Review of What Are Optimal Coding Functions for Time-of-Flight Imaging?

With more 3D imaging is preferred, the time-of-flight cameras become more popular. This article presents a mathematical framework for exploring and characterizing the space of continuous wave time-of-flight (C-ToF) coding functions, which are based on Hamiltonian cycles on hypercube graphs. This method can achieve up to 10 times higher depth resolution as compared to existing methods such as sinusoid coding, especially in low Signal-to-Noise-Ratio (SNR) settings. Hamiltonian coding functions are tightly related to the theory of Gray codes and achieve substantially higher depth resolution as compared to existing schemes, given the same total capture time, total power, and depth range. There are three main steps for ToF Imaging which are impulse ToF imaging, code design for C-ToF imaging, and simulation of C-ToF sensors.

The coding curve representation is a tool to design a family of novel high-performance C-ToF coding schemes. There are three important desirable properties of a coding curve. First, since the mean depth precision is inversely proportional to the coding curve length, the curve should be long. Second, in order to ensure a unique mapping between the unknown points and measurement points, the coding curve should not be self-intersecting. Third, the coding curve should preserve locality such as the distance of points measured along the curve should be proportional to the Euclidean distance between two points. In validation and simulation phase, numerical methods and simulations are used to compare the relative performance of various C-ToF coding schemes, with the same total capture time and emitted power. The proposed Hamiltonian coding achieves a mean depth error of about an order of magnitude lower than conventional sinusoid coding in both noise settings, consistent with the ratio of coding curve lengths.

Even the Hamiltonian coding is a substantial improvement, but there are still limitations to the method. The limitations that the Hamiltonian coding have are hardware constraints, multi-path propagation, and the derivation of the depth error measures are scene agnostic; they implicitly assume a uniform distribution of scene depths, albedos, and ambient illumination.

Overall the test results suggest that Hamiltonian coding, given its strong locality properties, outperforms Hilbert coding in most real-world scenarios. With the same multi-path mitigation technique applied to both Hamiltonian and sinusoid coding, Hamiltonian coding can potentially achieve similar performance gains over sinusoidal codes. With such a framework, it may become possible to analyze and design C-ToF coding schemes that are robust to multi-path interference, as well as coding schemes for multisource/multi-sensor systems.

Review of Bayesian Time-of-Flight for Realtime Shape, Illumination and Albedo

The success of depth cameras encourages and creates more possibility to improve computer vision applications. This article introduces a computational model for shape, illumination and albedo inference in a pulsed time-of-flight (TOF) camera. There are plenty of approaches that are suitable for the application such as Bayesian inference, maximum likelihood inference, maximum Aposteriori inference and regression tree. The regression approach has two advantages; first, it allows to approximate inference in principled probabilistic models under tight compute and memory constraints; second, it decouples the model from the runtime implementation, allowing continuing improvements in the model without requiring changes to the test-time implementation. With a strong calculus calculation from Bayesian inference and the regression tree decision, it is believed that the combination of both will produce realistic simulation with fewer depth errors.

For a generative model, a single direct response from the point being imaged is considered. In order to account for multipath, the model needs to be extended as to describe the additional multipath light being integrated at the pixel. It is important to ensure a realistic simulation as it leads to exposure design for reduced multipath artifacts, learning or obtaining realistic priors for multipath effects, and benchmarking. In order to achieve such goals, the following steps were experimented. First, the time of flight simulation is recorded. This helps with exposure profile design as taking two expectations, prior conditions and the assumed forward model, will minimize the loss when responses come from basic generative model.

After the experiment, the results show that Surfaces with low reflectivity have large depth errors, but the model is aware of this through a large inferred value. In addition, areas affected by strong multipath also have large depth errors. The two-path model (TP) improves depth accuracy in every scene but also reports increased model compared to the single-path model. The results also show that less invalidation happens in the two-path model. Finally, the most significant findings in this experiment is it indicates that forty percent of the errors are reduced by the two-path model.

The proposed method is based on sound probabilistic modelling given the understanding of the physical reality. Bayesian inference works great when it comes to calculation to perform depth inference. Even multipath might produced more errors but this problem can be reduced by converting the multipath into two-way path models. In the future, it is expected to introduce more refined models of multipath, for example by replacing the two-path pulse response by a more accurate analytic model of diffuse Lambertian multipath.

Comparison Between the Two Literatures

The intersection of domains between the two literatures are introducing new methods that help reduce depth errors. The first article is, which is the later article, indicates a way to optimize coding functions for time-of-flight imaging called the Hamilton coding. This method is based on Hamiltonian cycles on hypercube graphs. Since its methods consist of computation of model probability and close relationship with the theory of Gray code, it makes this method achieve high depth resolution when compared to others. The second article proposes a new method to reduce depth errors. The method is a combination of Bayesian inference and regression tree decision. Its goal is to produce realistic simulation. The approach of this method is to use Bayesian inference to calculate the depth inference and use regression tree to make the method more flexible and robust. This approach works well with two-way path model, but still has trouble when it comes to multipath model. Both methods are suitable for the graphic vision applications, but they still have limitations. For example, Hamilton coding is dependent on hardware while the second method has small affect on reducing the depth errors in multipath models. Even both methods cannot achieve one hundred percent improvement, but they are general and open enough that it will eventually lead to more possibilities of better implementation.

Citations

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