A Fast and Dense 3D Scanning Technique Using Dual Pseudorandom Arrays and A Hole-filling Method

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Abstract

Acquisition of 3D data accurately and densely in real time using a low cost structured light system is still an ongoing topic among the computer vision community as it is hard to achieve all these features together. Among several techniques the pseudorandom array technique is widely used in real time 3D scene capturing as it tends to concentrate the entire coding scheme into a single pattern. But existing pseudorandom array decoding methods cannot decode a given symbol in real time when it has missing neighbors. As a solution to this problem we proposed a dual pseudorandom array encoding and decoding method and a hole-filling method which can improve the reconstruction accuracy and time. In this paper we compare our method with several other methods to show how our method captures 3D scenes quickly and densely.

1. Introduction

Techniques for acquiring three dimensional range data from dynamic scenes receive increasing attention in the computer vision community during fast few decades. Emerging technologies such as 3D object modeling, automatic vehicle driving, biomedical applications and device free gaming interfaces are the reason behind that increasing attention. Several 3D measuring techniques such as laser scanning, time of flight, stereo vision, silhouette carving, structure from motion and structured light have been introduced in past years. But among these technologies very few can be used to acquire range data from a dynamic scene.

The stereo vision is such a technique which uses two or more cameras to imagine the scene from different views and measures the depth using triangulation. But it has the major problem of finding correspondences between multiple views accurately.

1.1 Structured Light

Structured light systems have been introduced to solve the correspondence problem in stereo vision [1]. Here one camera is replaced by a light projector which can be used to illuminate the target scene with a structured light pattern and create artificial correspondences in the scene. Then it can be captured by a camera and correspondences can be solved by finding the pattern in the captured image as shown in Figure 1. If we know the correspondences and the projection matrixes of the camera ($\bar{P}_c$) and the projector ($\bar{P}_p$), we can calculate the 3D points.

To find the pattern in the captured image, it is designed so that code-words are assigned to a set of pixels in the pattern. Thus there is a direct mapping from every code-word to their corresponding coordinates of the pixel in the pattern. Different strategies for assigning and representing code-words such as time multiplexing, direct coding and spatial codification have been introduced so far [1]. Time multiplexing methods can achieve good accuracy but it has a limitation in dynamic scene capturing because of multiple patterns. Direct codifications techniques also have limited capabilities due to the sensitivity to noise and light variation even it has a good spatial resolution. Among these techniques spatial codification techniques are widely used in real time 3D scene capturing as it tend to concentrate the entire coding scheme into a single pattern. Among the different kind of spatial codification techniques, pseudorandom coding has the advantage of windowed image processing and flexible system configuration compared to others.

1.2 Pseudorandom Arrays

A pseudorandom array can be defined as a $(m \times n)$ matrix where each element is taken from a given alphabet and each $(x \times y)$ sub matrix is unique within it [2]. In 1976 MacWilliams introduced a method to generate a pseudorandom array by arranging a larger one dimensional pseudorandom sequence into a two dimensional array according to a defined pattern [2]. Another method using

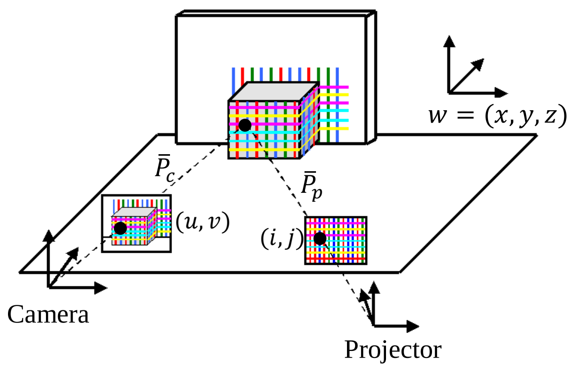

Figure 1: Structured light system with a camera and a projector

two horizontal and vertical pseudorandom sequences has been introduced by Griffin [3]. Morano introduced a brute-force algorithm to fill a pseudorandom array with random colors assignment starting from the top left corner [4]. Antonio introduced a hexagonal pseudorandom array with random color assignment and circular window property [5]. Several other methods also have been introduced by changing and adding some properties for above methods [6] [7].

1.3 Motivation

All these methods, especially the color pseudorandom arrays can easily miss some pattern symbols due to uncertain occlusions, shadows, light condition, depth variation and texture of the scene when they extract pattern symbols from the captured image. Then it cannot decode even some of the extracted symbols because of missing neighbors and it will eventually make holes in 3D shape reconstruction. We have introduced a dual pseudorandom array technique as a solution to this problem [8]. Here each symbol of the pattern has two code-words defined by (3×3) color window and (7×7) binary window. We introduced a dual decoding method and a hole-filling method which can decode a given symbol even it has some missing symbols using this color and binary code-words [9].

In this paper we compare this dual decoding method and hole-filling method with several other conventional decoding methods. With our experiment results we show that using the hole-filling algorithm together with the dual decoding method is the most effective way to achieve dense and fast 3D reconstruction compares to other methods.

2. Proposed Structures Light System

In our proposed structured light system we use a (60×45) color coded pseudorandom array shows in Figure 2. Here each (3×3) color window is unique within the whole pattern. And each (7×7) window only with red color (Binary window) is also unique within the pattern. The color of a given square symbol of the pattern is different from its eight neighbors. That means there are no connected same color symbols in the pattern. So we can

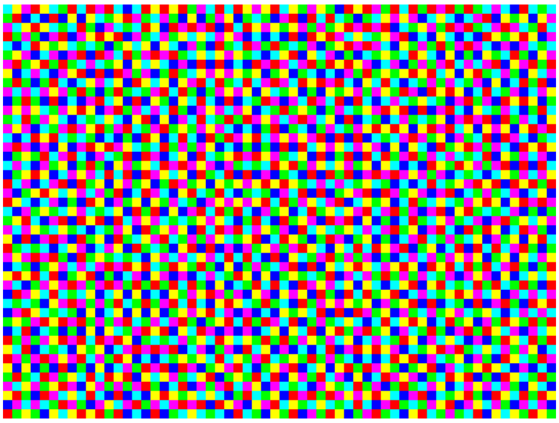

Figure 2: 60×45 Color pattern encoded on top of the binary pattern in Figure 7 with (3×3) window property

apply a simple color segmentation process to the captured image to identify square symbols separately from it.

Each symbol in the pattern except the symbols in the borders has two code-words. We use this property when decoding the pattern symbols. First we try to decode the symbols with (3×3) color window with the help of pattern network generated after extracting the square grid points in color segmentation process. If there is a missing symbol within the (3×3) window we go for the (7×7) binary decoding. The hole-filling method works inside the binary decoding. We can find the affine transformation of small (7×7) window between projected pattern and the captured image using the information of available neighbors. Then using this known transformation we can fill the holes within that window (Figure 3).

3. Experiment & Results

In experiment we compare our proposed method with several conventional methods. Conventional (3×3) color decoding and (7×7) color decoding methods are used to show the advantage of our hole-filling method. (7×7) Color decoding with hole-filling method is used to compare the advantage of proposed dual-decoding method. In TABLE I we show the number of 3D points and the time it consumed for decoding five different scenes using these four methods. Figure 4 shows the reconstructed 3D point clouds of scene 2. It clearly proves that the density of the two point clouds which have used hole-filling methods is clearly more than the other two.

When we consider the time there is a considerable amount of difference between (7×7) color decoding with hole-filling and proposed dual decoding method with hole-filling. It happens because (3×3) color decoding needs less time compared to (7×7) decoding. In dual decoding method it goes for binary decoding only if it cannot decoded by (3×3) color decoding. Because of the considerable amount of time it consumed we cannot use (7×7) color decoding with hole-filling method for real time capturing of 3D data. Figure 5 compares the 3D reconstructions of the scene 1 with (3×3) color decoding and proposed method.

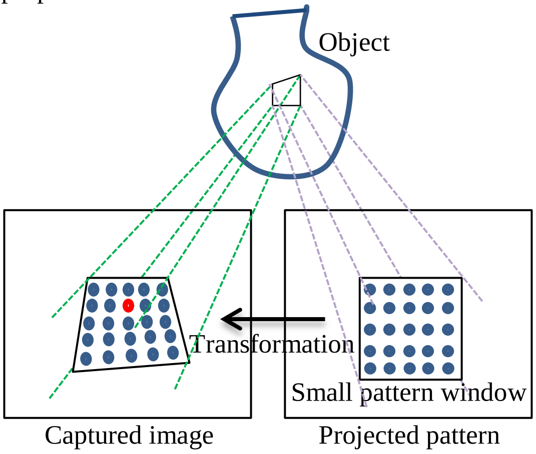

Figure 3: Applying affine transformation to find the image coordinates of a hole in captured image (Red color symbol)

4. Conclusion

We have introduced a new structured light codification system based on dual pseudorandom arrays which can be applied a dual decoding method and a hole filling method. With several experiments we have shown that it can achieve fast and more dense 3D reconstructions compares to conventional methods.

As a future work we are planning to improve the efficiency of the system by applying GPU programming.

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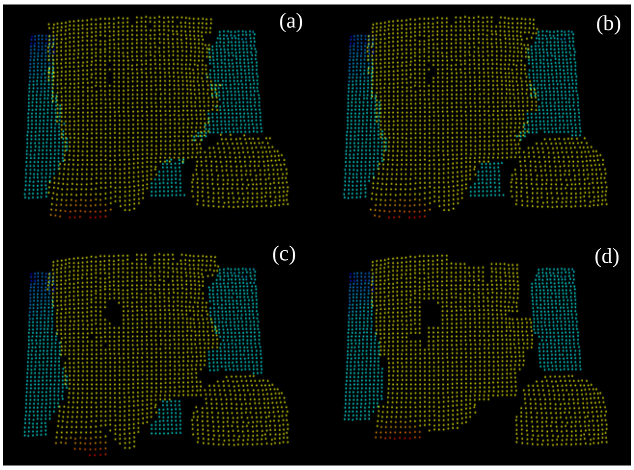
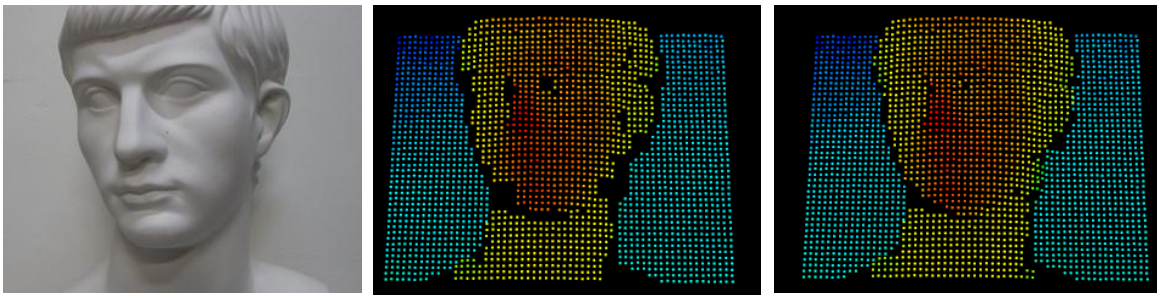


Figure 4: 3D point clouds of the scene 2 reconstructed using four methods we used for the experiment (a) 7×7 decoding with hole-filling (b) Dual decoding with hole-filling (c) 3×3 decoding (d) 7×7 decoding

TABLE I: Comparison between different decoding methods.

Decoding method	Scene 1		Scene 2		Scene 3		Scene 4		Scene 5	
3×3 color decoding	2477	0.32s	2419	0.31s	2578	0.32s	2204	0.29s	2470	0.32s
7×7 color decoding	2246	0.35s	2152	0.33s	2352	0.34s	1486	0.31s	2089	0.34s
7×7 color decoding with hole-filling	2590	2.40s	2553	2.39s	2652	2.31s	2448	2.18s	2616	2.36s
Dual decoding with hole-filling	2578	0.74s	2524	0.74s	2632	0.72s	2425	1.21s	2600	0.77s



(a) Scene 1 (b) Conventional 3×3 decoding (c) Proposed method

Figure 5: Comparison of the two point clouds of the scene 1 generated using proposed method and normal 3×3 decoding