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The Laser Line Detection for Autonomous Mapping Based On Color Segmentation

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***Abstract*—**Laser projection or laser footprint detection is today widely used in many fields of robotics, measurement or electronics. The system accuracy strictly depends on precise laser footprint detection on target objects. This article deals with the laser line detection based on the RGB segmentation and the component labeling. As a measurement device was used the developed optical rangefinder. The optical rangefinder is equipped with vertical sweeping of the laser beam and high quality camera. This system was developed mainly for automatic exploration and mapping of unknown spaces. In the first section is presented a new detection algorithm. In the second section are presented measurements results. The measurements were performed in variable light conditions in interiors. The last part of the article present achieved results and their differences between day and night measurements.

***Keywords*—**Automatic mapping, color segmentation, component labeling, distance measurement, laser line detection, vector map.

I. Introduction

FOR the accuracy of the whole mapping process is important the precision of the laser footprint detection on the target objects or on the background. There exist different approaches for the image detection of a laser footprint.

A good example may be the detection of the laser scan line which a robot carries out [1]. The advantage of this system is using of *YCbCr* color space. The algorithm is capable of dealing with many challenges such as sensor saturation, background light and obstacles in the area of scanning.

Another possible approach is based on mathematical methods [2]. The technique of the fuzzy weighted averaging filtering is used to remove the noise and enhance detection sensitivity for low energy lasers. The system also uses the image subtraction.

In the article [3] is described a new optical measurement device. Presented results obtained by testing showed its capability of the precise distance measurement in required range. The fundamental contribution of the solution lies mainly in the way of solving the distance measurement at each point on the detected vertical laser beam. The principle of distance measurement is based on image subtraction. The first image is captured with the vertical laser beam and the second without. For better precision of thresholding the algorithm was improved by adding of the modified Otsu's method [4]. Automatic measurement of an interior room based on fusion of ultrasonic and optical measurement devices is presented in [4].

Capturing of two images at a time is time-consuming and leads to a deceleration of the measurement process. This article describes a new approach to the distance determination based on vertical laser footprint detection by camera. The algorithm is based on the segmentation in RGB color space and the component labeling. The contribution of using of the component labeling is in speedup of the measuring process.

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II. Algorithm of Distance Determination

In this section we describe the basic idea of the distance determination first and the optical rangefinder principle. The new algorithm and obtained results are described in the last section.

A. Optical Rangefinder

As an optical rangefinder we used the optical measurement device equipped by vertical sweeping of the laser beam (see Fig. 1) introduced in the article [3]. This rangefinder is able to perform measuring distances with 10 % or less measuring error. The measuring range is15 meters.

The principle and algorithm of the distance determination was described in the article [3]. The distance D between measuring device and the target object is obtained as;

$$D = \frac{h \cdot f}{H_r \cdot ppx} \quad (1)$$

where h is the distance between camera and the laser emitter, f is focal length of camera lens, Hr is the physical horizontal frame dimensions of the camera chip and ppx is the number of pixels representing the measured difference.

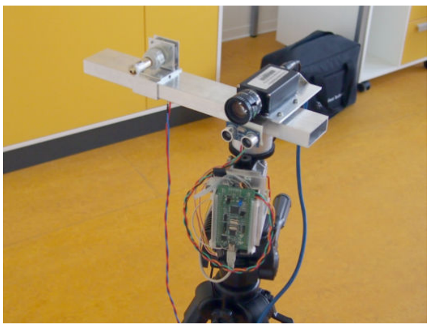


Fig. 1 The laser optical rangefinder

B. Novel Algorithm

The new algorithm will be explained at typical situation represented by one image from automatic measurement sequence, see Fig. 2.

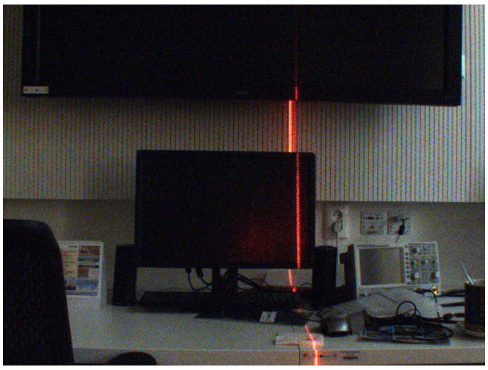


Fig. 2 The typical measurement image

The algorithm can be decomposed into four sequential steps, showed in Fig. 3.

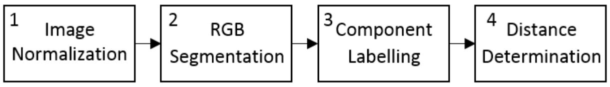


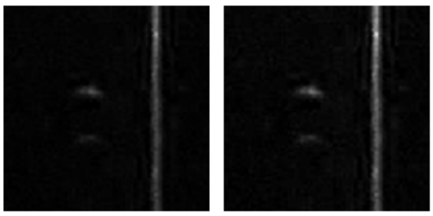
Fig. 3 Basic parts of the algorithm

1. Image Normalization

The image normalization is necessary in the case of low reflectivity objects. The normalization is done by image gain correction in *R* component of the image with respect to the color of selected laser. It can be calculated as follows;

$$I_{Ni}(R) = \frac{R_i}{\max(R)} \tag{2}$$

where $I_N(R)$ is the normalized *R* component of the image, index *i* represents the pixel index.



(a) (b)

Fig. 4 The example of normalization process (a) original R component (b) gained R component

2. RGB Segmentation

The color segmentation is the most crucial part of the presented algorithm. Correct segmentation influent the distance measurement accuracy. The monochromatic laser emits light in the red part of spectrum, thus the image matrix is separated into three color components *R*, *G,* and *B*. The red channel represents the laser light. Other components are important for the white light background estimation. The laser footprint separation from the background is done by thresholding in each color component. The pixel value is considered as the red laser according to the expression

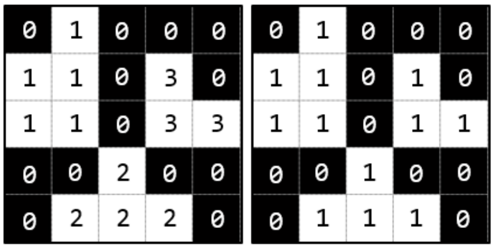
$$I_L = I(R > \mathrm{T_R})\,\&\,I(G < T_G)\,\&\,I(B < T_B) \tag{3}$$

where I_L are separated laser pixels and T_R, T_G, and T_B are appropriate color thresholds. Before the measurement should start there must be set thresholds and camera parameters manually on testing images. Fig. 5 shows the result of the separation.

Fig. 5 The segmented vertical laser line

3. Connected Component Labeling

At the segmented vertical laser were applied morphological operations for suppressing of small discontinuities and filling of the holes in the detected line. The component labeling process marks the components with specific numbers, see [5]. There are two possible way how to connect the components, see Fig. 6.



(a) (b)

Fig. 6 Labeled components. (a) 4 – connected components (b) 8 – connected components

The first variant of Four connected components merges object pixels in vertical and horizontal direction. The second variant Eight connected components algorithm adds diagonal connections. We use the variant of Four connected components in our example.

In [4], there was necessary to calculate the distance at each point on the detected laser line. In real situations detected laser line falls on objects with areas with constant distance. The main contribution of the component labeling method is in one estimation of distance for the whole covered area of the target object; see Figs. 7 and 8.

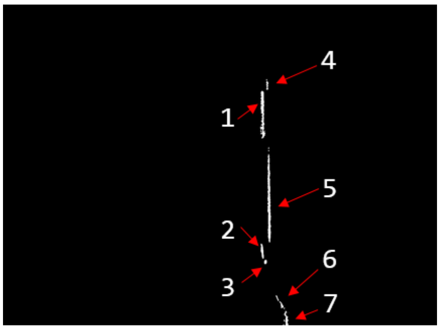


Fig. 7 Connected components

4. Distance Determination

As it was mentioned above the measurement result of one connected object is calculated at once according to (1), and the measurement result is assigned to the component. The value *ppx* is calculated as a horizontal centroid of the appropriate component. Fig. 8 shows measurement results for one captured image.

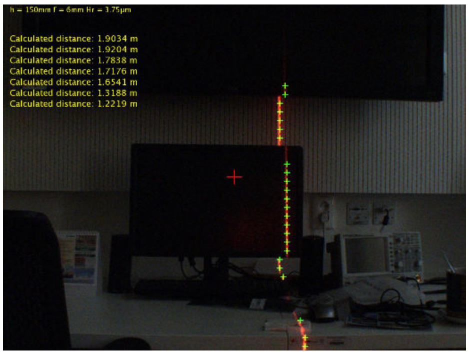


Fig. 8 Measurement results

C. Problems in Detection of the Vertical Laser Line

For separation of the laser beam from background daylight we used the *G*, and *B* components. The component labeling was also used for visualization of measurement results. If there is detected a too wide component, this component is split into small parts. These parts with high horizontal width are substituted by a null distance. Next figures show these problems.

1. Red Color Objects

The used CCD camera chip has high sensitivity to the laser light color. This property is used to distinguish red reflections. At first camera parameters have to be set for accurate detection of a laser light. Figs. 8 and 9 show significant laser footprint on images taken by camera at dark conditions. According to (3) the threshold for a laser light can be easily estimated from the image with and the background.

2. Sphere Objects

If there is a suspicion of the spherical object existence in the captured scene covered by a laser line (see Fig. 9) the whole connected component is split into small parts based on width of the component, Fig. 10. The small parts are suitable for distance measurement in smaller areas. The result showed in Fig. 10 confirms the measurement possibility of presented algorithm on the spherical object.

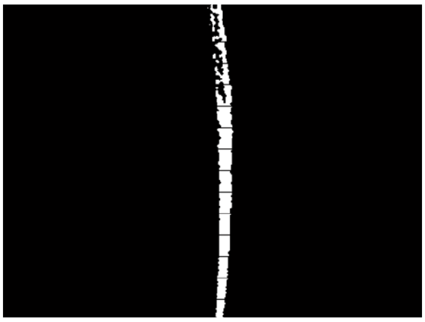


Fig. 9 The Component labelling on spherical object – zoomed ball

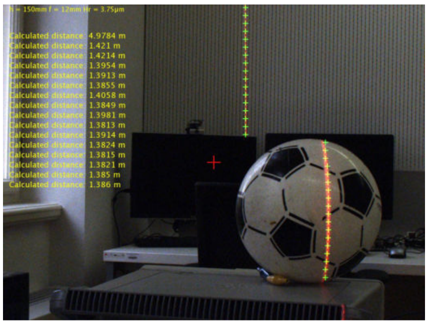


Fig. 10 Distance measurement on spherical object

3. Other Sources of Red Light

For some materials is typical significant reflection of the projected laser beam. If the angle between the source of a laser light and the surface of the object is near orthogonal the reflected beam is scattered to wide angle, see Fig. 11.

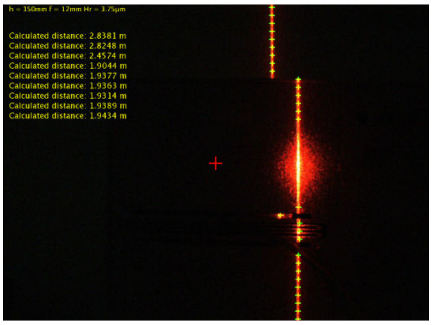


Fig. 11 Scattered reflected light

Area covered by the scattered beam into wide angle is omitted from results of the distance measurement, showed in Fig. 11.

III. Automatic Measurements

For automatic measurements we used a mobile platform with the optical laser rangefinder. The whole measurement device is pivotally carried by tripod, shown in Fig 1. In the project is used a high-quality high resolution Basler color camera with the ultrasonic rangefinder. The camera resolution is of about 1300x1000 pixels. The developed measurement device is connected by GiGE interface, which allows to achieve 32 fps and thus accelerates the process of measurement. The used laser diode has an output power of about 200 mW, especially for good recognition after vertical swapping. The laser spot is dispersed by an optical filter with an angle of about 60 degrees. The 360 degrees rotation of the measurement head provides a powerful stepping motor.

As a scanning object an interior room (see Fig. 12) was chosen. The room was scanned by 360 sequential steps. Vector maps are created in the same way as in the last article [4].

The measurement was performed in full daylight and at night, these decisions followed from the last automatic measurement [4]. The results showed the problem in the measurement of dark objects. These objects have a poor reflection from the black color.

The range of the measured height was also mentioned in the article [4]. The 95 centimeters at the distance 3.3 meters was achieved with the 12 millimeters camera lens. The new measurements were performed with 6 millimeters camera lens.

A. Measurement in Different Light Conditions

Results of the daylight measurement are presented in Figs. 12 and 13. There are also described important objects in the room.

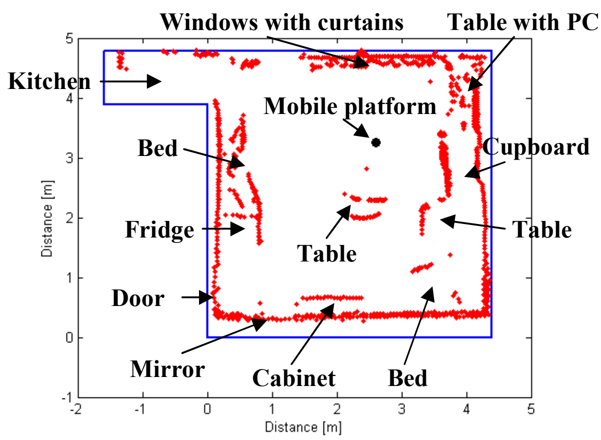


Fig. 12 2D vector map from all measurement points – daylight (top view)

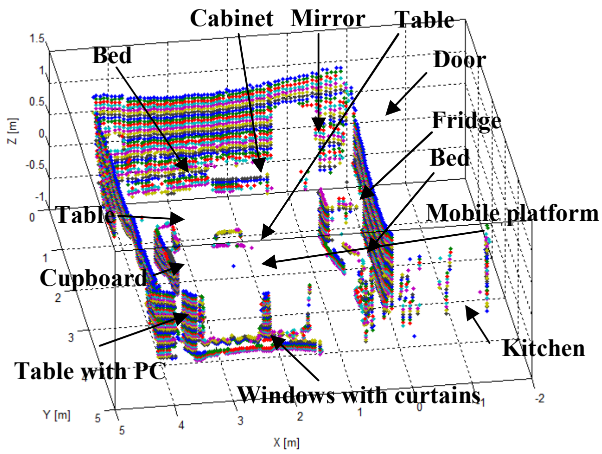


Fig. 13 3D vector map of room – daylight

The measurement results show a good precision of a proposed algorithm. The accuracy of measurement is lower than 10%. By using 6 millimeters camera lens the range 2.25 meters in Z axis at the distance 4.2 meters was achieved. The barrel distortion of the used camera lens was observed only at small distances. Maximal error caused by barrel distortion is 3% at the minimal measurement range of the rangefinder (0.5 meters). This error is insignificant at the distances which were measured. As shown on Fig. 13, the mirror, the door, and the windows were not detected correctly. The results of the night measurement are presented in Figs. 14 and 15.

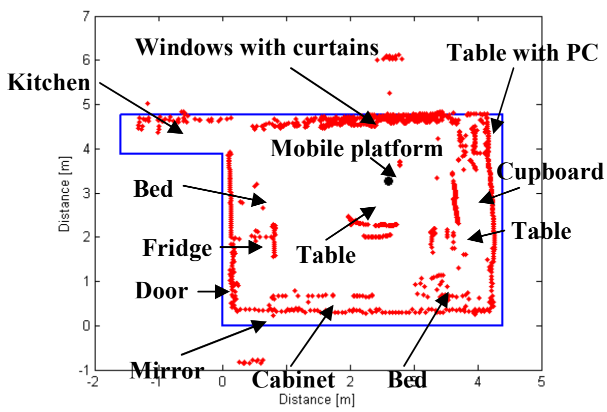


Fig. 14 2D vector map from all measurement points – night (top view)

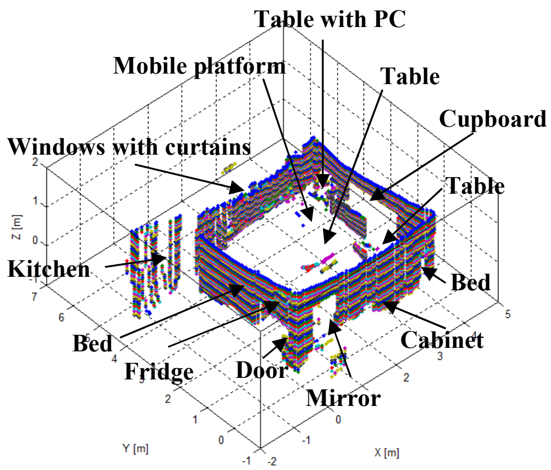


Fig. 15 3D vector map of room – night

The comparison between daylight and night measurement results leads to the conclusion that the night measurement is more successful in the number of detected measured points about 30%. In the daylight measurement there is not possible to measure distance at the places where windows are. The accuracy of the measurement is the same. The measurements show another issue in detection of the vertical laser footprint. The reflected laser light by the mirror and by the window glass caused that some results are outside the boundary of the room, see Figs. 14 and 15.

The new algorithm speedup the measuring process A full 360 degree scan can be done in time 10 seconds. Obtained measuring data are suitable for creation of 3D vector maps.

IV. Conclusions

The measurement results verified proposed algorithm. The accuracy is almost the same like at the algorithm used before with the benefit of speedup of the measuring time.

The function of presented algorithm was verified in variable light conditions such as outside light or other intensive light sources. System parameters setup has to be done manually before the measurement starts. In this step remains the space for future automatization of the measuring process.

The proposed system is not suitable for laser footprint detection on dark objects with small reflections. We performed the measurement at night also. The results are significantly better compared to results presented in [4]. Reflections from glass objects or from mirrors can cause mistakes in the distance determination.

The next work focuses on the fusion of the laser rangefinder with additional sensors. The speed of the algorithm will be also improved.

Acknowledgment

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