Chapter 7
High-Speed, High-Resolution 3D Imaging Using Projector Defocusing

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ABSTRACT

With the advance of software and hardware, three-dimensional (3D) scene digitization becomes increasingly important. Over the years, numerous 3D imaging techniques have been developed. Among these techniques, the methods based on analyzing sinusoidal structured (fringe) patterns stand out due to their achievable speed and resolution. With the development of digital video display technologies, digital fringe projection techniques emerge as a mainstream for 3D imaging. However, developing such a system is not easy especially when an off-the-shelf projector is used. The major challenging problems are: (1) the projection system nonlinearity; (2) the precise synchronization requirement; and (3) the projection system speed limit. This chapter will present an alternative route for 3D imaging while reducing these problems. The fundamentals of the proposed technique will be introduced, the analytical and experimental results will be shown, and its advantages and limitations will be addressed.

INTRODUCTION

With the release of Avatar and others three-dimensional (3D) movies, and the emergence of 3D TVs and monitors, 3D imaging technology started penetrating into our daily lives. Thus, 3D imaging has become unprecedentedly important and close to ordinary people.

3D imaging is essential to represent the physical object with 3D contents either in a digital format or by an analog means. However, an enormous amount of effort has been put to represent the scene digitally because it is easier to manipulate in this manner. To digitalize a 3D scene, there are mainly

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two approaches: passive and active. The passive methods (e.g., stereo vision) are to recover the 3D information from natural 2D photographs. They essentially capture photographs of the object from different viewing angles and obtain the depth by finding the correspondences between the image pairs, and by establishing the triangulation between the object point and the camera sensor locations. These methods work well for applications where the accuracy is not the primary focus, such as the entertainment. However, hinging on identifying the correspondences between image pairs, the measurement accuracy is not high if the object does not have very strong texture information (Zhang, 2010b).

Active methods, on the other hand, recover depth information by actively placing some vivid features on the object surface to assist the correspondence establishment. Typically, an active light is used because of its surface noncontact nature. The active light can be a single wavelength laser, a range of color spectrum, or a broadband white light. The active features can be dots, lines, and area structured patterns (Salvi et al, 2010). For high-speed applications, the whole area structured patterns are usually desired. There are many ways to generate the structured patterns, such as laser interference, gratings, slide projectors, etc. However, the most convenient means is to use a digital video projector. The patterns can be different in terms of shape and structures, binary, sinusoidal, narrow and wide, etc. Among these techniques, the sinusoidal structured (fringe) patterns based methods stand out because it is most close to the natural light propagation (in sinusoidal way). The phase-shifting techniques have been studied over the past decades and have been used broadly in numerous applications (Gorthi & Rastogi, 2010). Conventionally, the fringe patterns are generated by laser interference, which is good in terms of measurement accuracy and stability. Digital fringe projection techniques, where a digital video projector is used, start expanding its use because of its simplicity.

There is some success and advancement in the technological development of digital fringe projection techniques for 3D imaging, which has been thoroughly reviewed in reference (Zhang, 2010a). The commercial digital video display systems are designed for the purposes other than 3D imaging. There are a number of challenges in order to use them for high-speed and high-accuracy 3D imaging. These include handling the problems of (1) the projection system nonlinearity, (2) the precise synchronization requirement, and (3) the projection system speed limit (Lei & Zhang, 2010).

The objective of this chapter is to present an alternative route for 3D imaging technique using a digital fringe projection and phase shifting technique. This new technique has the potential to significantly reduce the problems of the existing digital fringe projection technique, to drastically simplify the system development for non-experts, and thus to speed up its use in our daily lives. In particular, we will present some of our most recent research in high-speed 3D imaging area that uses this technique.

BACKGROUND

Over the past decades, a number of 3D imaging techniques have been developed including some with real-time capability (Huang et al, 2005; Li et al, 2010; Pawlowski et al, 2002; Quan et al, 1995; Takeda & Mutoh, 1983; Zhang & Huang, 2006a). With recent advancement in computational and shape analysis techniques, high-speed 3D imaging has become unprecedentedly important. Over the years, a number of techniques have been developed to reach real-time capability, including spacetime stereo (Zhang, et al, 2004, Davis, et al, 2005), structured light (Rusinkiewicz et al, 2002), and fringe projection (Zhang & Huang 2006). Among these techniques, fringe analysis stands out because of its numerous advantages (Gorthi & Rastogi, 2010).

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