Doppler Time-of-Flight Imaging

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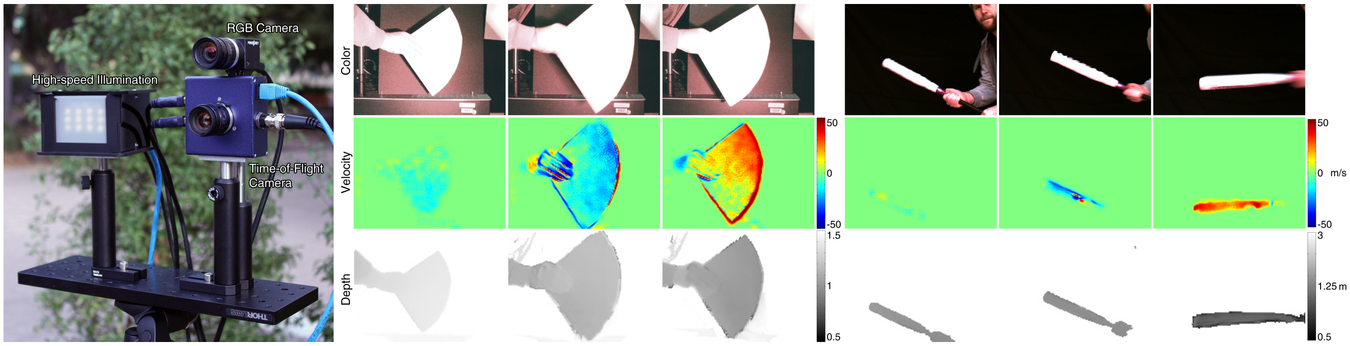

Figure 1: *We introduce a new computational imaging system that allows for metric axial velocity information to be captured instantaneously for each pixel (center row). For this purpose, we design the illumination and modulation frequencies of a time-of-flight camera (left) to be orthogonal within its exposure time. The Doppler effect of objects in motion is then detected as a frequency shift of the illumination, which results in a direct mapping from object velocity to recorded pixel intensity. By capturing a few coded time-of-flight measurements and adding a conventional RGB camera to the setup, we demonstrate that color, velocity, and depth information of a scene can be recorded simultaneously. The results show several frames of two video sequences. For each example, the left-most frame shows a static object (velocity map is constant), which is then moved towards or away from the camera.*

Abstract

Over the last few years, depth cameras have become increasingly popular for a range of applications, including human-computer interaction and gaming, augmented reality, machine vision, and medical imaging. Many of the commercially-available devices use the time-of-flight principle, where active illumination is temporally coded and analyzed on the camera to estimate a per-pixel depth map of the scene. In this paper, we propose a fundamentally new imaging modality for all time-of-flight (ToF) cameras: per-pixel velocity measurement. The proposed technique exploits the Doppler effect of objects in motion, which shifts the temporal frequency of the illumination before it reaches the camera. Using carefully coded illumination and modulation frequencies of the ToF camera, object velocities directly map to measured pixel intensities. We show that a slight modification of our imaging system allows for color, depth, and velocity information to be captured simultaneously. Combining the optical flow computed on the RGB frames with the measured metric axial velocity allows us to further estimate the full 3D metric velocity field of the scene. We believe that the proposed technique has applications in many computer graphics and vision problems, for example motion tracking, segmentation, recognition, and motion deblurring.

1 Overview

Pioneers of photography, including Eadweard Muybridge and Harold "Doc" Edgerton, advanced imaging technology to reveal otherwise invisible motions of high-speed events. Today, understanding the motion of objects in complex scenes is at the core of computer vision, with a wide range of applications in object tracking, segmentation, recognition, motion deblurring, navigation of autonomous vehicles, and defense. With the emergence of RGB-D imaging, for example facilitated by Microsoft's Kinect One[1], complex and untextured 3D scenes can be tracked by analyzing both color and depth information, resulting in richer visual data that has proven useful for many applications. However, capturing high velocity has not been possible til now.

We introduce a new approach to directly imaging axial object velocity. Our approach analyzes the Doppler effect in time-of-flight cameras: object motion towards or away from the cameras shifts the temporal illumination frequency before it is recorded by the camera. Conventional time-of-flight cameras encode phase information (and therefore scene depth) into intensity measurements. Instead, we propose Doppler Time-of-Flight (D-ToF) as a new imaging mode, whereby the change of illumination frequency (corresponding to axial object velocity) is directly encoded into the measured intensity. The required camera hardware is the same as for conventional time-of-flight imaging, but illumination and modulation frequencies are carefully designed.

We can combine depth and velocity imaging using either two time-of-flight cameras or using the same device by alternating the modulation frequencies between successive video frames; color images can be obtained with a conventional camera.

2 User experience

Since our camera-system allows to capture velocity videos at real-time frame rates, many exciting applications can be demonstrated. Visitors of our booth will be able to swing a baseball bat, punch in the direction of the camera or potentially throw a baseball in the direction of the camera. Finally, we imagine a scoreboard keeping track of who achieved the highest speed.

[1]microsoft.com/en-us/kinectforwindows/

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