3D Bioprinting Directly onto Human Anatomy: Can Dynamic Vision Sensors Improve Performance?

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Background and Methods

Background

Additive manufacturing of 3D biomaterials is proving successful in printing organs for transplant and faster healing [1]. Recently, O'Neill et al. demonstrated that 3D bioprinting directly onto free-moving human anatomy is feasible [2], enabling a new class of surgical procedures for editing tissues in real time. However, the accuracy of such printing is fundamentally limited by unpredictable motion which occurs between acquired camera frames (e.g., at roughly 60 Hz). We propose dynamic vision sensing to mitigate this loss of information (e.g. with μs-scale updates). We herein quantify the potential error introduced by dynamic vision sensor (DVS) events between acquired frames for a 3D bioprinting fiducial setting.

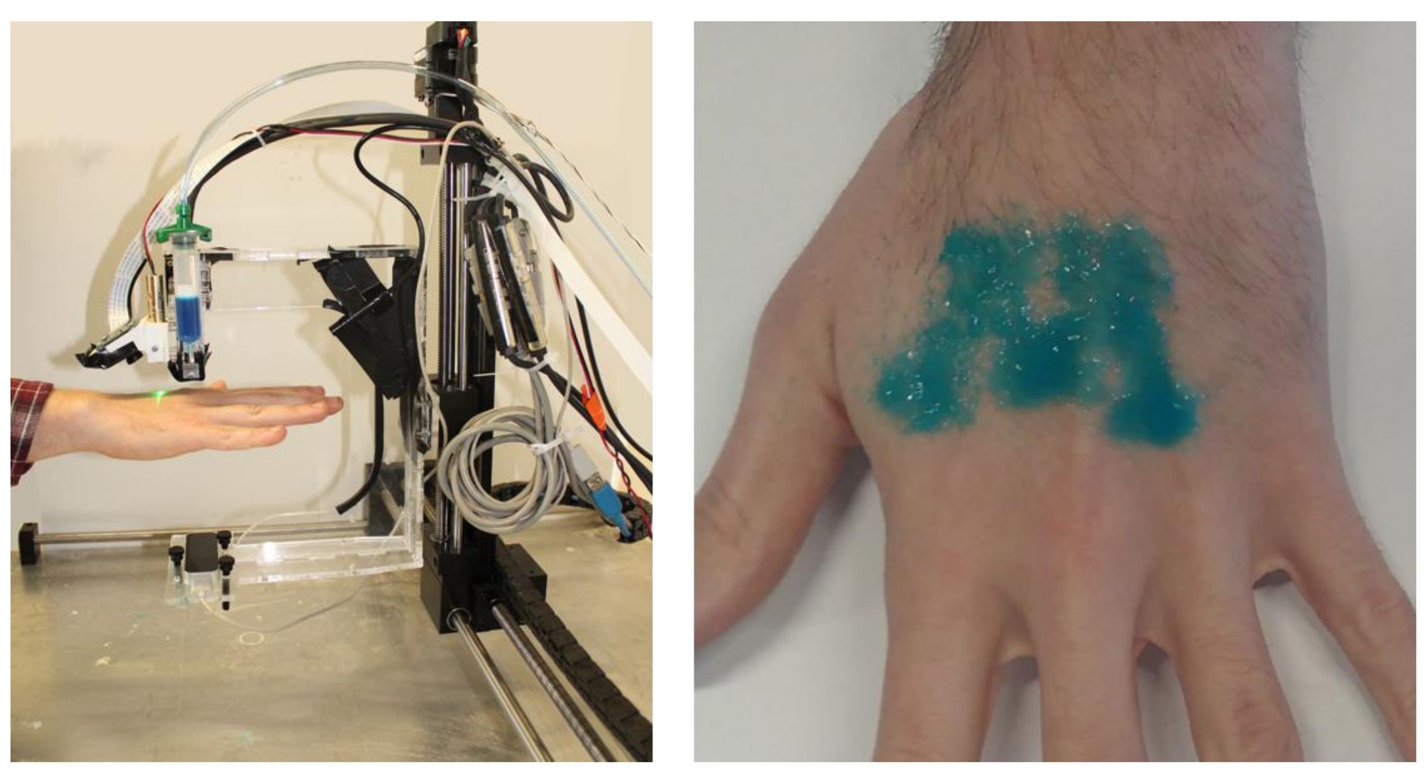

FIGURE 1: Bioprinting onto a moving human hand (left), and resulting 3D printed 'M' (right) [2]

Methods

The accuracy of fiducial tracking using the DVS sensor was tested according to the following procedure:

- Record the motion of a manually oscillated checkerboard image using A DAVIS 240c (iniLabs Zurich, Switzerland) sensor
- Extract fiducials using simple circle matching method
- Extract checkerboard corners using the MATLAB Computer Vision Toolbox
- Create homography matrix relating the measured checkerboard image (in pixel space) to the true checkerboard image (in Cartesian space)

Methods (continued) and Results

- Project measured checkerboard corners (in pixel space) onto true checkerboard corners (in Cartesian space)
- Determine the absolute average error between the measured $(\widehat{U}_C)$ and true (X_C) checkerboard corner location in Cartesian space:

$$E_X = \left\| \widehat{U}_C - TX_C \right\|$$

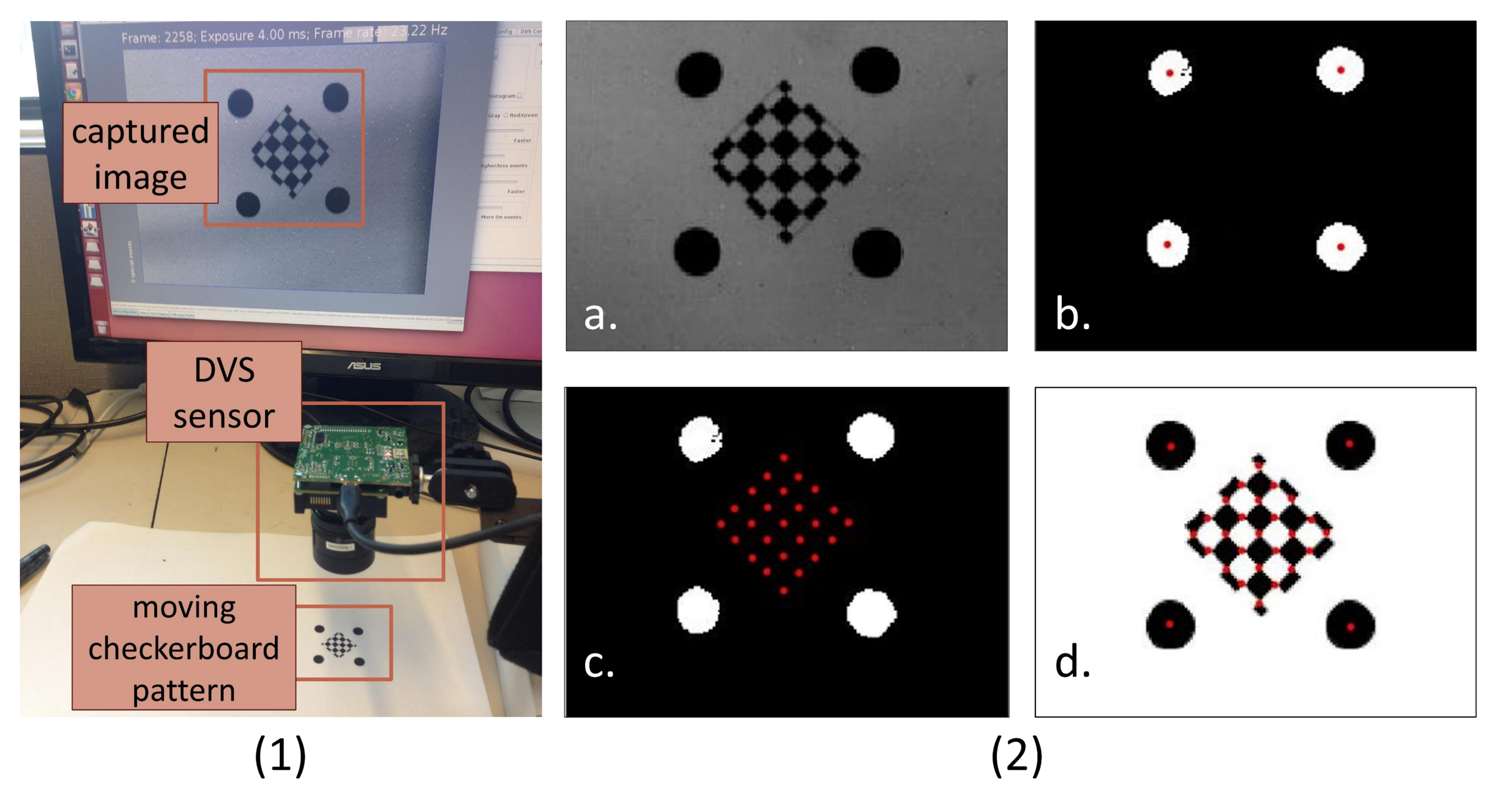

FIGURE 2: (1) Experimental setup, (2) **a.** Captured image, **b.** Extracted Fiducials, **c.** Extracted checkerboard corners, **d.** Measured checkerboard corners projected onto true checkerboard corners (in Cartesian space)

Results

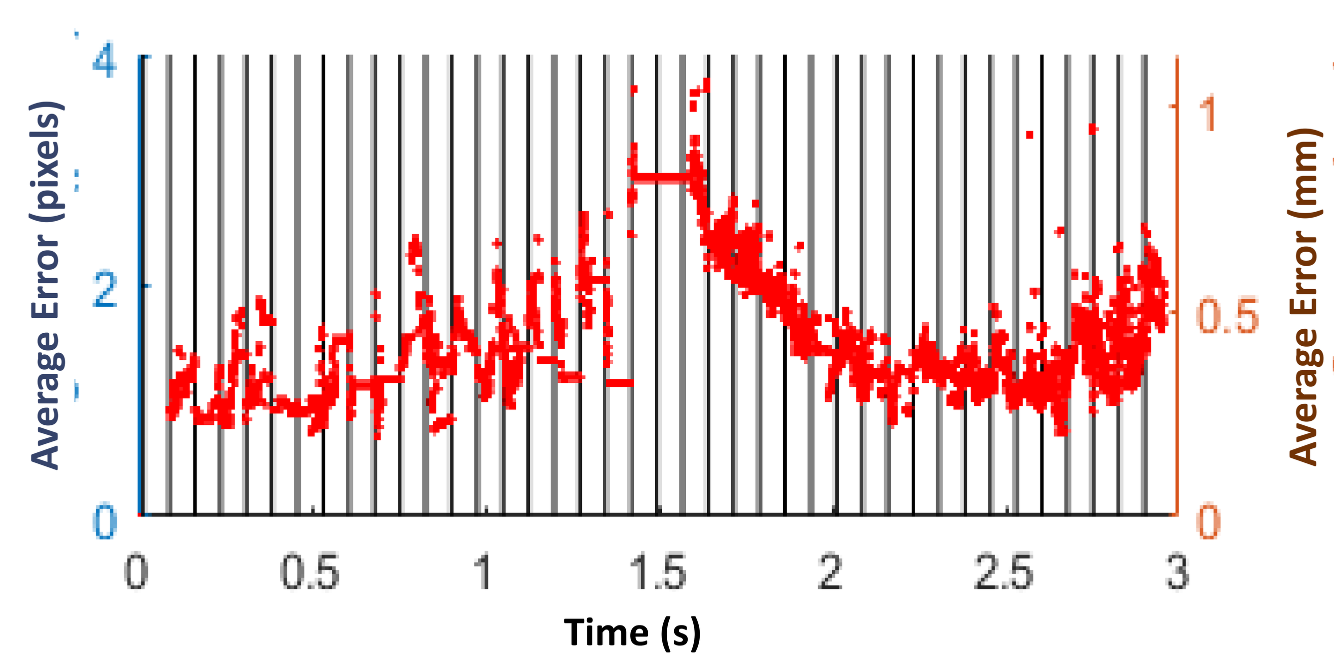

FIGURE 3: Average projected error over 3 seconds of data acquisition showing global frames (vertical lines) and DVS events (red dots)

Discussion and Acknowledgments

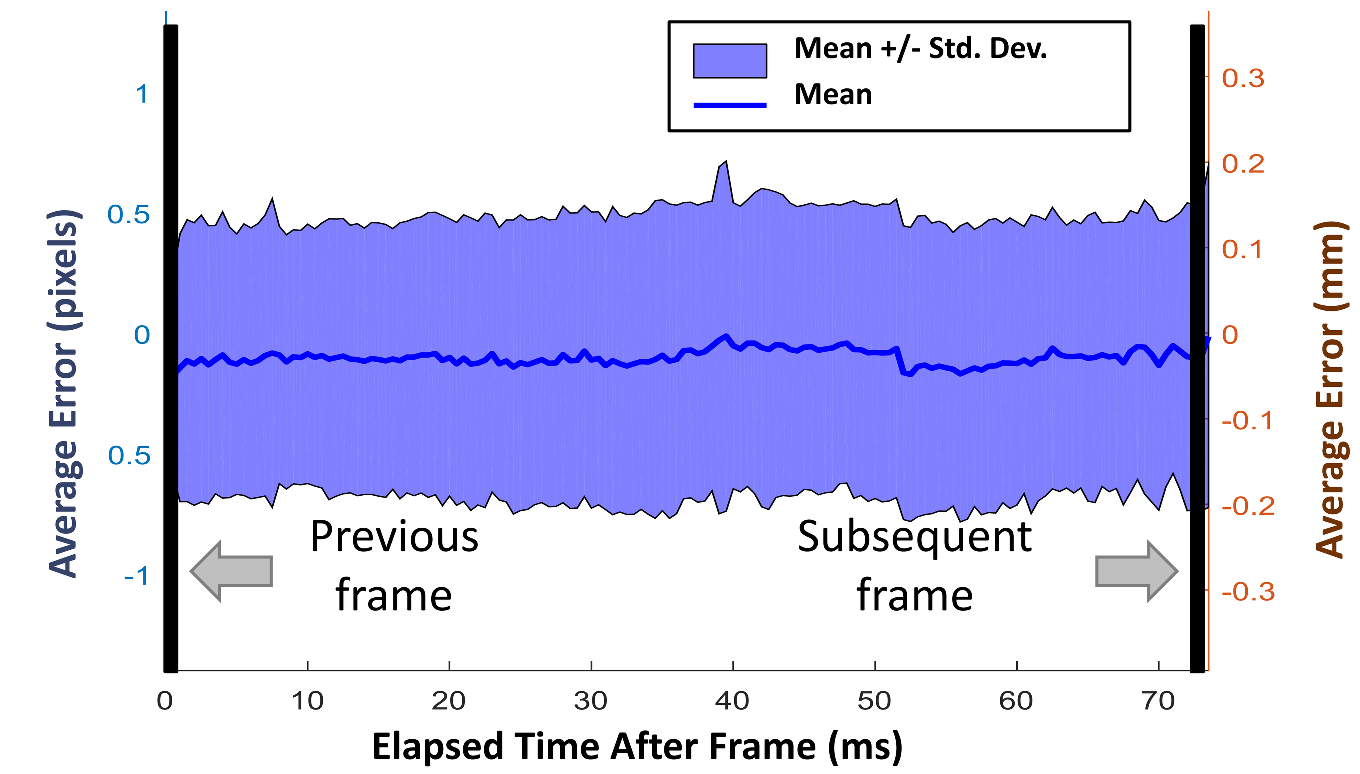

FIGURE 4: Overlaid average error occurring between subsequent frames.

Discussion

- The results demonstrate that DVS events are not a significant source of error beyond the error acquired using only global frames
- There is no significant relationship between the amount of error accrued and the amount of time elapsed between frames
- Dynamic vision sensors may improve accuracy of 3D bioprinting onto moving targets by providing actionable information regarding unexpected motion between frames

Acknowledgments

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References

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