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How Camera Positioning Effects Marker-less Motion Capture

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Introduction:

Problem

Marker-less motion capture (MOCAP) is a technology that utilizes high-definition cameras to analyze human motion, primarily focusing on gait patterns. As marker-less motion capture starts to become a more prominent technology to measure gait, it is necessary to understand the limitations, consistency, and abilities of the technology. The following study uses marker-less MOCAP with the software Theia3D (Theia Markerless Inc., Kingston, ON) to observe gait kinematics. Theia3D uses 2D images from video cameras to track the kinematics of a subject by predicting the placement of virtual markers on the subject's body. This technology is like marker-based motion tracking, however limitations such as placing 51 physical markers on the subject is not required.

One of the questions that need to be answered about MOCAP is how camera angle and positioning affects the consistency of the technology. By seeing how camera positioning affects accuracy, the data can be used to inform future markerless collectors of locations with the most promising results. The following experiment was designed to see exactly how camera positioning and angles affects the accuracy of MOCAP. By accessing multiple subjects' movements in various directions, it can be checked if there are large discrepancies in any of the directions, thus evaluating its consistency.

Hypothesis

It was predicted that camera angles would have little to no effect on gait kinematics. With the MOCAP software used, the requirements for accurate MOCAP are that 6 cameras must view the subject to get all the dimensions of rotations and movements per joint [Kanko], so it is expected that the areas with inconsistency would correspond to where less of the cameras view the subject. Therefore, it was predicted that there will be no specific line that the subject walks that causes more errors, but areas where there is less visibility.

Summary of Findings

After the study was conducted, it was found that camera angles do not affect MOCAP, as all the walking directions had very similar gait patterns, but rather camera positioning affects the effective capture volume. Areas right before the edges of the walks tended to have more BAD points and tracking errors (BAD events are events with unrealistic joint angles, while tracking errors are events where body segments are missing completely). This allowed for a more in depth understanding of how to optimize MOCAP with Theia3D and can be used with further research to create a quantitative analysis of area vs accuracy to find the optimal area for MOCAP by any camera positioning.

Methods:

Plan

To measure the accuracy of MOCAP with cameras in various angles and direction, instead of moving the cameras around, subjects were asked to walk in lines in various directions to see how consistent their gait patterns are in every direction. The subjects walked in a starlike movement, so the cameras tracked a diverse number of angles and orientations of the subject. Since gait patterns within individuals are very consistent, each of the directions that the subjects walk can be compared to see if there is a difference in measurement. Each direction that the subject walks will be a separate event (alphabetically labeled from event A to E)

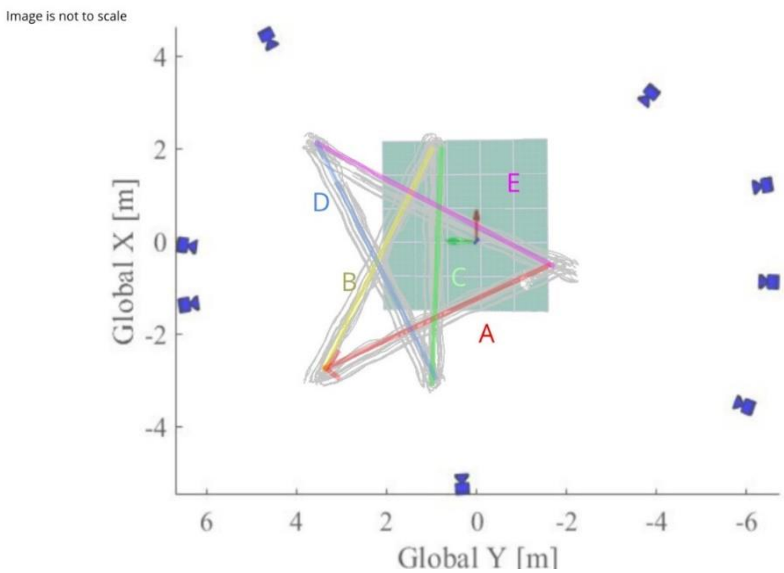

Figure 1 shows a layout of star trials that the subject is walking relative to the cameras and coordinates of the lab. Each of the colored arrows represent the walking directions of the subject and the blue cameras show the position an orientation of the cameras.

Trial Details:

The data was recorded at the Human Mobility Research Lab at Queen's University, Kingston, Ontario. Eleven subjects were asked to perform the star trial walk as shown in [Figure 1] and were recorded. Eight Sony RX 0 Mk II cameras were placed around the perimeter of the lab and were connected to ensure that they recorded synchronized video data. The trials were then recorded, and processed through the MOCAP software, Theia3D. Afterwards, Visual3D (C Motion, Kingston, ON) and the open-source software R was used to measure inverse kinematic patterns, specifically both sides of the hip, knee, and ankle angles in each direction that the subject walks. This data was then analyzed by looking at the range of motion, mean and standard deviation of the joint angles to see if there were any common pattern in any of the directions. Finally, all the subject's positions throughout the trial were mapped out to see where tracking errors occurred most frequently.

Technology Used

Sony RX 0 Mk II:

All the 11 subjects' data was recorded with 8 Sony RX0 Mk II cameras, calibrated and fixed in position throughout the trial.

THEIA 3D

Theia3D is a 3D pose estimation software used for marker-less motion capturing. The software takes all the videos recorded from all 8 camera angles and performs 3D pose estimation using a deep learning algorithm. Subjects' whole body pose as represented by 4x4 transformation matrices for each body segment is then exported as c3d files for analysis in visual 3d software.

Visual 3D

Visual3D is an advanced biomechanics analysis software that is used to capture specific data from trials. It is used for skeletal modeling, analysis, and reporting. In the lab, this software was used to obtain joint angle measurements from the c3d files and export these measurements into a readable format in R. This was done through creating Pipelines (series of code used to execute commands in Visual3D), starting from using the pelvis to track every time a subject switches direction, and then the hip, knee, and ankle angles were measured every time the subject's heel strikes the ground. Then hours were then spent filtering the data for BAD events (events where there is a computing error, and the subjects join angle value is extremely unrealistic) to ensure that the data being used is reliable and consistent. Pipelines were also used to track the center of mass coordinates of the subject while they walk around lab for their position as well as their velocities to check how similar their speed was in each walking direction. Finally, a large pipeline was created to take all the data and convert into txt files in folders for every subject.

R

R is an open source phyton based software used for statistical computing and graphics. In the lab, R was used to create all the plots and figures that were used for analysis and conclusion of the results. The plots made that will be referenced to include standard deviation and mean graphs, max/min/range of motion box plots, waveform graphs, and position tracking of the subject using a scatterplot.

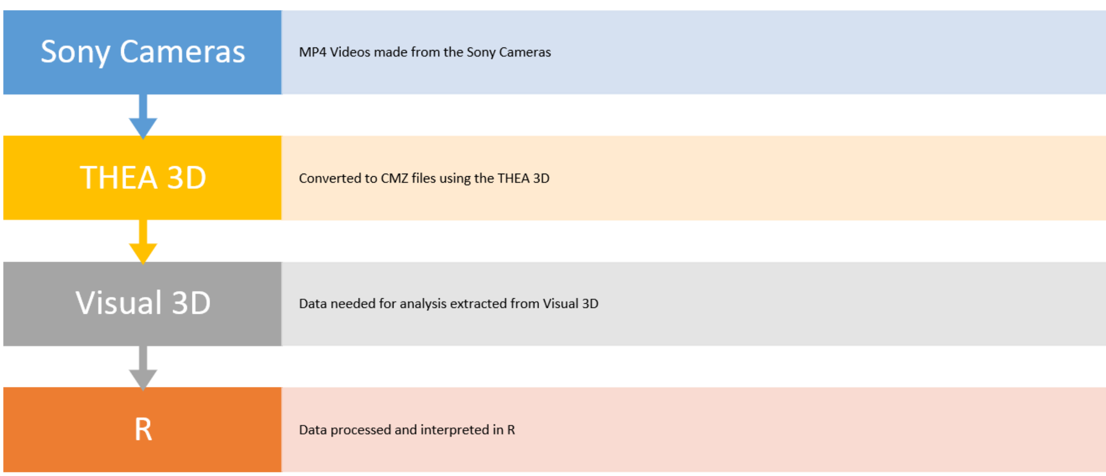

Figure 2 represents a diagram of how the data was processed in each step

Results:

Waveform Analysis:

The first analysis that was done in R was a simple waveform graph for each subject. The waveform graph's x axis represents one gait cycle and then each subjects left, and right hip, knee and ankle angles were recorded, in the x, y and z axis. The values in the data were separated by color for each walking direction, labeled alphabetically A to E. The values for each event's walking directions were divided into gait cycles represented by the same color

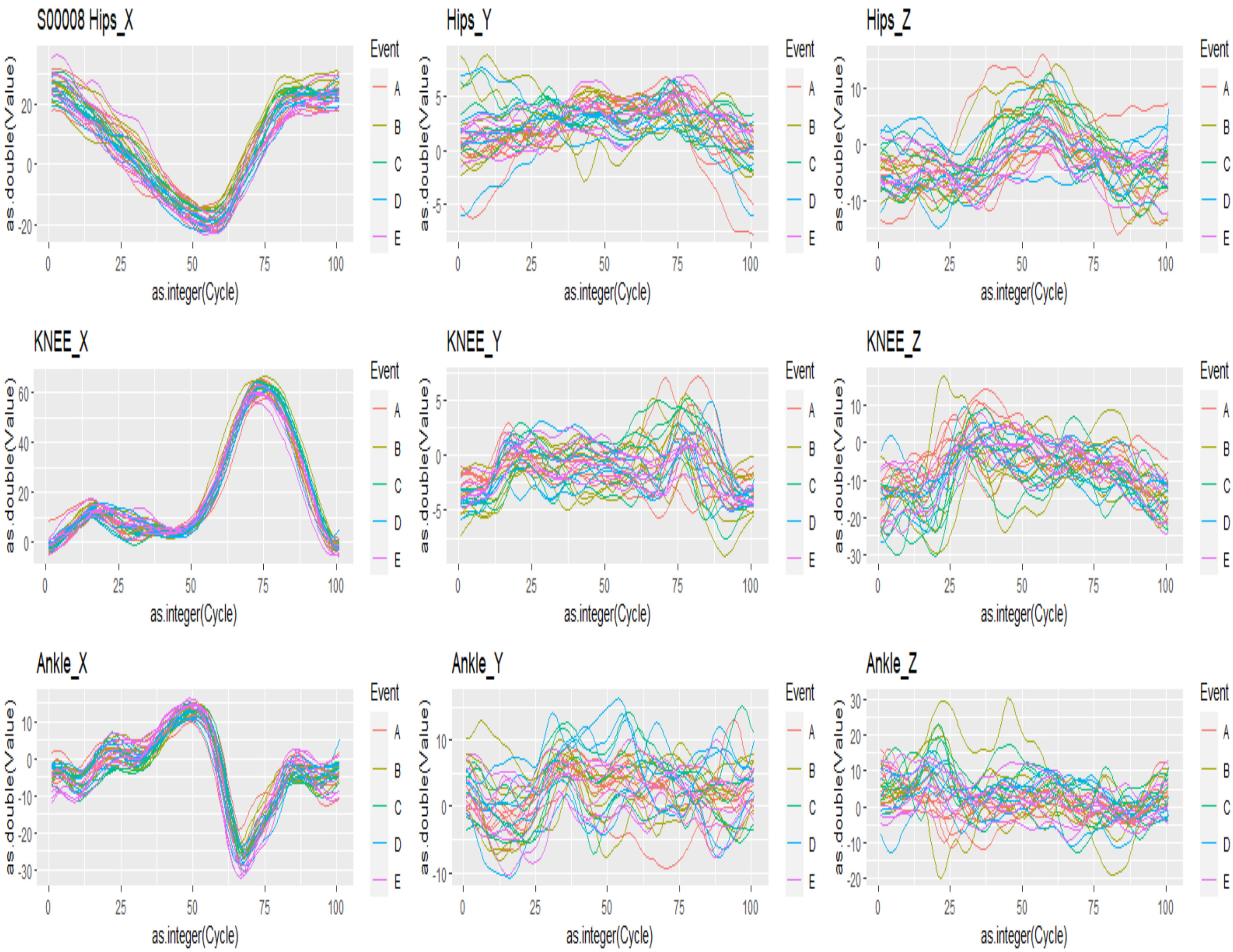

Figure 3 shows a sample waveform data from subject 8's walking patterns in the x, y and z direction for the left and right ankle hip and knee markers.

All the subjects tested showed that there is the most variability in the joint angles in the z direction while the x axis had the least variability. There was also no specific event that stood out amongst all the subjects.

Mean and Standard Deviation trails

RaNext, the mean and standard deviation from [Figure 3] data were found to see if any additional data/patterns could be found.

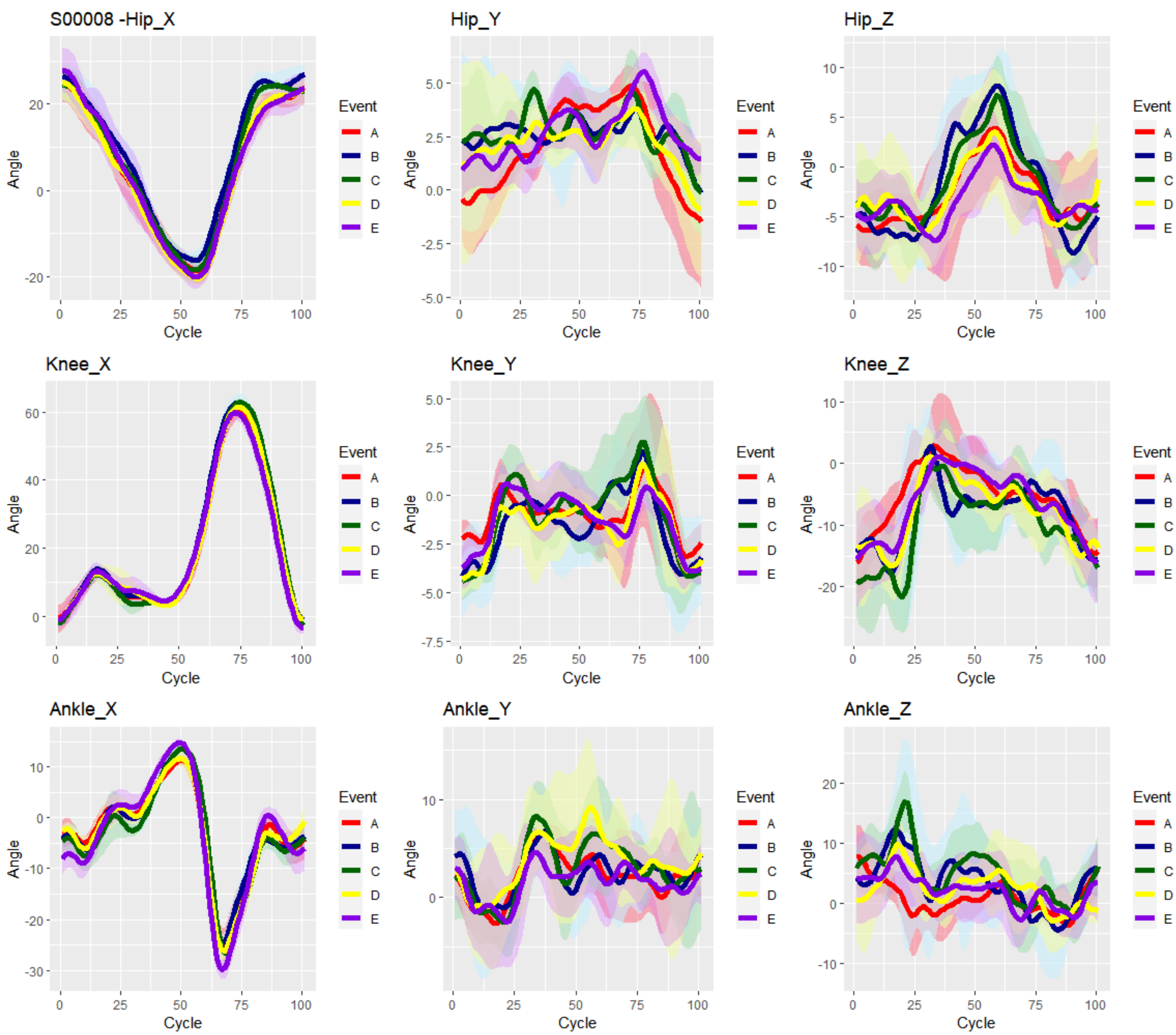

Figure 4 is he mean and standard deviation for each stride cycle in each walking direction for the x, y and z axis for each walking direction.

The mean and standard deviation graph for all the subjects showed the least variability in the x components and the most in the z and y components.

Min, Max, and Range of Motion

The maximum angles, minimums angles, and range of motion was found for every cycle so that all the subjects' data can be compared in one plot.

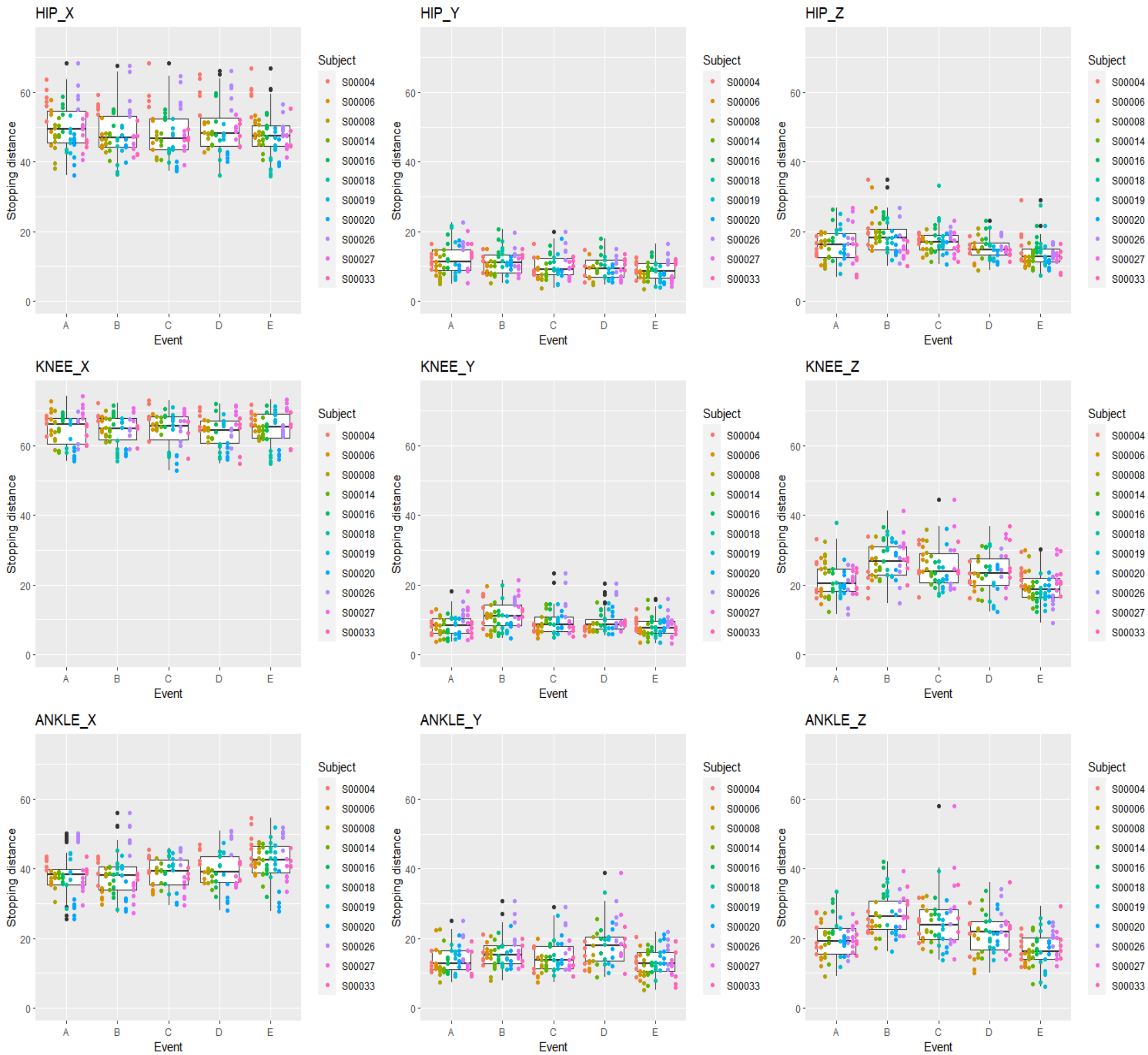

Figure 5 Is a box plot that shows all subjects' range of motion for the x, y and z direction, for the left and right ankle, hip, and knee markers.

The max, min and range of motion displayed that knee and ankle joint angle z-components during event B had a higher range of motion than the other events, while the range of motion of the joint angle x- and y-components were similar across all walking directions.

Star Map:

To see how the quality of MOCAP was affected by subject position within the capture volume, the center of mass of every subject in the x and y axis of the lab was plotted. In [Figure 6] the coloured lines show the tracking errors (areas where the camera could not track the subject's location) and the diagonal squares show the BAD events. The black squares show the camera location while the black.

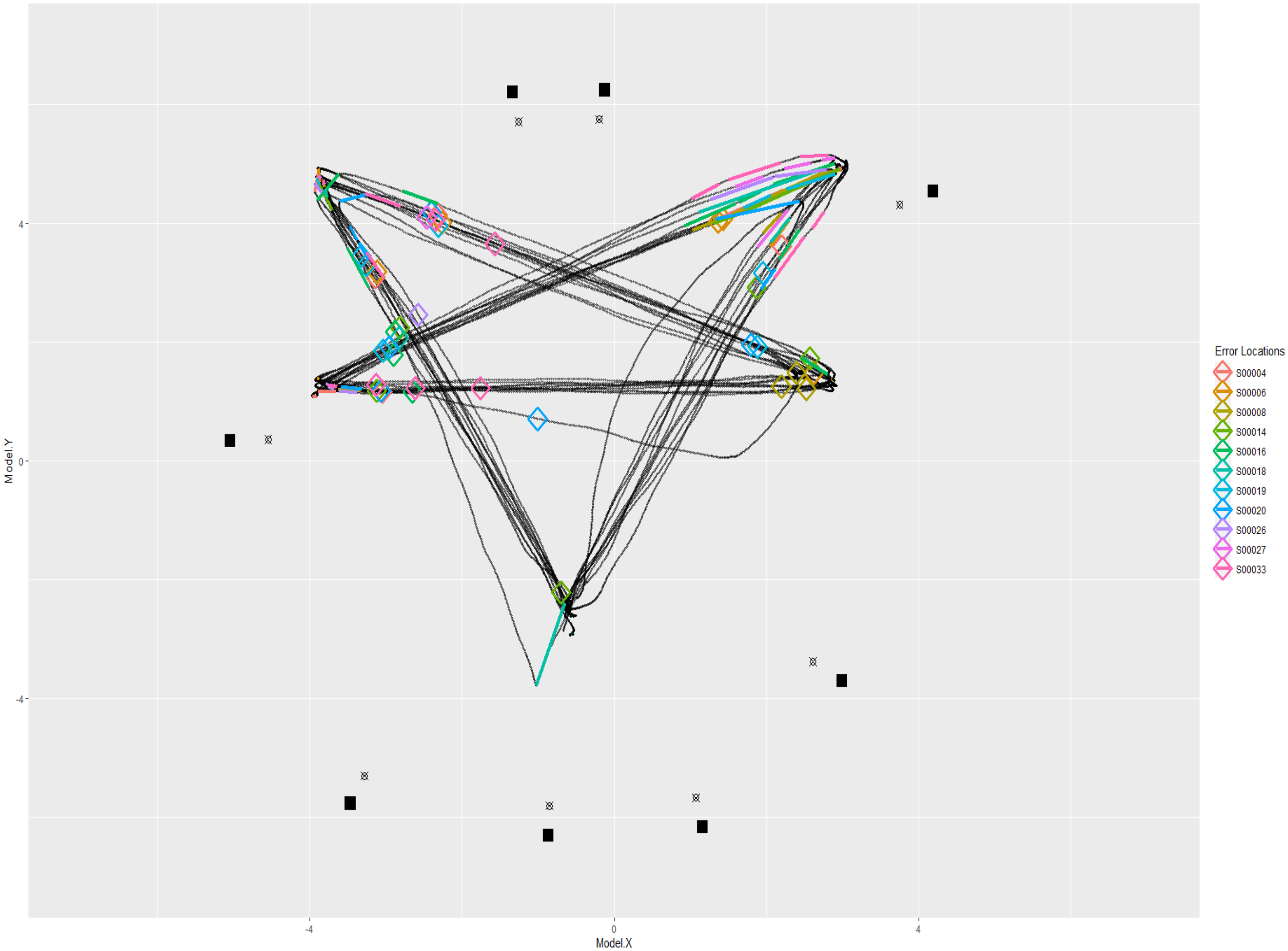

Figure 6 shows the walking path that every subject took in the x and y axis.

Figure 6 shows that the corners where fewer cameras can see the subject cause the most tracking and bad errors, while the middle area where all cameras can view the subject cause little to no errors.

Velocity Check:

To check whether each subject's speed varied between walking directions, the velocity of every subject was measured. Since changes in velocity can cause gait measurements to differ [Kanko], it was important to measure subjects' gait speed in every walking direction.

	Walking Direction									
Subject:	**Vel-A**	SD	**Vel-B**	SD	**Vel-C**	SD	**Vel-D**	SD	**Vel-E**	SD
S00004	1.46	0.27	1.54	0.23	1.54	0.21	1.58	0.24	1.59	0.25
S00006	1.63	0.2	1.59	0.19	1.49	0.17	1.54	0.16	1.63	0.21
S00008	1.43	0.2	1.47	0.19	1.37	0.18	1.46	0.19	1.46	0.22
S00014	1.39	0.21	1.48	0.17	1.3	0.19	1.47	0.17	1.51	0.18
S00016	1.42	0.25	1.48	0.2	1.38	0.2	1.38	0.22	1.4	0.21
S00018	1.37	0.17	1.34	0.17	1.25	0.15	1.25	0.17	1.33	0.18
S00019	1.35	0.28	1.47	0.2	1.44	0.22	1.42	0.2	1.46	0.2
S00020	1.28	0.15	1.37	0.18	1.25	0.13	1.26	0.16	1.33	0.15
S00026	1.59	0.24	1.5	0.23	1.3	0.31	1.36	0.28	1.34	0.21
S00027	1.48	0.2	1.42	0.19	1.38	0.16	1.44	0.19	1.43	0.2
S00033	0.45	0.47	1.36	0.16	1.25	0.2	1.38	0.18	1.42	0.17

shows a sample data of the average velocity (m/s) and standard deviation of each subject in every walking direction

It was observed that most of the average velocities for each subject's walking directions events fell under ± the standard deviation values, indicating that subjects maintained relatively consistent walking speeds throughout the trial despite changes in walking direction.

Discussion

Waveform and Mean Graph Analysis:

The waveform graphs [Figure 3] made it clear that the joint angles in the x direction were not affected by camera angles, due to their similarity across all walking directions. However, it was difficult to analyse the Z and Y components due to the variability of these measurements. I was evident that the x-axis also had a higher range of motion than the other axes yet produced the most consistent results in each event. There were no specific walking directions that deviated more than others in any of the axis for any of the subjects.

The mean and standard deviation graphs [Figure 4] also supported the claim that the joints angles from every walking direction in the x axis did not deviate much from each other while the y and z axis did. When analyzing the mean and standard deviation graphs there were no specific walking directions that differed in joints angle more than the others.

Min, Max, and Range of Motion

The Min, Max, and Range of Motion box plots [Figure 5] all showed very similar results. The x-components had no specific event with greater range of motion than others, while the y-axis did not either. It appears that for the z axis event B consistently had a slightly higher range of motion than the other events, however it is assumed that it is not due to camera angle, because all the walking directions were still very close to each other, and such variability were not found in the other graphs.

Star Map:

The position tracking of all the subjects [Figure 6] shows that most tracking errors and BAD events tend to be when the subject is nearing the corners where less than six cameras can view the subject at once. In event D every subject had a tracking error nearing the corners. However, once the subjects reached the end of the path and stopped, there were no tracking errors. This suggests that even in corners where subjects can minimally be tracked, there is still some tracking potential when they are static.

With the Star Map it is evident that MOCAP results are more dependant on camera volume optimization rather than walking direction, as in the areas where all cameras can see the subject, MOCAP has little to no errors. This analysis allowed for the idea of a green zone in MOCAP, which is the optimal location for motion capturing to occur.

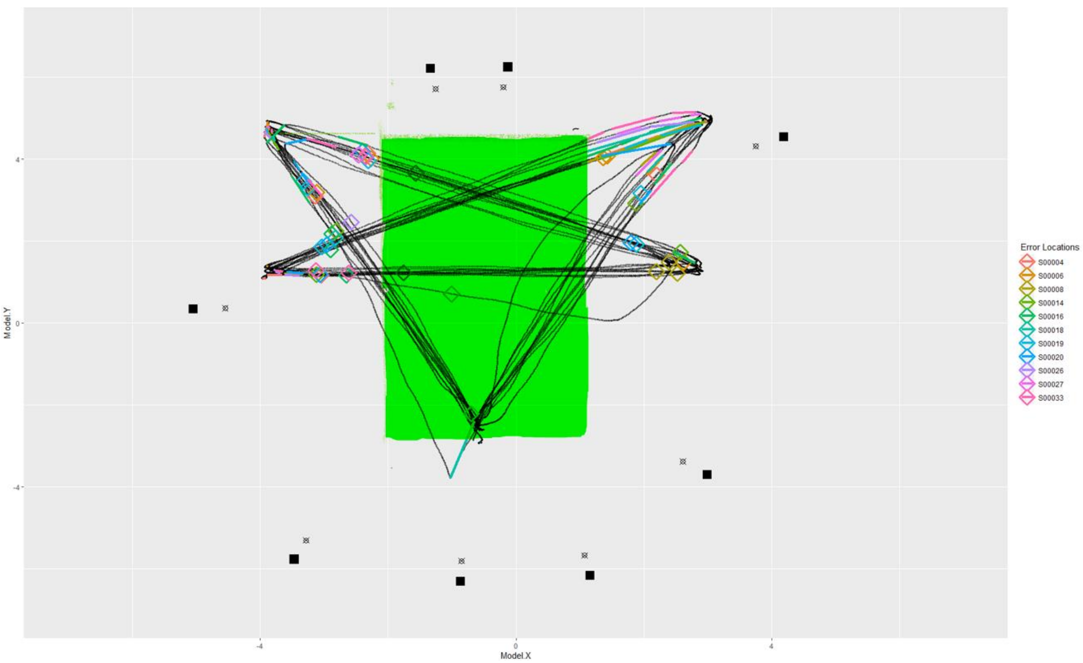

Figure 7 shows the predicted green zone- most optimal area for tracking based off the camera setup for this trail

As shown in [Figure 7]'s predicted green zone, there is very minimal bad events and no tracking errors in the highlighted area. With more research and trials that cover more volumes of the lab, a mathematical representation of the most accurate tracking area could be achieved.

In in [Figure 7], it was also noticed that Event B had the worst errors, suggesting that the variability of event B in the range of motion could have been due to unfiltered BAD events. For this reason, an experiment was conducted where the range of motion of values in the green zone was found. These values corresponded very similarly to the original range of motion graph, showing the accuracy of the filtering done initially.

Velocity Check:

The velocity check made it even more probable that each subject maintained a relatively consistent walking speed throughout each trial, across all walking directions. By measuring the average velocity and standard deviation for each subject at each walking direction, it was shown that most of the velocities for the subjects differed to the amount of standard deviation per walking direction.

Conclusion:

Final Findings:

After looking at all the data, it is evident that camera placement affects MOCAP on a per volume basis. As the further a subject gets further from the cameras, the motion tracking tends to become more inconsistent, as the number of BAD events and tracking errors increase. However, there was a “Green Zone” area (in this situation around 3m by 7m in area), where very few errors were found. With more data, this Green Zone can be analyzed quantitatively to predict the area where there is good MOCAP with various camera setups.

Furthermore, the research found that walking directions most likely has no effect on MOCAP. It is important to note that event B consistently had a higher range of motion than the other walking directions in the z axis. However, the difference in range of motion was minimal, and the waveform and standard deviation graphs found the z axis to have the most random waveforms, indicating that walking directions do not affect camera angles. Further research would need to be done for a definitive conclusion, but the discrepancy was more likely due to factors that were unaccounted for, due to the consistency of all the other graphs.

In conclusion, camera positioning effects the MOCAP on a volume basis but not walking directions.

Next Steps:

The study done can be built upon to find the best camera positioning for outdoor trails. Using marker-less MOCAP outdoors in the future will allow for more consistent and realistic studies, so it is important to understand what needs to be done to find the most optimal camera placement outdoors. As mentioned in the conclusions section, the research done can be taken further by creating a lab that measures tracking errors and bad events in a more volume-based approach rather than camera angles. For instance, a subject could walk in zigzag patterns to cover up most of the area of the lab, and then their position could be mapped for tracking errors. Afterwards, the camera positioning can be changed, and the subject can be asked to walk the same route again. This will allow for a more in depth understanding of how camera positioning affects MOCAP and can be used to find the optimal distance/positioning for the cameras. Such data would be very useful for outdoor trials of marker-less MOCAP as the environment is not consistent, so having an idea of how far the cameras should be apart for different results will create a more accessible and promising MOCAP experience.

References

- Robert Kanko – Lab Manager at the Human Mobility Research Lab
    - Advisor, Editor Mentor, Helped with all the Pipeline
- Jereme Outerleys – PhD student at the Human Mobility Research Lab
    - Advisor, Mentor
- Vajra Keller – Masters students at the Human Mobility Research Lab
    - Advisor, Mentor
- Elise Laende – Post Doctoral Fellow at the Human Mobility Research Lab
    - Advisor
- Kevin Deluzio - Director of the Human Mobility Lab , Dean of Engineering
    - Advisor

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