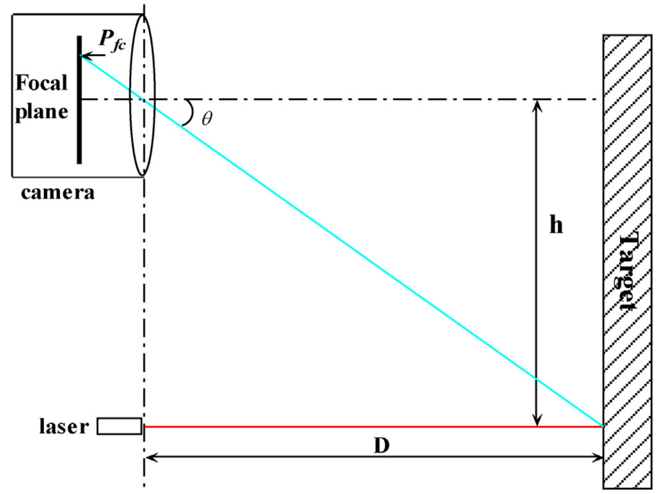

Fig. 1. The triangulation diagram of the mono-cam based laser rangefinder.

$$\frac{h'}{h} = \frac{f}{D} \Rightarrow D = f \cdot \frac{h}{h'} \tag{1}$$

where h' is the height from the image point of the spotlight to the center of the focal plane; f is the focus of the camera. In this equation, it is not convenient to obtain h' in the form of the metric unit. Therefore an alternative equation is applied as

$$D = \frac{h}{\tan\theta} \tag{2}$$

where θ is the angle from the optical axis of the camera. In this equation, h can be treated as an intrinsic parameter, and is obtained when the camera and laser are installed. θ is estimated by

$$\theta = P_{fc} \cdot R_{pp} + r_o \tag{3}$$

where P_{fc} is the number of pixels from the image of the spotlight to the center of the focal plane. R_{pp} is radians per pixel pitch and r_o is the radian offset i.e. compensates for alignment errors. These two parameters are the calibration coefficients determined through the calibration procedure. The detailed calibration process can be found in [10]. Substituting Eq. (3) into (2), we retrieve the distance by

$$D = \frac{h}{\tan(P_{fc} \cdot R_{pp} + r_o)} \tag{4}$$

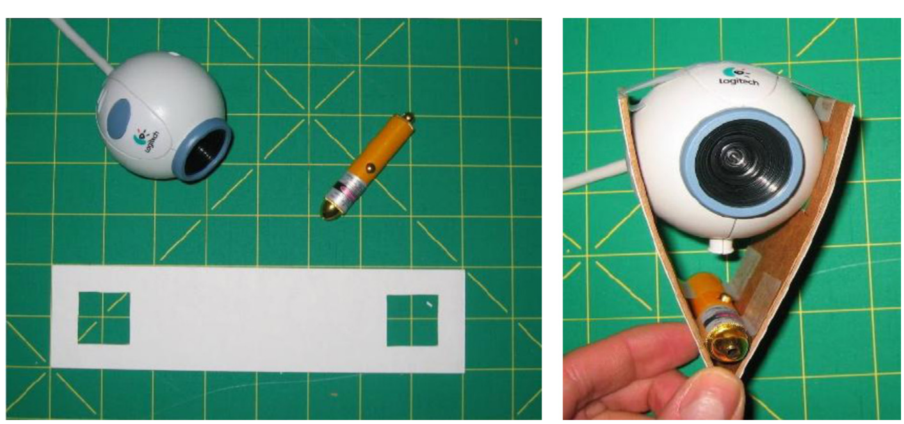

Fig. 2. The original sensor framework of the web-cam based laser range finder (cited from [10]).