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INDICATORS OF MOTION INDUCED INTERRUPTION OCCURRENCES IN HEAVY–WEATHER SEA CONDITIONS

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ABSTRACT

During a recent heavy-weather sea trial, human postural stability experiments were performed which included measurements of joint positions using a motion capture system, and foot pressures using instrumented footwear insoles. From these data, centre of mass, centre of force, and base of support parameters were determined. These data were then compared to observed occurrences of motion induced interruptions in order to determine if a simple correlation exists between them.

Keywords: Sea trial, human postural stability, centre of mass, base of support, motion induced interruption, MII

INTRODUCTION

Human postural stability experiments were carried out on the ship Canadian Forces Auxiliary Vessel (CFAV) Quest during the Q-348 heavy-weather sea trial from November 20th through November 28th, 2012 [1]. Participants took part in experimental sessions in which they were asked to maintain balance while performing a cognitive task, at various orientations with respect to the ship, and at various sea state conditions. The data measurement techniques used were unique in that they attempted to measure all of the sensory inputs that a person might use to maintain balance, including joint positions and orientations, and foot pressure/force data. This paper presents a short overview of how portions of that data have been post-processed, and an early look at various derived parameters that may be indicative of loss of balance events known as motion induced interruptions (MIIs) [2].

MOTION CAPTURE DATA

Motion tracking data was recorded using two Microsoft Kinect sensors and an iPi Studio software package. The software's proprietary algorithms map depth data recordings from the two sensors onto a model of a human skeleton. A sample of the skeleton model used is shown in Figure 1.

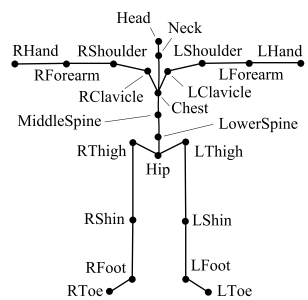


Figure 1: Skeletal structure output by iPi Studio software.

GLOBAL JOINT POSITIONS

The motion tracking data are stored in Biovision or BVH files, which is a file format designed to be used to record the motion history of a body with a rigid skeletal structure. The files begin with the initial positions of each joint and the degrees of freedom of motion available to each. Following that is a time history of joint angle 'channels', which are used to specify changes to the initial geometry over the course of the recording. This means that as long as the correct coordinate and rotation conventions are followed, it is possible to calculate the global position of each joint at any point in time.

The rotation convention used is XYZ Euler angles (Bryant angles), so the transformation between individual joint coordinate systems is defined as:

$$R = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \mathrm{c}_{\theta_x} & -\mathrm{s}_{\theta_x} \\ 0 & \mathrm{s}_{\theta_x} & \mathrm{c}_{\theta_x} \end{bmatrix} \begin{bmatrix} \mathrm{c}_{\theta_y} & 0 & \mathrm{s}_{\theta_y} \\ 0 & 1 & 0 \\ -\mathrm{s}_{\theta_y} & 0 & \mathrm{c}_{\theta_y} \end{bmatrix} \begin{bmatrix} \mathrm{c}_{\theta_z} & -\mathrm{s}_{\theta_z} & 0 \\ \mathrm{s}_{\theta_z} & \mathrm{c}_{\theta_z} & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Rotations are defined as the relative angles between coordinate systems. A sample joint position calculation can be presented as:

$$r_D = R_{a/O}\{(r_{B/A})_a + R_{b/a}\{(r_{C/B})_b + R_{c/b}(r_{D/C})_c\}\} \quad (2)$$

where the uppercase subscripts indicate relative joint positions and the lowercase subscripts indicate which coordinate system they are defined in. While this is not a typical form for this type of calculation, it is computationally efficient if the global positions of intermediate joints are not required. Using this form, the global right ankle position can be calculated as:

$$\begin{aligned} r_{RFoot/inertial} = r_{Hip} + R_{Hip}(r_{RThigh} \\ + R_{RThigh}(r_{RShin} + R_{RShin}(r_{RFoot}))) \end{aligned} \quad (3)$$

where the subscripts indicate which initial position or recorded channel should be used.

CENTRE OF MASS POSITION

Of practical use is an estimate of the location of a person's centre of mass (CoM), which can be derived at each moment in time from the motion capture data. Approximate mass values and centre of mass locations of each individual body segment were calculated using proximal distances and mass fractions taken from literature [3]. Overall body CoM position was calculated by using a weighted average of all of the individual segment locations.

INSOLE DATA

Pressure-sensitive insoles were used to measure subject foot pressures during the sea trial experiments. A sample software view of one data frame is shown in Figure 2.

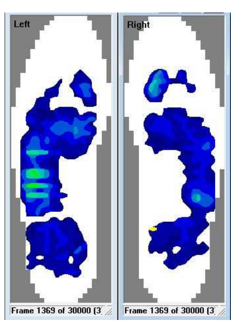
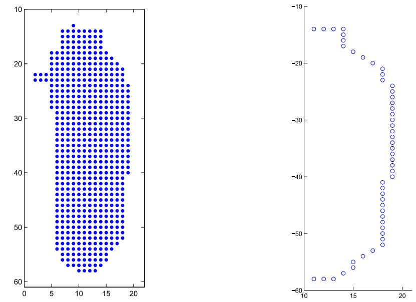


Figure 2: Screenshot of insole pressure recording software.

Recordings of this type of data were used in conjunction with the motion capture data to calculate individual base of support (BoS) boundaries for each participant at any point in time. The relationship between BoS and CoM is a common metric in postural stability studies [4]. The first step was to calculate a mask which would encompass the area beneath a subject's foot. The next step was to reduce that to an outline



(a) Insole mask (b) Insole outline

Figure 3: Insole data processing steps.

based on the outer limits of the mask. Sample results from each calculation step are shown in Figure 3.

Additional steps were carried out which included:

- Estimation of ankle locations based on ground-foot contact areas.
- Calibration of pressure measurements based on subject mass, subject and ship motions, and auxiliary force measurements made using a load cell located under one foot.
- Summation of foot pressures in order to determine the overall vertical force exerted by each foot.
- Matching of the insole's coordinate system to the motion capture's coordinate system and translation of insole data to ankle locations.
- Calculation of BoS boundaries that connect the left and right insole outlines.
- Calculation of total body centre of force (CoF) based on locations of individual foot forces and their relative magnitudes.

A sample result of all of these calculations is shown in Figure 4.

RESULTS

The objective of the analysis in this paper is to observe several metrics derived from the calculations performed in the previous sections in order to determine whether there are any trends that can indicate the onset of MIIs.

Shown in this section are two short data profiles of a single participant during a single experimental trial. The participant was instructed to stand facing at an angle of 90 degrees with respect to the ship centreline while performing a cognitive clipboard/tablet task, and while maintaining balance in heavy-weather sea conditions. The ship's motion was dominated by roll so this was the most difficult stance direction to maintain.

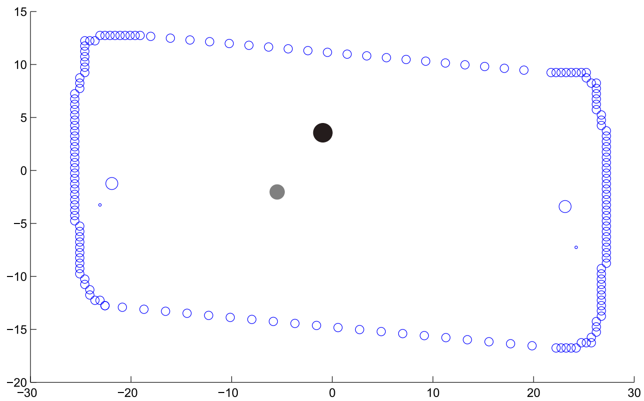


Figure 4: Base of support outline with ankle locations (small side circles), individual foot CoF locations (large side circles), body CoM (black and larger filled circle), and overall CoF (gray and smaller filled circle).

MEASUREMENT METRICS

The following metrics are presented in graphical form:

Right Foot Relative Position

During the experiments, participants were instructed to keep their left foot on top of a load cell plate. Because of this they naturally tended to correct stance imbalances by moving only their right foot. This means that relative motion of the right foot was a good indicator of the onset of and recovery from MIIs.

Centre of Mass to Base of Support

The shortest distance between the CoM and BoS was calculated and plotted.

Subject Reaction Moment

The subject reaction moment is the moment generated by the CoF about the CoM. It is calculated as the total vertical force measured by the insoles, multiplied by the distance between the CoM and CoF.

Base of Support Angle

Another useful metric for determining when an MII has occurred is to check if the CoM is no longer contained within the BoS. This can be calculated by adding together all of the angles created by two adjacent points of the BoS, and the point corresponding to the CoM. If the CoM is within the BoS, this sum should be equal to 360 degrees.

Ship Motions

There is undoubtedly a relationship between the magnitude of ship motions and occurrences of MIIs, although no research to date has been able to form a conclusive correlation. Plotted here are the two ship motions that would dominate a subject's response while standing at 90 degrees with respect to the ship centreline: roll angle and lateral acceleration.

SAMPLE DATA 1

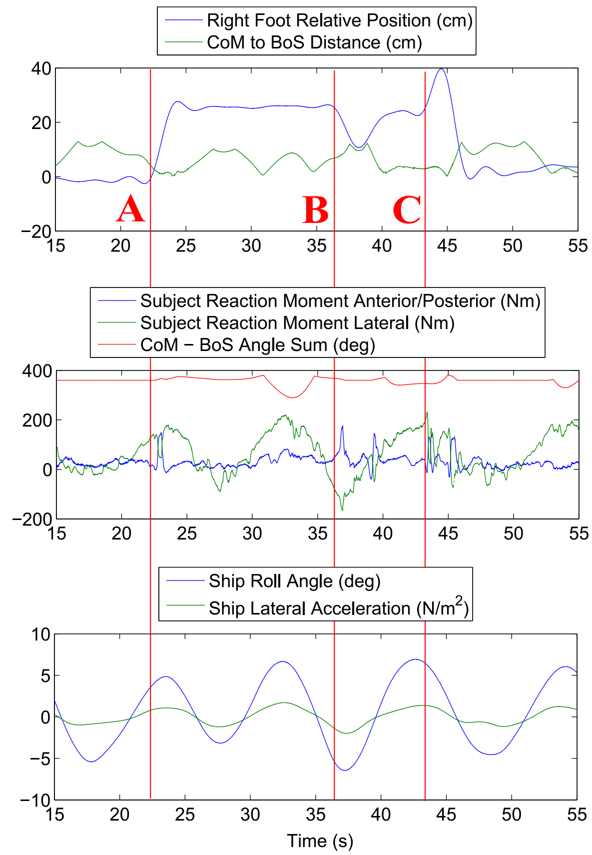


Figure 5: Measured and calculated postural stability data containing 3 MII events.

The letter labels on the graph indicate the occurrence of MIIs, which were identified manually from the motion capture recordings.

- A - Starting from neutral, subject steps back and decides to hold that position.
- B - Subject steps forward and then moves back to previous foot position.
- C - Subject steps even farther back, then returns to neutral.

SAMPLE DATA 2

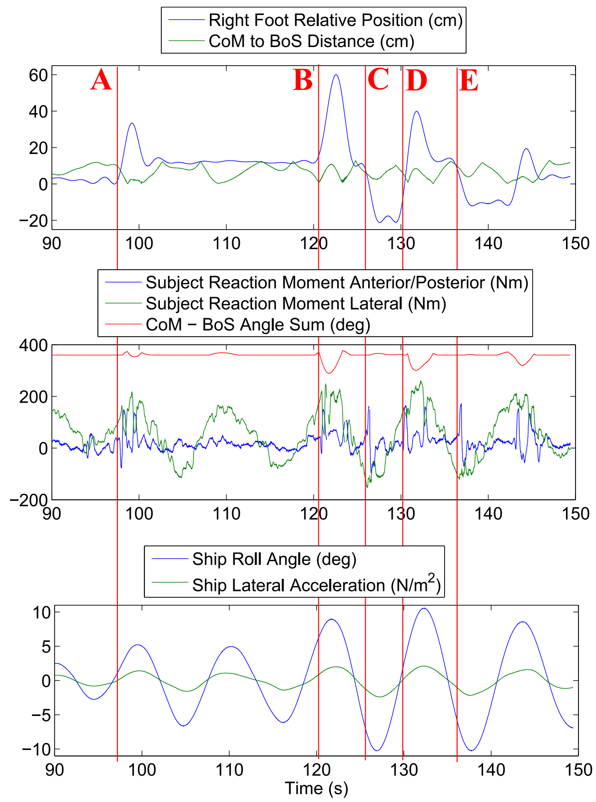


Figure 6: Measured and calculated postural stability data containing 5 MII events.

- A - Subject steps back and returns to neutral.
- B - Subject steps back and returns to neutral.
- C - Subject steps forward.
- D - Subject attempts to return to neutral but is forced to step back instead, then returns to neutral.
- E - Subject steps forward and holds before repositioning to neutral.

DISCUSSION

Several useful observations can be made from the two data sets presented, and from the process of generating them.

1. Foot position is a useful indicator of the onset of MIIs. An alternative approach that was tested was to only look at the total magnitude of the foot's movement. This was also useful for indicating the onset of MIIs, but had the disadvantage of not indicating the step direction. This is important information because frequently a participant would miss and step through the neutral position rather than returning to it due to unexpected ship motions.
2. The CoM - BoS angle sum is of questionable usefulness. While it does indicate the occurrence of MIIs, it is also subject to false positives.
3. While the reaction moment does not appear to provide information on the onset of MIIs, it does appear to display a trend on the recovery from MIIs. While it is fully expected for there to be a peak in lateral reaction moment due to one foot carrying all of the force while stepping, there is also a peak in the anterior/posterior direction.
4. There does not seem to be any definite trend between CoM - BoS distance and the occurrence of MIIs, although it has been observed in these data sets and others, that the distance is often close to its maximum (CoM centred) before the onset of an MII rather than at a minimum (CoM near the edge of BoS).
5. From these data sets there does appear to be some relationship between roll angle, lateral acceleration, and occurrence of MIIs, although as expected, it is not a simple relationship.

CONCLUSIONS

This paper examines the relationship between occurrence of motion induced interruptions (MIIs) and various measured and derived parameters that may have relevance to the study of human postural stability. Those parameters are mainly focused on the locations of body centre of mass (CoM) and centre of force (CoF), and their relative positions within the base of support (BoS). These measurements were experimentally derived from motion capture data and foot pressure insoles during a recent heavy-weather sea trial. Future work will improve on this result by comparing the results in more detail with specific published results and by including a dynamic model of the human participant in the analysis.

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