3D marker tracking with GoPros and XMALab: A low-cost 3D tracking set-up

Nathan C.A. Jackson, David Wakely, and Peter L. Falkingham.
School of Biological and Environmental Sciences, Liverpool John Moores University, UK

Introduction

- We present a low-cost, easy-to-use setup for motion tracking using two comparatively inexpensive GoPro Hero 7 cameras. We applied the XROMM workflow[1,2] (https://www.xromm.org/) specifically XMALab[3] to the GoPro videos.
- Cameras were calibrated using a LEGO object that spanned much of the field of view.
- We measured accuracy and precision by tracing markers on a separate moving LEGO object and assessed reprojected 3D distances.
- Although the cameras were simultaneously triggered via wireless remote, synchronisation required manual post-processing.
- This experimental setup is relatively low cost (<£600), whilst offering high-resolution (up to 4k)) or high framerate (up to 240fps) video capture.
- We plan to apply this method to cadaveric range of motion studies (unfortunately COVID restrictions have delayed this part of the project).

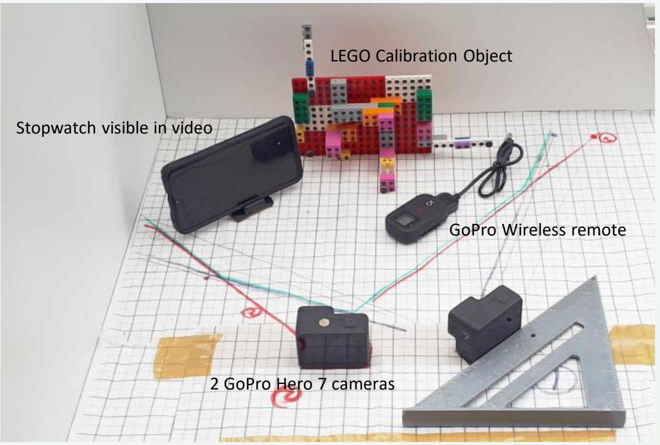

Figure 1 - Study setup for calibration object. GoPro cameras (in foreground), along with the remote control. In the background, mobile phone (used for post-process synchronization) and, in centre, LEGO calibration object. In this image, lines were drawn on paper to visualize each camera's field of view. 3D reconstruction can occur where the fields of view of each camera overlap.

Total cost of hardware (excluding computer) <£600

Experimental setup;

- 2x GoPro cameras
- LEGO (for calibration want and object)
- Stopwatch

Software:

- Data was calibrated and digitised using XMALab (https://bitbucket.org/xromm/xmalab/src)
- Videos were synchronized using 3D Blender (www.blender.org)

Methods

Calibration

- A calibration object (see Fig. 1) was constructed that could fill the volume of interest and extend in 3-dimensions. XYZ co-ordinates of each raised nub were entered into a CSV file based on known LEGO dimensions.
- Four specific nubs were chosen as reference points to aid calibration in XMALab, with a separate .ref file created with this information.
- To capture footage, two GoPro cameras were placed at 45 degrees to each other, facing the object, and 3 seconds of footage captured.
- Cameras were triggered via wireless remote.

Motion tracking

- A second LEGO object (herein referred to as the "wand", Fig. 2) was used for tracking. This was manipulated by hand in front of the cameras for three seconds, in a rotating figure of 8 motion.
- Even with the wireless remote, cameras were poorly synchronized. A mobile phone was used as a stopwatch displaying milliseconds to aid post-processing synchronization.

Post-processing

- We used Blender to synchronize videos based on the visible stopwatch.
- After this, data was analysed in XMALab, with mean intermarker distance used as a measure of accuracy, and standard deviation of that distance used to quantify precision.
- We tested two resolutions (1080p and 2.7k) and two framerates (24 and 120fps), with 3 trials per configuration. For this study, we limited our resolutions and framerates to those available in linear field of view

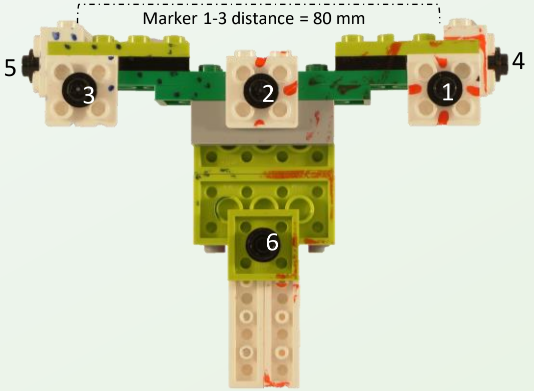

Figure 2 - LEGO marker wand - six black circular pieces are used as markers and are labelled here. Accuracy and Precision were measured using the distance between markers 1 and 3 as calculated by XMALab from the tracked videos. Marker pen was used to break up solid colours to help with photogrammetry of the object for later 3D reconstruction.

Results

- The configuration with the highest accuracy was 2.7k/24 and the most precise was 1080p at 120fps
- Average reprojection error (a measure of how well aligned the cameras are) was low, between 0.4 and 0.2 pixels.
- Synchronisation: Using the wireless remote, videos were, on average, ~0.1 seconds out of sync (though up to ~0.5 seconds in places). Videos were synchronised to the same start position and cropped using the Video Editor in Blender, though individual frames within videos could still be up to 0.05 seconds out of sync (but average difference in time between frames was often <0.01 seconds after manual synchronization).

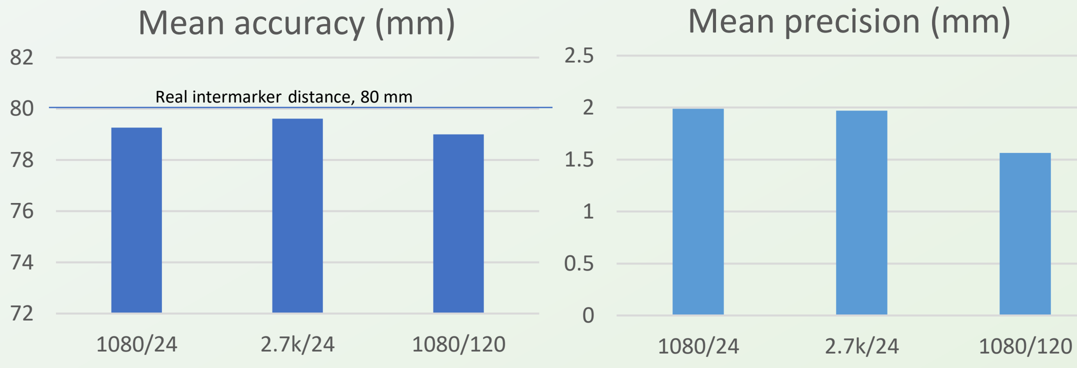

***Figure 3** – Mean accuracy and precision for resolutions of 1080p and 2.7k, and framerates of 24 and 120fps, as measured for distance between markers 1 and 3 (horizontal). True distance was 80 mm. Accuracy measures the mean inter-marker distance and precision is the standard deviation of inter-marker distances, as reported by XMALab.*

Conclusions and future work

- Increasing the resolution led to a small increase in accuracy, as would be expected.
- Higher framerates improved precision slightly. In our trials so far, we have only moved the wand slowly. We expect framerate to have a much larger effect on high-speed movements.
- We plan to test the ability of the XMALab workflow to deal with the more distorted wide-angle view at higher resolutions and framerates (e.g. 1080p @ 240fps, 2.7k @ 120fps, or 4k @ 60fps), and explore whether manual undistortion is required.
- This method builds on previous work, which used Raspberry PI Cameras (PiROMM)[4]. Whilst PiROMM utilised networked cameras for good synchronisation, resolution and framerate were severely limited. Here, cost is slightly higher, and synchronisation requires manual post-processing, but the higher framerates and resolutions provide excellent accuracy and precision, and the robustness (including waterproofness) of the GoPro cameras makes them far more versatile.

References

1. Brainerd, E. L. *et al.* (2010) 'X-ray reconstruction of moving morphology (XROMM): precision, accuracy and applications in comparative biomechanics research', *J Exp Zool A Ecol Genet Physiol*, 313(5), pp. 262–79. doi: 10.1002/jez.589.
2. Gatesy, S. M. *et al.* (2010) 'Scientific rotoscoping: a morphology-based method of 3-D motion analysis and visualization', *J Exp Zool A Ecol Genet Physiol*, 313(5), pp. 244–61. doi: 10.1002/jez.588.
3. Knorlein, B. J. *et al.* (2016) 'Validation of XMALab software for marker-based XROMM', *J Exp Biol*, 219(Pt 23), pp. 3701–3711. doi: 10.1242/jeb.145383.
4. Falkingham, P. (2017) 'Reconstructing moving morphology using RaspberryPi (PiROMM): Range of motion in ostrich cervical vertebrae at progressive stages of dissection', p. 159830543 Bytes. doi: 10.6084/M9.FIGSHARE.5155462.V1.