Problem 1.

1. (20%) There are two basic approaches for Time-of-flight camera: continuous wave modulation approach and pulsed-based approach. Briefly describe their principles and what are their major differences?

Ans(a): A continuous wave time of flight camera uses modulation to measure the phase and determine the properties of the return signal. This in turn can be used to calculate range.

The above is accomplished by first modulating a wave and detecting the return signal

*s(t)* = *a*1 + *a*2 cos*(*2*π f t),*

*r (t)* = *A* cos*(*2*π f t* − 2*π f τ)* + *B*

The cross-correlation gives us after some mathematical footwork:

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Now, note here that tau is our time delay, and that x is a variable in our original cross-correlation. Using equally spaced samples in one modulation period: 0, pi/2, pi. And 3\*pi/2 we can solve C and solve for

Phi, A and B.

Now, on the other hand a pulsed based time of flight camera sends out pulses of light by a laser or diode that once detected by the object are then computationally processed with time to digital converters (TDC) and time to amplitude circuits to reconstruct the signal

Ans(b)

The major difference is that CW cameras are measuring phase differences between a continuous signal and a pulse-based camera is directly measuring the round-trip. Related to each of these systems based on their measurement technique they each have limitations. For the CW this is dealing with the phase ambiguity and for pulsed it is the accuracy of the SPAD sensor.

Problem 2.

2. (20%) How does single photon avalanche diode work? Why it can be used to detect single photon?

Ans part a:

See the figure below. If you reverse bias a photodiode and dope the semiconductor material in a certain way you are essentially making it unstable. Now normally, materials are impure and there will be some electrons in p-type material and holes in n-type. So, if the material is properly doped then a SINGLE photon can start an avalanche breakdown. (a sort of runaway current as more electrons creates more holes).

Diagram, timeline

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Ans part b:

The reason that these single photons can be detected as because instead of using an ADC(analog to digital converter) a time to digital converter is used.

Given the engineering limitations of ADCs, that include resolution and sampling times, using them to compute a single photon event does not seem practical. On the other hand if you model photon flux as:

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where g is the initial pulse, tau is a discrete Dirac function and a[t] is the ambiguity photon flux,

Now the SPAD outputs:

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where eta if probability and d represent false events.

Next, if the above experiment can be repeated N times, then the probability of detecting a certain number of events is a Poisson distribution, given by:

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Now we can use the histogram to compute statistically single photons.

Problem 3.

3. (10%) Briefly describe how structured light 3D surface imaging works.

Ans:

Here in the diagram below two known patterns of grayscale column images are similar except one is phase shifted in relation to the other. Now, both are projected sequentially to the object. The deformation of the patter helps us to topologically map distances of the object correctly, helping us reconstruct the shape/

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Problem 4.

4. (20%) Name two techniques for ultrafast transient imaging and describe their basic principles.

One method is with femto-photography using streak camera.

Another method is with the use of SPADs

Problem 5.

5. (30%) Transient image reconstruction using MATLAB. Download the dataset and code from Transient imaging with SPADS link, choose one dataset, and use MATLAB (demo code is provided and demonstrated during the class) to reconstruct the transient images. Try different PSF options for reconstruction and see which is better.