

High-resolution superfast 3D imaging

Song Zhang

Department of Mechanical Engineering, Iowa State University, Ames, IA 50011, USA

Web: <http://www.vrac.iastate.edu/~song>

Email: song@iastate.edu, Tel: 515-294-0723

Abstract

High-speed, high-resolution 3D geometric motion capture is becoming increasingly important in both academia and industry, with broad applications including medicine, homeland security, and entertainment. In recent years, we have made some progress, and developed an unprecedented 60 Hz rate 3-D imaging system with a digital fringe projection and phase-shifting method. However, a hardware bottleneck was met to further improve its speed. Recently, we have been studying a new method that could potentially eliminate this speed bottleneck. This technique is essentially to generate sinusoidal fringe patterns by properly defocusing binary ones. It coincides with the operation mechanism of the digital-light-processing (DLP) technology, and thus permits some speed breakthroughs. This talk discusses some of our recent studies: (1) realizing simultaneous 60 Hz 3-D geometric motion capture at more than 300,000 points per frame; and (2) achieving kHz rate 3D imaging for capturing extremely rapidly changing scenes. In this talk, I will explain the principles of the technologies, will show some experimental results, and will present some potential applications.

Introduction

With the release of Avatar and other 3-D movies, and the emergence of 3-D TVs and monitors, 3-D images have started penetrating into our daily lives. Thus, 3-D shape measurement has become unprecedentedly important and close to ordinary people.

High-speed, high-resolution 3-D shape measurement becomes increasingly important, with broad applications including medicine, homeland security, and entertainment. Over the years, numerous 3-D shape measurement techniques have been developed including stereo, spacetime stereo, structured light, and fringe projection. However, only a few of these have the capability of achieving high spatiotemporal resolution. Among these techniques, fringe analysis stands out because of its potential to simultaneously reach high spatial and high temporal resolution for very complex structure measurement

Phase-shifting techniques are capable of measuring 3-D shape with very complex structure, and with very high accuracy. It has been extensively used in optical metrology. To reach high speed, the phase-shifted fringe patterns must be switched at a very high speed, so that the number of patterns required for 3-D reconstruction can be reached within a short period of time. We have developed a real-time 3-D shape measurement system using a digital fringe projection and phase-shifting method. This system can simultaneously acquire, reconstruct, and display 3-D shapes in real time (40 Hz). This technique takes advantage of the unique projection mechanism of the single-chip digital-light-processing (DLP) projector that projects three primary color (red, green, and blue) channels sequentially at a very high speed. Later on, we improved the measurement speed (60 Hz) and realized absolute 3-D shape measurement

However, the existing real-time 3-D shape measurement technique using a DLP projector has the following limitations: (1) maximum speed of 120 Hz since this is the refresh rate of a digital video projector; (2) precise synchronization between the projector and the camera due to the fundamental image generation mechanism of a DLP projector; and (3) nonsinusoidal waveform calibration because the nonlinear gamma effect of the commercial video projectors.

Since 2009, we have studied a new method that could potentially alleviate all these problems: namely 3-D shape measurement with projector defocusing. This technique is essentially to generate sinusoidal fringe patterns by properly defocusing binary ones. Because it coincides with the operation mechanism of the digital-light-processing (DLP) technology, this technique permits some speed breakthroughs in the field of high-speed applications. This paper summarizes some of our recent study with this technology. In particular, we will include three major pieces: (1) double the speed of our real-time 3-D shape measurement system without significantly increase the hardware cost; (2) reach tens-of-kHz rate 3-D shape measurement by using a relatively inexpensive and off-the-shelf DLP projector; and (3) achieve kHz rate phase shifting for superior high-speed, high-quality 3-D shape measurement with the DLP Discovery platform.

Talk contents

In my talk, I explained the principles of the structured light 3D imaging, and the motivations behind advancing such a technology. My talk focused on the recent progress in my research in the past few years. Specifically, I presented an unprecedented 60 Hz rate 3-D imaging system with a digital fringe projection and phase-shifting method that I developed before 2008.

And I explained that a hardware bottleneck was met to further improve its speed. My talk was then switched to the most recent research on exploring a new method that could potentially eliminate this speed bottleneck. This novel technique that I presented was essentially to generate sinusoidal fringe patterns by properly defocusing binary ones. It coincides with the operation mechanism of the digital-light-processing (DLP) technology, and thus permits some speed breakthroughs. I then presented both the hardware and the software I developed that could achieve kHz rate 3D imaging for capturing extremely rapidly changing scenes.

Due to huge amount of size collected by the high-speed 3D imaging technology I developed, we have to find a way to compress the data so that they could be easily stored or transported. My last component of talk was to show the newly innovation on compressing 3D range videos into 2D videos for superior quality with a very high compression ratio.

In this talk, principles of behind all these technologies were explained, experimental data were shown, and the potential problems were also addressed.