THE OPTICAL MEASURING DEVICE FOR THE AUTONOMOUS EXPLORATION AND MAPPING OF UNKNOWN ENVIRONMENTS

Pavel Chmelař[1], Marin Dobrovolný[2]

Summary: This article describes the developed rangefinder measurement device suitable for automatic mapping systems. This device uses a high-quality optical capture sensor and a laser beam. In this article are presented the measurement results and the distance measurement algorithms based on image processing methods. This system is mainly used for distance measurement, but it is suitable for automatic exploration and mapping systems too. The advantage of the developed system is a distance measurement process processing each point on the detected vertical laser beam and the possibility of using low-cost components.

Key words: triangulation method; camera; laser; space mapping; space exploration; image; image processing

INTRODUCTION

The systems for automatic mapping and exploration of spaces are now widely distributed in many fields of robotic navigation (4), (5). The most common applications are exploration of unknown spaces, exploration of abandoned mines, dangerous environments, etc. Mapping of the space is used to create the overview vector maps of unknown environments. The map is then processed in the controlling systems or in a variety of software resources (8).

The mapping process is especially important in the unexplored areas with poor accessibility for human rescuers. A good example might be old underground mines, or abandoned buildings. Creating of the vector maps will provide clear information about its extent and condition (6).

A common problem for all these systems is a reliable method of measuring of the distances to ambient objects.

For the mapping process can be used a variety of sensors and techniques. For example the robot can explore unknown spaces by compass sensors, accelerometers and topological maps processed by neural networks (5). In this case, the robots detect new unknown areas using artificial neural networks and in this way progressively create the maps. The function of the system is controlled by the robots itself without any additional systems.

Another possible approach demonstrates the system with the robots navigated by the ultrasonic sensors (4). These sensors continuously measure the reflection characteristics of individual objects in the space.

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Since every robot is often equipped with a camera, it is possible and advantageous accurately measure distances by using of the optical Rangefinders systems.

1. OPTICAL RANGEFINDERS BASED ON THE CAMERA SENSORS

The Rangefinders based on triangulation method and the cameras are currently popular applications of cameras and lasers. For sensing device can be used a regular webcam, but this type of camera is usually low quality with low resolution and the optical lens system is poor. These parameters have a direct impact on the accuracy of the measuring system. In this case increase mainly the error of determining laser beam position. A good example of a system for measuring distance based on the triangulation method is the portable distance measuring system presented in (1). This system was developed with regard to the lowest price while maintaining good characteristics of the system.

Another example is the measuring system consisting of a pair of cameras. The system is used by robot to track objects in a real-time with distance measurement (2). The system function is similar to human vision. The system uses a rotation of the head movement around the vertical and horizontal axis like a human eye.

2. DETERMINING THE DISTANCE WITH CAMERA

The camera based measuring systems have many advantages such as rapid non-contact measurement of many points simultaneously in a real time. A common application is measuring in an unknown 3D space. The measured data are suitable for further processing and application of high-level algorithms.

- Single camera measurement systems

In the case of single camera is the measuring of distance possible only with knowledge of the objects size in a target scene. A good example represents a system for car license plate recognition (7). This system is not appropriate for our purposes.

- The measurement system with two cameras

A frequent solution of the distance measuring problem is the using of two complement measuring sensors (a stereoscopic system). The main disadvantages of these systems are the necessity of using multiple cameras (price and hi data-stream) and strong requirements on a constant system parameters. The measuring is realized as angle detection (2). Also this system is not suitable for us.

- The measuring based on camera and laser fusion

The systems based on fusion of camera and laser can be very accurate. The accuracy is mainly given by the sensor resolution. The second advantage is the direct focusing of laser beam to the target object. For the measuring process there exist multiple methods (4): triangulation, measuring of laser beam propagation, measuring of phase shift, etc.

For our purposes is the most appropriate the triangulation method.

3. THE CONSTRUCTION OF DISTANCE MEASURING SYSTEM

The developed rangefinder for mapping systems is based on the triangulation method. Previous described methods mainly using a laser beam focused on one point. The presented system uses a laser beam spread out into the line. The device is thus able to measure the distance at any point along the laser line and in conjunction with rotation around the vertical axis over the whole surrounding area.

3.1 The principle of the distance calculating

The method is based on detection of the laser beam in the images taken by the rotating camera. The principle of the distance determining will be explained for one particular point.

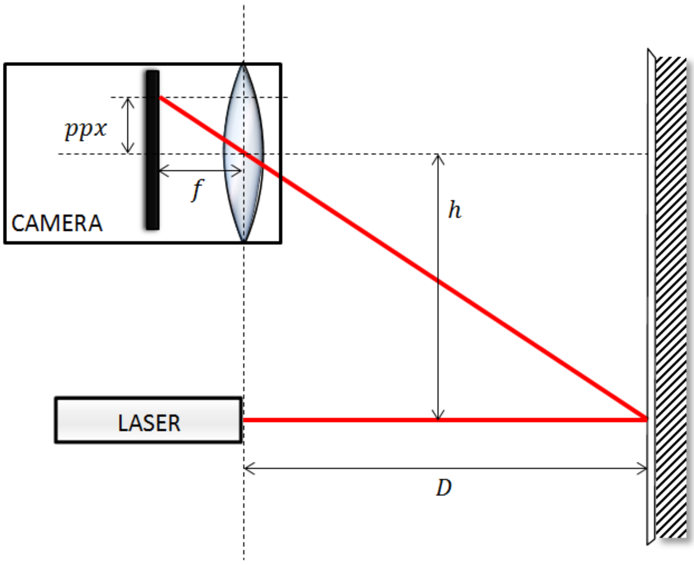

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Fig. 1 – The principle of the distance determining (example for one point of the laser beam)

For the calculation of the distance D is necessary to know three basic parameters:

- *f* – Focal length of camera lens.
- *h* – The distance between camera and the laser emitter. Laser can be placed (in relation to the camera) in horizontal or vertical plane.
- *ppx* – Number of pixels representing the measured difference (also referred as a pixel offset).

The (Fig. 1) presents two important triangles. The first triangle is determined by: laser emitter (which emits direct laser beam), spot on the subject, and the camera lens. The second triangle is located behind the camera lens. It consists of the camera lens, the center of the camera sensing chip and the point where the beam falls on the camera chip.

There exists linear dependency between these triangles (1):

$$\frac{h}{D} = \frac{ppx}{f} \tag{1}$$

The values of h relation, D and f are in standard metric dimension. The value ppx is the number of pixels from the center of the frame and is dimensionless. Each type of camera has usually a different size of picture element depend on the sensor chip. The equation (2) describes the relationship between the physical frame dimensions of the camera chip (w_m, h_m), the image size (horizontal and vertical Hr, Hv) and the pixel size of the frame (H, W):

$$Hr = \frac{w_m}{W}[m], \quad Hv = \frac{h_m}{H}[m]. \tag{2}$$

The conversion of the *ppx* value to metric is done by multiplying the number of pixels corresponding to the physical dimensions of the camera chip (3):

$$ppx = Hr \cdot ppx[m] \tag{3}$$

The calculation of parameter D (4) can be expressed from (3) by substituting into (1):

$$D = \frac{h \cdot f}{Hr \cdot ppx}[m] \tag{4}$$

3.2 The image detection algorithm

The most important step in the presented algorithm is the laser footprint detection in the captured frame. This can be done by several methods. The position of the laser beam can be determined, for example, from one image by the color segmentation followed by thresholding or by other image processing approaches. Another approach represents mostly the background estimation methods, which use difference between two or more images. The first image is taken with a laser point on. The background is then estimated from the one or more images taken with laser beam off. The resulted image is disturbed by noise and the chip saturation. The noise can be removed by Gaussian filter or by thresholding. But after thresholding the edges are not solid. This problem can be solved by application of basic morphological operations (like the morphological image opening (5) or image closing (6) (7)).

$$X \circ B = (X \ominus B) \oplus B \tag{5}$$

$$X \bullet B = (X \oplus B) \ominus B \tag{6}$$

After application of these steps it is possible to determine the laser spot very accurately (with precision better than 3 px). The (Fig. 2) presents the results of measurements.

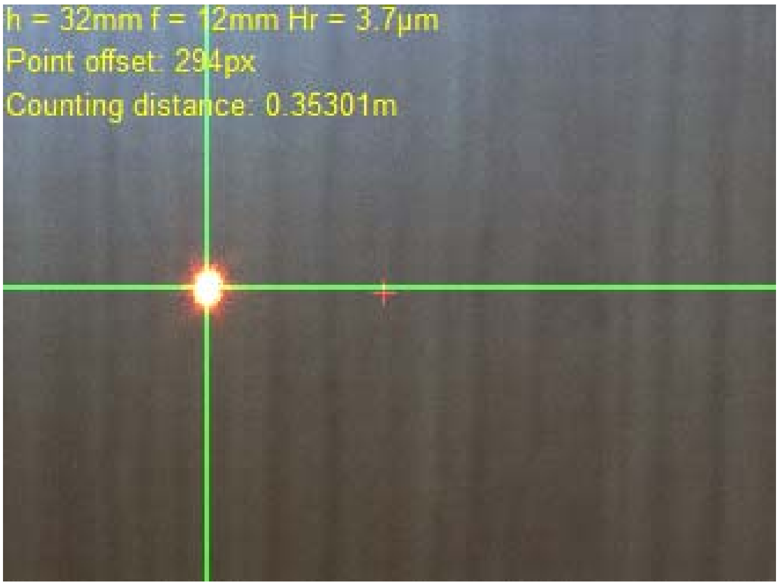

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Fig. 2 – The result of the measurement

3.3 The measurement with the vertical sweeping of the laser beam

The developed system will be used for the mapping of the ambient space. Due to the vertical sweeping of the laser beam it is possible to perform measuring at any point of the vertical axis (Fig. 3).

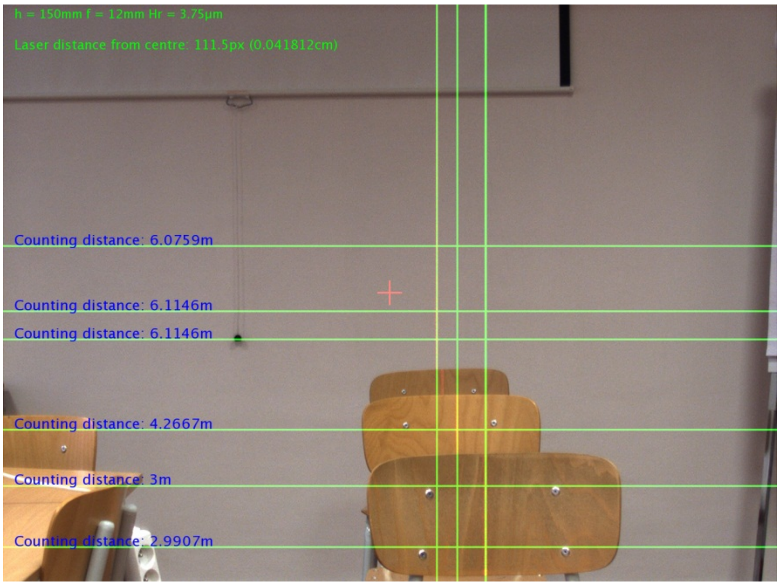

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Fig. 3 – The measurement with the sweeping of the laser beam

By in this way obtained data it will be then possible to construct a vector map of the ambient environment.

3.4 The construction of the equipment

The whole measuring device is pivotally carried by tripod (Fig. 4). In the project is used high-quality Basler color camera with a resolution of about 1300x1000 pixels. The developed measuring device is connected by GiGE interface, which allows achieving 32 fps and thus accelerating the process of measuring. 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 measuring head provides a powerful and fast stepping motor.

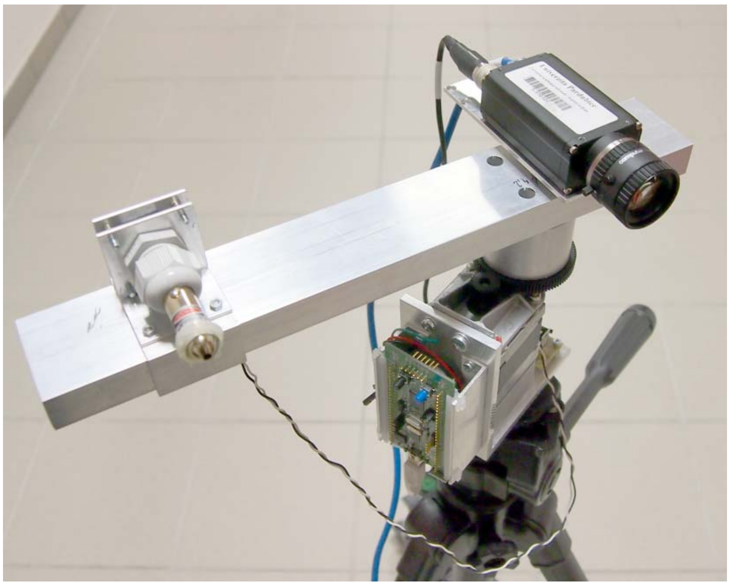

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Fig. 4 –The developed measuring device

To the possibility of change of distance measured range is the variable distance between the laser and the camera implemented. Laser and stepper motor are controlled by the developed control board with an auxiliary 32b microprocessor.

3.5 Calibration of the system

For accurate measurements is important the initial calibration of the system. The first step in the calibration process represents the right choice of the proper distance h between camera and laser. The system parameters f and Hr in the equation (4) are given by the used sensor chip. For the measuring on larger distances is necessary to increase the distance h and vice versa. The equation (4) is nonlinear and change of the h parameter lead to the change of the systems parameters (Fig. 5). By the changing of the h parameter it is necessary to control the constant alignment of camera and laser beam on the target plane (Fig. 1).

3.6 Nonlinearity of the system

The equation (4) describes the overall non-linearity of the system. The non-linearity most affects the measuring process on the large distances (Fig. 5).

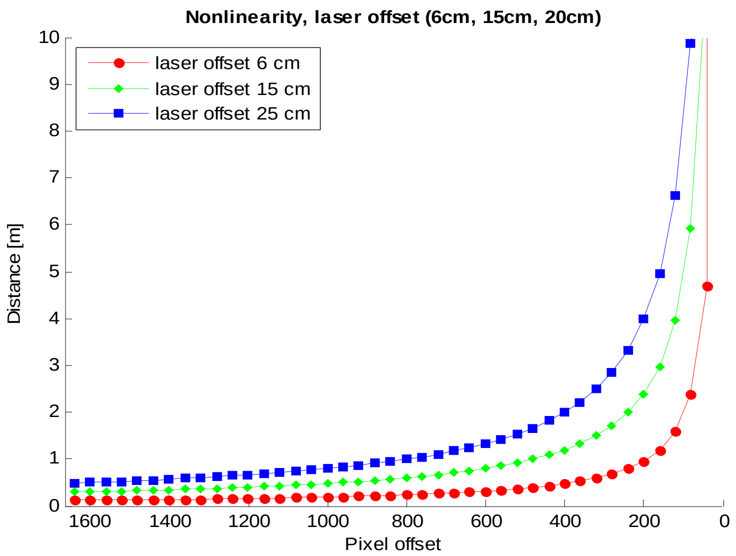

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Fig. 5 – Non-linearity of the system

By changing of the parameter *h* it is possible affect the non-linearity in favor of the measured range. The advantage of the measuring process with small *h* is very accurate measurement of small distances of up to about two meters (Fig. 5). When a large value of *h* is set then can be taken measuring of large distances very well.

In the calibration process it is necessary to consider these facts and choose the best combination parameters with respect to the desired range.

3.7 Measured results

For verification of the system function was performed several typical measurements under various conditions. First, it was necessary to verify the impact of the nonlinearity to the system accuracy. Based on the progress on (Fig. 5) there was selected the smallest possible value of *h* parameter to six centimetres. At this level, several measurements were performed (Fig. 6). During every measurement the measured real distance and the by equation (4) calculated distance were recorded and there was also determined the measurement error (Tab. 1).

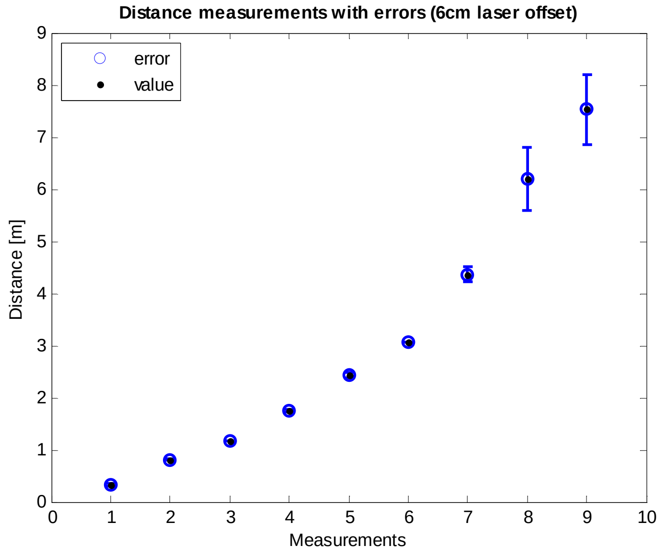

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Fig. 6 – Measured results for *h* = 6 cm

Tab. 1 – Measuring results by distance equal to 6 cm

Distances (m)	0,32	1,18	2,49	4,23	5,59	6,85
Real distances (m)	0,33	1,17	2,44	4,36	6,19	7,53
Abs. error (%)	0,96	0,61	2,09	3,21	10,78	9,90

The measured error in the distance of about five meters is less than 3.5%. The measure error corresponds to the estimates in comparison with the progress on (Fig. 5). At distances greater than five meters the error greatly grows. The accuracy of the measurements (*h* = 6 cm) is not suitable for the interior mapping process due to the system nonlinearity.

The second distance of *h* parameter was chosen fifteen centimeters (according to (Fig. 5). The measuring process was realized like in the previous example. The (Fig. 7) and (Tab. 2) shows the measurement results. The measured error in the distances less than ten meters is better than 3.5%. At larger distances, the error grows. The error is around 6 % at distances of about fifteen meters.

When parameter *h* was set to fifteen centimetres, the nonlinearity less impacts at the system accuracy. The error variation by this setting is acceptable and the system is suitable for interior mapping.

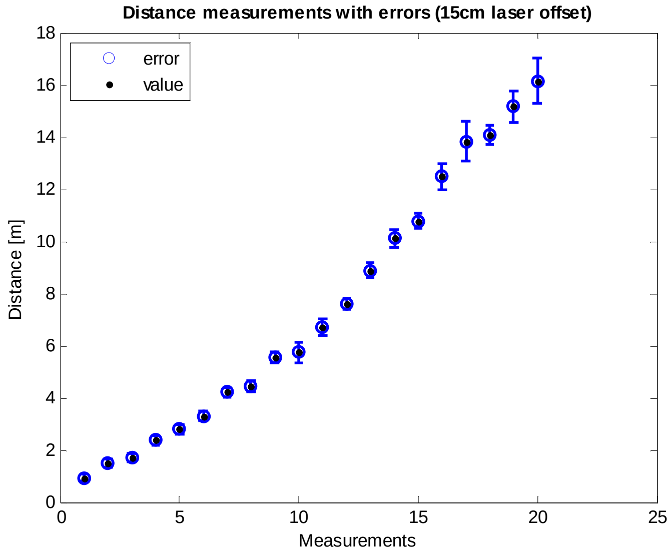

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Fig. 7 – Measured results for *h* = 15 cm

Tab. 2 – Measuring results by distance equal to 15 cm

Distances (m)	0,79	2,59	5,22	10,12	13,84	16,16
Real distances (m)	0,80	2,62	5,34	9,78	13,08	15,28
Abs. error (%)	0,96	0,61	2,09	3,50	5,78	5,71

CONCLUSION

The measured results confirm the theoretical expectations of the used triangular method and presented results obtained by testing shows its capability of the precise distance measuring in required range. The developed device is suitable for the indoor space mapping. 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 measurement accuracy was achieved thanks to the precise calibration and setting of camera and laser alignment. This setting has the lower impact on the nonlinearity of the equation (4) for our purposes.

The development of the measuring device is still not over. The possibilities of improvement are mainly in the better detection of the laser beam pattern in the infra-red spectrum and in the compensation of the nonlinearity. For the automation of the space mapping process will be necessary to improve the coordination of the measurement devices and the stepper motor controller.

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