CoDAC: Compressive Depth Acquisition using a Single Time-resolved Sensor

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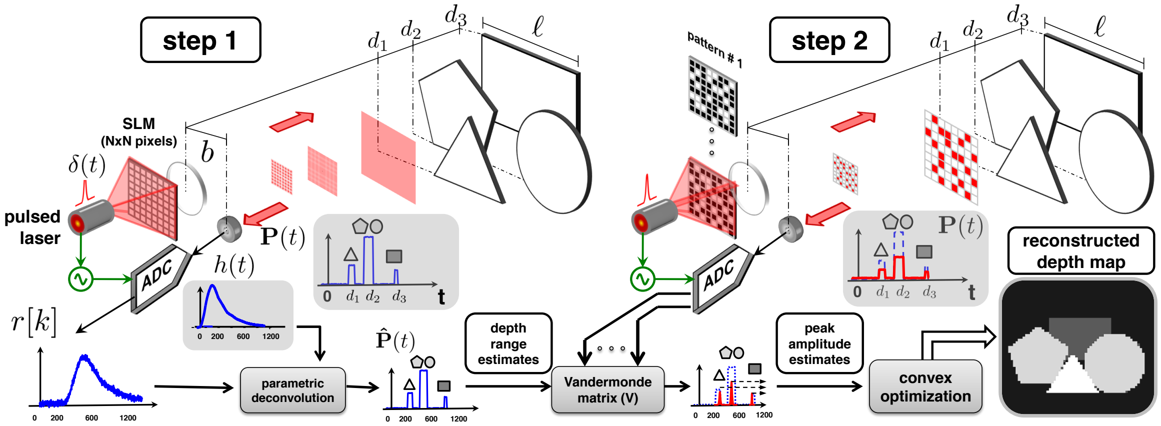


Figure 1: *CoDAC depth sensing architecture uses a spatial light modulator (SLM) to spatially pattern a temporally-modulated light source. In step 1, time-resolved measurements from a single omnidirectional sensor are processed using parametric signal processing to recover scene depth information. We estimate the three distinct depths in this fronto-parallel scene with sub-centimeter resolution even with pulse width of 3ns (rise-time 0.7 ns). Spatial resolution was recovered through step 2 of the algorithm using only 205 SLM patterns. This corresponds to* 5% *of the total number of* 4096 *pixels in the depth map.*

1 Introduction

CoDAC is a method for compressive acquisition of scene depth with high spatial and range resolution using a single, omnidirectional, time-resolved photodetector and no scanning components [Kirmani et al.]. Light detection and ranging (LIDAR) systems use time of flight (TOF) in combination with raster scanning of the scene to form depth maps, and TOF cameras instead make TOF measurements in parallel by using an array of sensors. Moreover, existing depth sensing technologies do not use the high compressibility of scene depth to reduce acquisition costs. Here, we present a framework for compressive depth map acquisition using neither raster scanning by the illumination source nor an array of sensors.

Our depth map reconstruction relies on parametric signal modeling of the impulse response of piecewise planar scenes. We use parametric deconvolution to achieve much finer depth resolution than dictated by the illumination pulse width and the detector bandwidth. Spatial resolution in our framework is rooted in patterned illumination followed by decoupling the inverse problems of range estimation and spatial resolution recovery during computational processing. Spatial resolution equal to that of the spatial light modulator (SLM) is achieved despite using fewer SLM patterns than the number of pixels in the SLM. Proof-of-concept experiments have verified the validity of our modeling, algorithms and improved spatial and range resolution over existing methods. CoDAC enables depth acquisition in a compact form factor, with significantly-reduced hardware cost and complexity as compared to state-of-the-art LIDAR systems and TOF cameras.

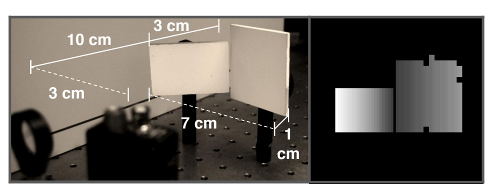
2 Modeling and Algorithmic Framework

CoDAC has a two-step reconstruction procedure. Step 1, uses omnidirectional illumination or no spatial patterning, i.e., a fully-transparent SLM configuration. Under the assumption that the scene is approximately piecewise planar, we have shown that the continuous-time light intensity signal at the single photodetector is well approximated by a piecewise linear signal [Kirmani et al.]. For fronto-parallel scenes, this parametric signal is simply a series of short square pulses as shown in Figure 1. Estimation of the underlying parametric signal $P(t)$ implies recovery of the range or depth content present in the scene. The use of a parametric signal modeling and recovery framework enables us to achieve high depth resolution relative to the speed of the time sampling and the photodetector bandwidth. After depth identification in step 1, the remaining problem is to find correspondences between spatial locations and depths to form the depth map.

Step 2, uses several pseudorandom binary patterns on the SLM. For each pattern, the received time-resolved signal is processed to yield amplitude data. Again for fronto-parallel scenes, the amplitude of each peak in the parametric signal is equal to the *fraction of the scene at a particular depth* that is illuminated by the projected pattern. Since we assume that the scene is approximately piecewise planar, this translates to the Laplacian of the depth map being approximately sparse. We introduce a convex optimization problem [Kirmani et al.] that finds the depth map consistent with the measurements that approximately minimizes the number of nonzero entries in the Laplacian of the depth map. Solving this optimization problem yields the desired depth map.

3 Hardware Implementation

We conducted proof-of-concept experiments to demonstrate the range and spatial resolution capabilities of the CoDAC framework. We used a pulsed laser source at 780nm and 70mW average power to illuminate the SLM with 64×64-pixel resolution. The reflected light was collected at a Si PIN photodiode with rise-time of $0.7ns$. The recovered depth maps for a fronto-parallel scene is shown in Figure 1 and for piecewise planar scenes is shown below.



References

Kirmani, A., Colaço, A., Wong, F., and Goyal, V. Exploiting sparsity in time-of-flight range acquisition using a single time-resolved sensor. *OSA Opt. Express* (Oct 2011).

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