Stand-Alone Hand-Eye 3D Camera for Smart Modular Manipulator

Sukhan Lee, Muhammad Atif and Kukjin Han

Abstract— **This paper presents a standalone structured-light 3D camera system with an ARM architecture-based embedded system. The implemented design consists of an embedded projector, a high-speed camera with 120 frames/s, and an ARM architecture-based embedded system. It can achieve scan rate of 2 Hz (18 patterns) with a high speed synchronization between the camera and projector. State of the art 3D decoding mechanism is implemented to have accurate depth information. The proposed standalone 3D camera has the advantages over conventional 3D cameras; i.e. smaller dimension, lower weight and capability of direct 3D data output without external computing platforms. Suggested smart and compact design of can be used as hand-eye 3D camera for smart modular manipulators.**

I. Introduction

Recently, the demand for high-precision 3D vision is increasing in various areas. The research in these areas focuses primarily on a precise RGB-D measurement for high precision manufacturing [1], art data archiving [2], quality inspection [3], and visual SLAM [4]. Various approaches, such as time-of-flight (ToF), structured light and stereo, are being used to recover 3D information. Structured light method offers a higher precision of 3D depth information than ToF and stereo based camera. Meanwhile, the performance of ARM architecture has been drastically improved due to the advancement of Smartphone technology. Thus, there has been active research on the usage of ARM architecture on computer vision libraries. In this paper, we combine an ARM architecture-based embedded system and a structured-light 3D camera for an independent, lightweight, and high-speed standalone 3D camera system.

II. Stand-Alone Structured Light 3D Camera

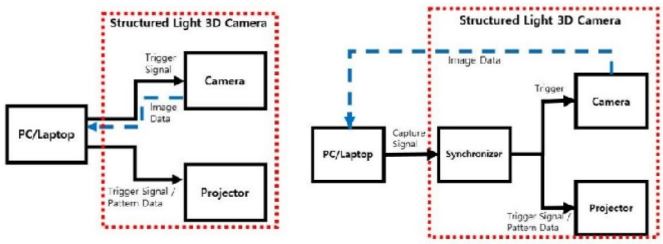
Components of a 3D camera system are structured light patterns, decoding of patterns, projection and capturing mechanism and standalone system are discussed in later part of this section.

A. HOC Patterns & Boundary Inheritance Codec

There are many types of coding techniques used in structured light system: Binary coding, Grey level coding and color coding. Binary coding is well known coding scheme because it is more immune to noise. In binary coding there are only two states of pixel either zero or one. To reduce the length of the codes S. Lee et al [5] developed hierarchical orthogonal coding (HOC), in which orthogonal codes are arranged hierarchically. HOC patterns are used to construct 3D point cloud. The decoding of captured patterns is performed by detecting stripe pattern boundaries as well as shadow boundaries, then regions between detected boundaries are formed in each layer and finally, the boundary inheritance and region correspondence inheritance from upper layer to the lower layer are performed to produce accurate and robust boundary-correspondence pairs for 3D triangulation. Boundary inheritance Codec [6] is implemented for reconstruction of 3D Point cloud.

B. High Scan Speed

In Conventional structured-light 3D cameras synchronization of projector and camera is performed by PC [9] which is shown in Fig1a, high scan speed cannot be achieved by these kind of systems due to limited control on system interfaces through operating systems. Lee et al. [7] presented embedded system based projection and synchronization signal to project the patterns fast and capture the frames accurately which is shown in Fig 1b, the only limitation with these kind of systems is the process of 3D reconstruction is performed on PC, so these systems could not be used as standalone for smart manipulators. In this paper, we have presented an independent standalone 3D camera system that has high-speed synchronized capturing and on-board 3D reconstruction. High projection speed is achieved by using embedded projector which can project binary patterns fast and generates trigger for camera.



(a) PC based projection (b) Projection through embedded

Figure 1. Conventional Structured 3D Camera System

C. Stand Alone System Design

Block diagram of a standalone 3D camera system is shown in Figure-2. Single module based suggested design consists of a camera, projector and embedded system. It processes all data internally, including high-speed synchronization, decoding, 3D reconstruction and sends information to external platform.

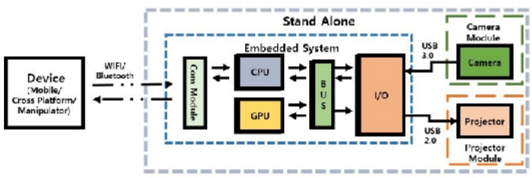


Figure 2. Block diagram of Stand Alone 3D Camera System

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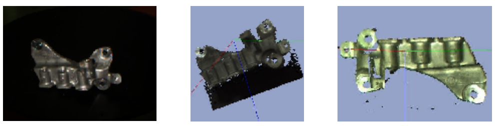
Point Grey Inc. Flea3 camera is used to capture projected patterns which supports high-speed capturing at 120 frame per sec. (fps). Texas Instruments DLP Light Crafter Evaluation Module (EVM) was selected as the projector to project the patterns fast and generate the trigger signal for camera. CPU Exynos5422 is composed of 8 cores in total: quad-core ARM Cortex-A15 and quad-core ARM Cortex-A7, demonstrating high performance which also supports USB 3.0 and allows to use of high-speed cameras [8]. This complete one module can work independently without using external processing and control.

III. Experimental Results

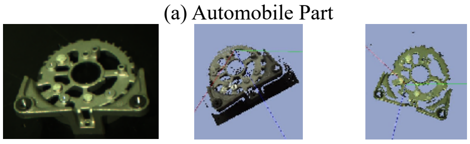
Figure-3 shows the developed standalone structured-light 3D camera consisting of LightCrafter high-speed embedded projector that can control the digital micro mirror device (DMD), 120-fps high-speed camera, and ODROID XU4. Scan rate of 2Hz is achieved by implementation of high-speed synchronization between camera and projector. In addition, on-board decoding and 3D reconstruction is performed to obtain 3D point cloud. The usability is made convenient through Linux-based user-friendly graphical interface (GUI).

(a) (b)

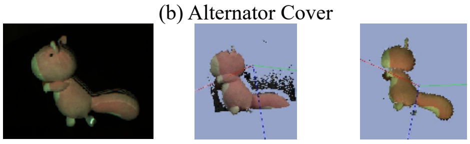
Figure 3. (a) Stand Alone Structured 3D Camera.(b) Operational Setup



(a) Automobile Part



(b) Alternator Cover



(c) Toy

Figure 4. 3D Capture of Objects Left Column:Ground Truth, Middle Conventional System, Right: Standalone system

TABLE I. 3D Points Captured By Conventional and Standalone Systems

Objects	Conventional (Points)	Standalone (Points)	Percentage (%)
Automobile Part	49785	60676	21
Alternator Cover	61589	73935	20
Toy	72177	70732	-3
Average	61183	68447	12.6

The comparison of the total number of points reconstructed using developed standalone and conventional cameras [9] is shown in TABLE I and Figure-4 which clearly shows that we have obtained 12.6% more 3D points by using suggested method. The comparison summary of the conventional and developed systems (TABLE II) shows that for the same performance parameters, the developed standalone 3D camera has smaller dimensions, lower weight and higher data output capability.

TABLE II. Design Comparison

Camera Type/ Parameters	Conventional	Standalone
Dimension	21 X 6.8 X 9.5cm	15 X 8 X 9cm
Weight	700g	500g
Resolution	640 X 480	640 X 480
Scan speed	0.5Hz	2Hz
Accuracy	0.2mm @ 1m	0.2mm @ 60cm
Data output	No	Yes

IV. Conclusion

Suggested standalone 3D camera system design can work for smart modular manipulator independently due to its small size, high scan rate and accuracy. Scan speed can be increased by using high speed camera's.

Acknowledgment

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