# COMPUTER GRAPHICS I COMP.5460

# LITERATURE REVIEW 1

## Snapshot Difference Imaging using Correlation Time-of-Flight Sensors

This research paper is about finding new techniques to record two or more images and then compute the difference between them. The authors explore a new approach to capturing difference images in a single exposure and generalize difference imaging to a variety of applications. They propose to re-purpose time-of-flight (ToF) sensors to facilitate instantaneous difference imaging.

This functionality is achieved by a pixel architecture that employs two potential wells for photoelectrons to be stored in during the exposure, and that subtracts the charges accumulated in these two wells. They demonstrate how ToF sensing technology can be used to conveniently implement a range of computational photography techniques, including direct-global separation, direct depth edge imaging, spatio-temporal gradient imaging, and more. The capabilities unlocked with snapshot difference imaging are particularly interesting for applications that require low-power, low-latency on-board processing with low bandwidth communication channels, such as internet-of-things devices.

The major benefit of this proposition is a difference image within a single exposure allows for faster time scales to be recorded than capturing two separate images and subtracting them digitally. Secondly, the noise properties of difference imaging before A/D conversion are shown to be favourable over digital subtraction post A/D conversion.

The authors have used correlation sensors for time-of-flight imaging because they are the most widespread and affordable. A pixel in a ToF sensor measures the amount of correlation between the incoming temporally varying photon flux and a sensor modulation signal $f(t) \in [0, 1]$ that also varies in time. Firstly, reduce the modulation frequency to a point (1–5 MHz) where the propagation of light through near-range scenes can be assumed to be instantaneous and $f(t)$, typically generated by a digital circuit, only assumes the values 0 and 1. Secondly, use two light sources, one (LS1) driven using the same function $f(t)$ and the other one (LS2) with its logical negation $f(t)$.

Two different prototype for snapshot imagers are constructed. first prototype is a recreation of Heide et al.'s system [2013] that is based on the discontinued PMD Technologies CamBoard nano. The second prototype combines the Texas Instruments (TI) OPT8241-CDK evaluation module with external modulation and light sources in a similar way to the system. Each of our light sources carries three OSRAM OSLON LEDs that are switched using the same signal.

APPLICATIONS:

1. Polarization-based direct-global separation: There can be two types of decomposition of light direct component, i.e., light that has undergone exactly one scattering event between light source and camera, and a multiply scattered indirect, or global, component. Being able to investigate these components separately has been shown to enable, for instance, more realistic digital models for human skin.

2. Bipolar colour matching functions: The spectral aspect of this work, using our PMD setup to construct an active camera that discriminates between objects of red and blue reflectance in a single shot. By equipping L1 with red and L2 with blue LEDs, we obtain a bipolar colour camera that measures a positive response for objects that are predominantly red, and a negative response for bluish objects.

3. Depth edge and directional gradient imaging: The setup can be used to produce directional gradient images of a scene, visualizing depth continuities as shown in Fig. 7. In this mode of operation, two identical light sources of opposite polarity are placed on opposite sides of the sensor. Whenever a depth discontinuity shadows one of the light sources, the resulting image displays positive or negative values. All other pixels obtain a value around zero. By varying the distance between the light sources, different edge widths are obtained.

4. Quantitative Noise Analysis: To compare the relative performance of snapshot difference imaging with two-shot, post-capture difference imaging under otherwise identical conditions, we acquired three image sequences of a still scene, each N frames long: one sequence with both light sources activated and two more with only LS1 or LS2 turned on, respectively.

To conclude, they proposed a new imaging system for direct recording of image differences in a snapshot. The proposed technique directly maps to the emerging technology of time-of-flight sensors and will therefore continue to benefit from the on-going technological development in that area. The primary benefits of snapshot difference imaging include high video frame rates that are only limited by the readout interface as well as lower noise and reduced alignment artefacts as compared to sequential, digital difference imaging.

# Computational Imaging with Multi-Camera Time-of-Flight Systems

This research paper is about the design and applications of phased multi-camera time-of-flight (ToF) systems. The authors have developed a reproducible hardware system that allows for the exposure times and waveforms of up to three cameras to be synchronized. Building on the concept of orthogonal frequency design, we demonstrate state-of-the-art results for instantaneous radial velocity capture via Doppler time-of-flight imaging and we explore new directions for optically probing global illumination, for example by de-scattering dynamic scenes and by non-line-of-sight motion detection via frequency gating.

Today, range imaging technology is largely dominated by time-of-flight (ToF) cameras due to their small device form factors, good resolution, robustness in the presence of ambient light, low power, and fast on-chip processing. The design and applications of synchronized (i.e. phased) multi-camera systems. While such phased arrays have many interesting applications, they also suffer from potential multi-device interference (MDI), that is created when light sources of multiple ToF cameras interact with one another, thereby corrupting the measurements for all sensors. multi-device interference is a limitation that diminishes the usefulness of ToF cameras for applications where multiple cameras are crucial, such as collaborative work, automotive applications, and AR/VR applications with multiple users. the first phased multi-camera ToF system and demonstrate unique benefits for instantaneous range and velocity imaging, multi-device interference cancellation, descattering of dynamic scenes, non-line-of-sight (NLOS) motion detection.

Most time-of-flight cameras operate in amplitude-modulated continuous-wave (AMCW) mode, where a fast, active light source illuminates a scene with a time-varying signal or waveform. The AMCW time-of-flight problem is an estimation of the phase shift -, and with it, the scene depth. For this purpose, the temporally-varying signal incident on the sensor s(t) is demodulated by a sinusoidal function f (t) = cos(!t +  ). In practice, this demodulation is implemented by periodically directing photoelectrons into one of two “buckets” within each sensor pixel.

Direct imaging of per-pixel radial velocity information is possible with Doppler Time-of-Flight Imaging [Heide et al. 2015]. Here, the time-of-flight camera operates in heterodyne mode, where illumination frequency !g and sensor demodulation frequency !f are different.

Waveform design for velocity imaging, we propose to cancel the contribution of all but one light source for each camera using mutually orthogonal frequency pairs to mitigate MDI artifacts.

APPLICATIONS:

1. Fast Range Imaging with Phased ToF Cameras: The most intuitive application for a phased time-of-flight camera arrays would be to capture all of these measurements in parallel. This is beneficial for mitigating motion artifacts observed for dynamic scenes.

2. Motion Detection for Non-Line-of-Sight: simply look for intensity changes in the heterodyne images that indicate the presence of motion in indirectly reflected illumination but we do not aim to recover their shape. While a single light source is sufficient, multiple lights with orthogonal frequencies can be used to boost the sensitivity to a larger range of object velocities. This mode of operation is easily supported by our hardware system. The concept of motion detection not only applies to motion of objects outside the direct line-of-sight but also of objects that are veiled by scattering.

To conclude, I can say that the authors developed a multi camera with phased time-of-flight system. It can be used for a multiple applications and it also serves as a platform for evaluating computational imaging applications.

# Similarity between two papers:

Both the papers have used Time-of-flight sensors as their main subject. The first paper uses correlation for snapshot while the second one is more towards computational imaging. The first paper is more focused on getting difference in the same image using time of flight sensors while the second one is trying to build multi-camera system.

References:


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ACM Transactions on Graphics, Vol. 36, No. 6, Article 220. Publication date: November 2017

# Computational Imaging with Multi-Camera Time-of-Flight Systems

ACM Trans. Graph., Vol. 35, No. 4, Article 33, Publication Date: July 2016