Development of a Hybrid Stereo Vision System for 3D Shape Estimation

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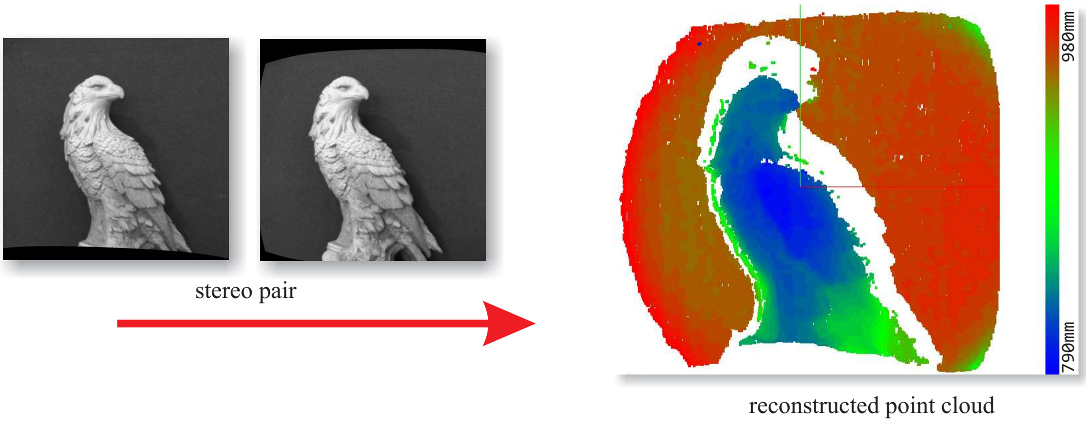

Fig. 1. Result of our method: from stereo pair (left) to 3D cloud (right) by phase-based correspondence + triangulation

***Keywords*-3D shape; 3D vision; dense correspondence; stereoscopy.**

I. Introduction

Robotic systems need to extract information about the environment to perform their actions. Different approaches based on sensors such as sonar, cameras and lasers have been used. However, in recent times the application requirements have required a more detailed perception of the scene. Now, high level tasks as recognition, navigation and manipulation need to be performed.

In this paper, the study and the development of a hybrid vision system intended for robotics applications is described. Both passive and active approaches were combined in a single system in order to improve the results obtained with conventional stereoscopy. Results demonstrate the effectiveness of the proposed system in 3D shape characterization.

A. 3D Measurement Principles Overview

In passive stereoscopic vision, where just a set of cameras is employed, 3D information can be obtained by solving calibration, matching and reconstruction [1]. High accuracy is achieved on well-defined object features like coded targets or artificial and natural object texture and edges. However, this approach does not provide satisfactory results when measuring objects with homogeneous intensities surfaces [2]. Here, the intensity values of the images assume a central role in the description of each object point. For many scenarios this kind of description will not be robust since the intensity value of each point is sensitive to influences such as differences in the camera gain, radiometric variations, among others. Consequently, the step of finding matching points in the stereo image pairs obtained by the binocular system will fail, and as a consequence the measurement result will be compromised.

In structured light projection, in turn, a system comprising a camera and a laser or even a white light projector is employed [3]. Using such a system, a pattern of light is projected over the objects being measured. The projected pattern is deformed when it reaches the surface of the objects. The estimation of $3D$ coordinates is based on calculating the phase of the projected signal instead of evaluating the original intensities of the observed object. This way, the problem related to surfaces with homogeneous intensities is solved. Accurate results can be obtained with this technique, but the calibration of the set is significantly more complicated than the calibration of the cameras pair in passive stereo systems [4].

II. Proposed Methodology

The system described in this work will be integrated and used in a robotic welding application, where metallic structures need to be repaired. Therefore, the main functional requirement that has guided the development of the vision system is the estimation of dense point clouds for 3D shape characterization of objects placed at an approximated distance of 1000

mm. To overcome the limitations and take the advantages of both active and passive methods, we chose to develop a hybrid system. As shown in figure 2 - a, the developed system is composed by a pair of cameras and a projector of white light. A Flowchart describing the main steps of the measurement method is shown in figure 2 - b.

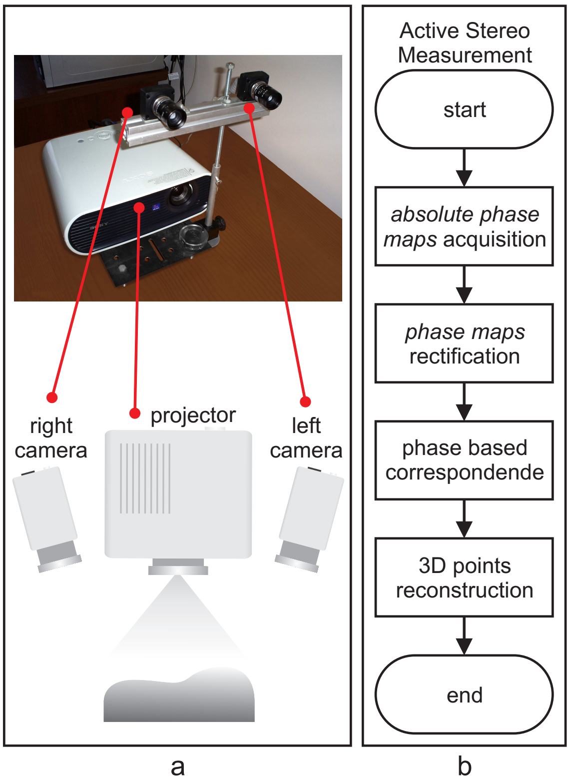

Fig. 2. Developed system

The proposed method corresponds to an approach where both the passive technique based on stereoscopy [1] and the active technique based on fringe projection [5] are combined. First, as a setup step, a calibration procedure is performed in order to estimate the parameters describing the binocular system. As a first step of the measurement flow, the fringe projection technique is used to calculate relative phase maps for each camera. Next, phase jumps on the obtained phase maps are removed by using a jump removal procedure [6]. The absolute phase maps are then rectified in order to align epipolar lines. Then, a disparity map is calculated by using a dense correspondence method based on window correlation. Here, a modified SAD cost function is used in order to use phase values instead of intensity values. *Left-Right Consistency check* is applied to remove wrong disparities. Finally, a $3D$ point cloud is obtained by stereo triangulation.

The main advantage of the described approach is the elimination of the use of intensity values of the measurement process, as originally employed in a stereo system. Here, phase information obtained by using the fringe projection method is used instead. It is also important to note that the projector is used only to calculate the phase maps, and is not directly used in the depth estimation, as originally employed in active measuring methods. The depth estimation is based on reconstruction by triangulation, and uses the parameters that describe the binocular system and the disparity maps. Thus, for system calibration is enough a conventional rigid stereo calibration procedure [7] without estimation of the projector parameters.

III. Experiments and Evaluations

The measurement results obtained with the described system were evaluated based on different criteria and also considering different measurement scenarios. One of the measurement scenario is shown in figure 1, where the measured object corresponds to a plaster statue of an eagle. In this case a cloud with approximately 140000 points were obtained when using cameras resolution of $640X480$ pixels. Through a visual assessment, it is considered that the obtained point clouds characterize adequately the $3D$ shape of the objects and that the generated information is enough to guide different actions on robotic operations.

In order to perform an objective overall evaluation of the measurement result, the *Point-to-Plane Error Metric* was used. For a measurement distance of 1000 mm, the obtained average error was 2.0136 mm.

IV. Conclusions

In this work the results obtained in the development of a vision system which combines active and passive measurement techniques are described. Refined results are obtained when using the proposed method. The information can be used in tasks requiring a greater level of detail of the measured objects. The proposed configuration, which combines the two approaches into a single system, allow us to extend the possibilities and scenarios of use for robotic applications.

Future works include the substitution of the phase shifting by another technique that eliminates the need of multiple frames acquisition [8]. Additionally, the inclusion of a passive method addressing correspondence on homogeneous regions, by using planes fitting, for example, would be interesting.

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