An Omnidirectional Ranging System*

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Abstract. In this paper, a ranging system is proposed that is able to measure distances to environment objects omnidirectionally, that is, over 360°. This ranging system is based on a structured-light imaging system with a catadioptric omnidirectional mirror. In order to make the ranging system robust against environmental illumination, efficient structured-light image processing algorithms have been developed: sequential integration of difference images with modulated structured light. A distance equation was derived for an omnidirectional imaging system with a hyperbolic mirror.

Keywords: Omnidirectional image, ranging system, laser structured light, distance equation, sensitivity analysis.

1 Introduction

Distance data is essential for the autonomous navigation of a mobile robot. Distance data is used for the localization and object map-building in an unknown environment as well as simple collision avoidance for a mobile robot. There exist several kinds of distance measurement sensors such as stereo cameras, ultrasonic sensors, laser scanners, and structured-light-image-based sensors [1]. The structured-light system avoids the computationally intensive correspondence problem of the conventional stereo vision system and is more robust in the presence of ambient light variation. The ranging sensors based on the structured-light image project a light of a distinct frequency in a particularly structured pattern onto the environment and compute the distance based on the distortion of the structured pattern, which is a function of the distance to the objects. Many results are available from systems that have used this method [2, 3]. Bulky laser equipment and lengthy image processing time have discouraged the use of this method in the past, but recent advancements in semiconductor laser equipment and fast processors have made this system more viable and economical.

It is obvious that wider distance measurement is more helpful for the autonomous navigation of a mobile robot. In order to obtain wide distance data, the well-known

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omnidirectional imaging method can be combined with a structured-light-image-based ranging sensor. The omnidirectional imaging method uses a catadioptric approach to obtain a horizontal 360° image by using a bowl-shaped curved mirror with a conventional camera. In [7], a conical mirror is used to obtain an omnidirectional structured-light image. However, because a motorized scan was used to project 360° structured light, the system has some problems related to real-time processing and durability. However, in [6], a parabolic mirror and a cylindrical lens are used for omnidirectional image acquisition and 360° structured-light projection. This way of distributing laser stripes eliminates the mechanical parts and can spread the stripes over larger areas, speeding up the process of distance measurement. However, the cylindrical lens lowers the light energy density by spreading the structured light, and the ambient light noise can interfere with the extraction of the structured light from the image. Thus, a robust image processing method is required to improve the structured-light extraction.

In this paper, development of a new omnidirectional ranging system based on a structured-light image is addressed. In order to improve robustness against environmental illumination and computational efficiency in structured-light extraction, a novel image processing algorithm is proposed: integration of difference images. Because the proposed image processing algorithm requires fast computation, a dedicated FPGA image processor is implemented in this study.

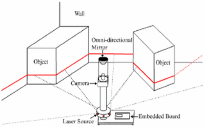

Fig. 1. Overall omnidirectional ranging system based on structured-light image

2 Structured-Light-Image-Based Omnidirectional Ranging System

The proposed distance measurement system shown in Fig. 1 consists of 1) an omnidirectional image acquisition part, 2) a 360° structured-light projection part, and 3) an embedded image processor. A conventional camera and a hyperbolic mirror are used for the omnidirectional image acquisition part. The structured-light projection component has a cylindrical lens to convert the point light source into a line. Several pairs of cylindrical lenses and point lasers are used for 360° structured-light projection. In mobile robot applications where the horizontal distance is more important than the vertical distance, the structured light should be projected horizontally at a constant height to obtain the horizontal distance to obstacles.

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