Finding Distance to Objects using a Joint Transform Correlator

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Background

Vander Lugt's 1963 matched-filter correlator (MFC) was the first correlator to see wide use, but it required precise alignment of its instruments [1]. Weaver and Goodman then invented the joint transform correlator (JTC) in 1966, which required less specialized hardware and less precise alignment at the cost of space efficiency [2].

Computers brought the advent of digital correlation, the process most commonly used to find distance through stereoscopic parallax [3]. However, digital correlation is slow and computationally expensive compared to optical correlation.

Research Objective

The objective of this research is to investigate the possibility of using a JTC to find the distance to an object. Though the joint transform correlator was originally developed as an optical system, the correlation can be performed programmatically as well.

We used two webcams to generate stereo images. It is expected that a similar configuration can be achieved by one or more camera-equipped CubeSats to measure distance to nearby objects in space.

Process

Images were generated by two Microsoft LifeCam Cinema webcams aligned horizontally with 9.5″ baseline separation between cameras. The subject was a 2″x1.5″ Post-It note. Both images were cropped, decolorized, and passed into the joint transform correlator, with each image serving as both target and filter.

Results

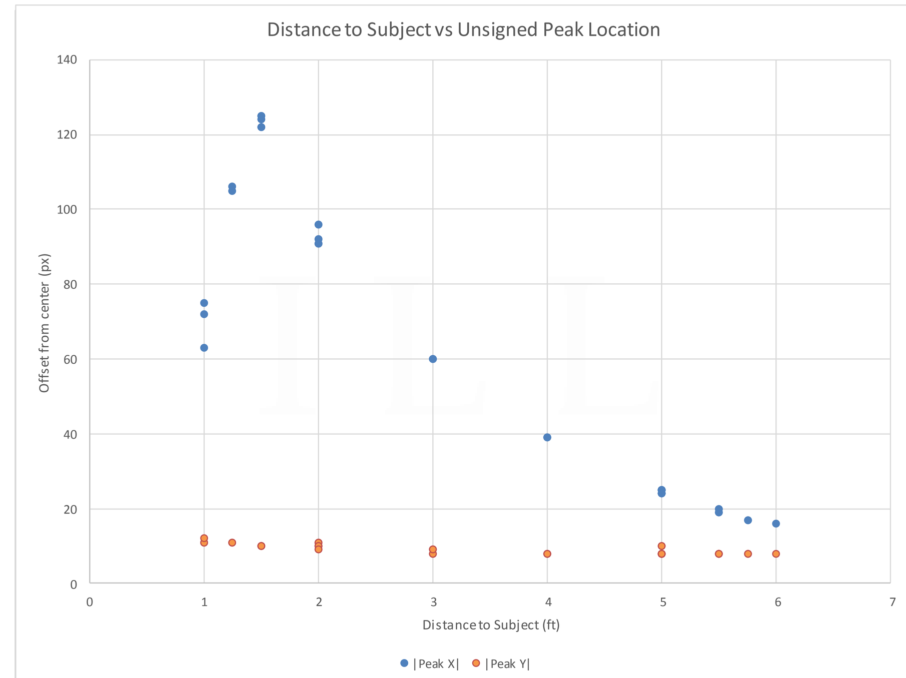


Fig. 1: Comparing distance with peak location.

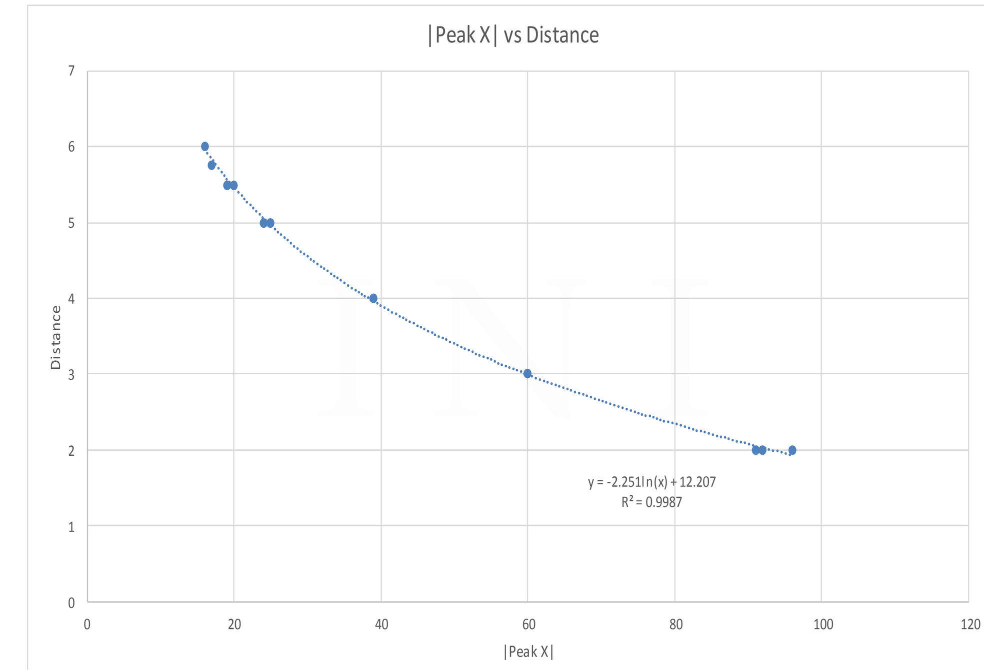


Fig. 2: Correlating peak X location with distance.

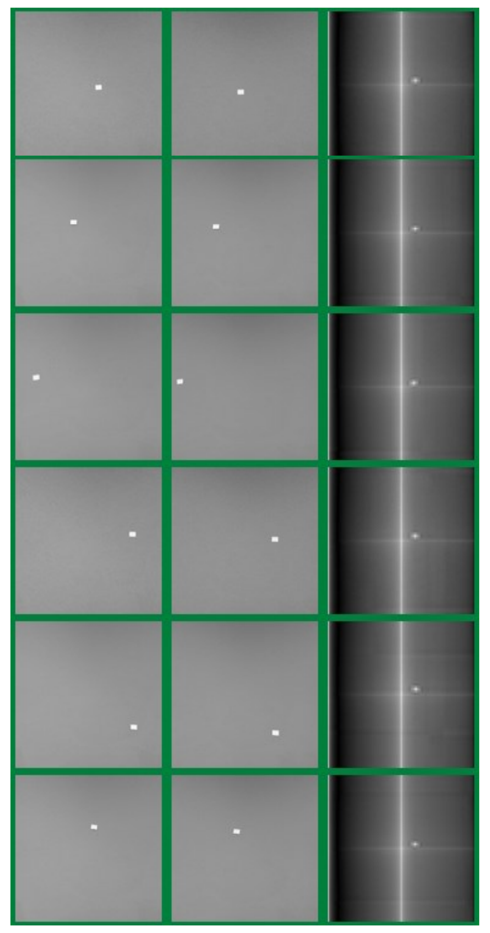
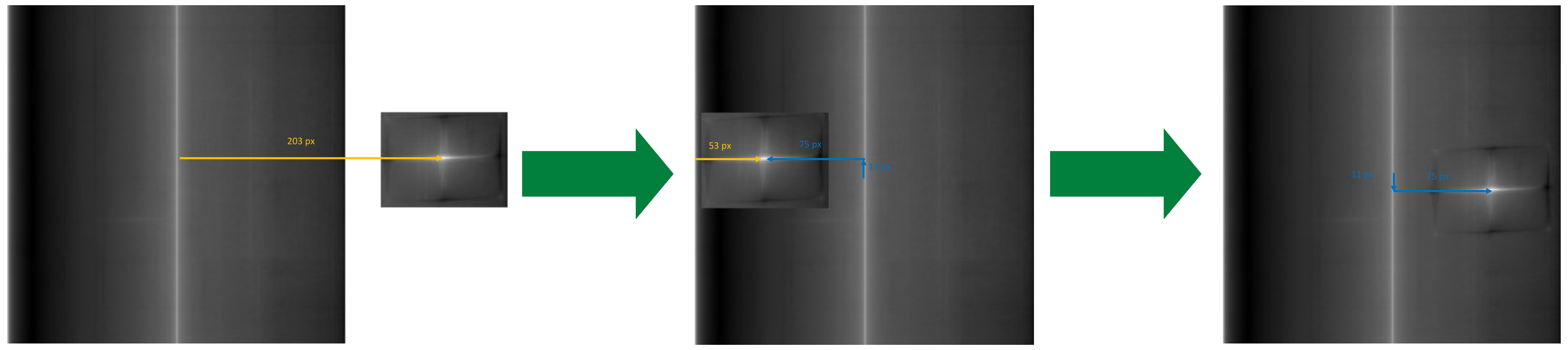


Fig. 3: Testing subject location's effect on peak location.

As distance to the object decreases, the X coordinate of the peak increases, up to a maximum of half the image size (Fig. 1). With our testing environment, this occurs at around 1.5 feet. If actual distance to the object decreases beyond that, the peak will wrap around the image and then get both coordinates flipped:



If we restrict our analysis to distances that do not produce the above effect, we may invert the data and a regression becomes quite obvious (Fig. 2). Excel gives the following logarithmic model:

$$d = -2.251 \ln|x| + 12.207$$

It is important to note that this formula was generated under the specific conditions, including a 73° field of view and a 9.5 in baseline, but it is expected to lay the groundwork for a more general formula. With this formula we were able to determine distances from 2 ft to 5 ft, with an accuracy of ±3 in.

There is no relationship between the peak's Y coordinate and the distance to the object (see red series on Fig. 1). This is because the difference in camera heights is constant.

Additionally, the location of the object has no effect on the peak's location (Fig. 3), as long as the object is fully contained in both input images. An object partially off-image will result in inaccurate peaks (Fig. 4). An object fully off either or both images will result in no peaks (Figs. 5 & 6).

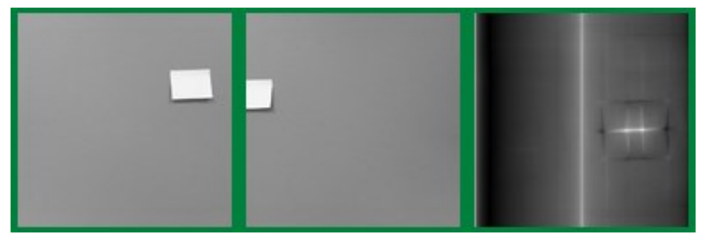


Fig 4: Object partially off one image.

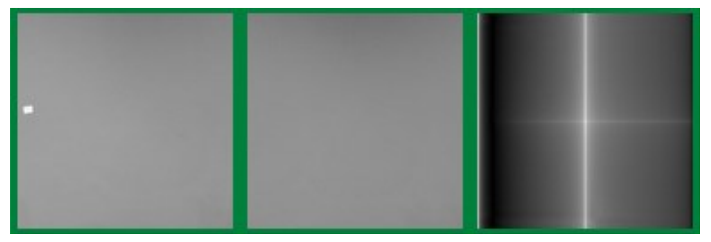


Fig. 5: Object off one image.

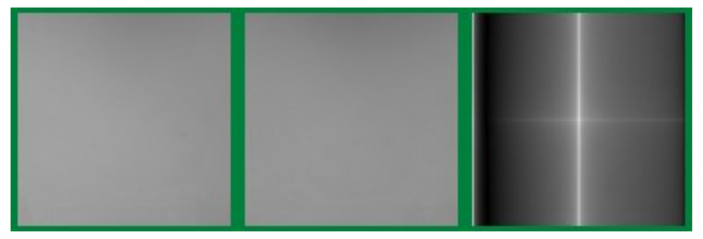


Fig. 6: Object off both images.

Conclusion and Future Work

The work to date achieved its goal of proving that distance can be recovered from a joint transform correlation peak. While this work shows promise, further work is needed to elucidate and generalize the relationship between peak location and distance. This will move us closer to the ultimate goal of finding a formula relating Peak X, Peak Y, field of view, baseline, and distance.

The wrapping and flipping effect presents a formidable challenge to this goal, and will likely be the next target of investigation. Another obvious direction future research will take is to test the effect of varying baseline on the location of the correlation peak.

Finally, at this time the method has not been tested for practical applications like the CubeSat platform. The work to date and near-future work is entirely proof of concept, and we may expect that applications follow once a strong foundation is laid.

References

1. A. Vander Lugt, "Signal detection by complex spatial filtering," IEEE Transactions on Information Theory, vol. 10, pp. 139-145, 1964.
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3. Jernej Mrovlje and Damir Vrančić, "Distance measuring based on stereoscopic pictures," 9th International PhD Workshop on Systems and Control: Young Generation Viewpoint, 2008.

Acknowledgements

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