Capturing movement patterns during procedural control activities in Air Traffic Control

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ABSTRACT

The Air Traffic Controller (ATCo) is responsible for monitoring aircraft movement within a specified airspace by using radar and/or procedural control as its monitoring instrument. Research looks at the possibility of using human motion analysis in capturing signs of distress during sole procedural monitoring activity by the ATCo. In this research, it is hypothesized that a higher mental task load during a procedural control monitoring activity will be exhibited through more rapid or unusual body movement. To analyze this, a human-in-the-loop (HITL) experiment was conducted to monitor the ATCo physical response, specifically upper body movements during control activities. This was done using KINECT® as the device to monitor the movement. Based on the results, the subjects did exhibit a change in frequency or extremity of their upper body movement during the course of the experiment. However, this could be either due to task-related or stress-related body movement. Thus, a more elaborate study on baseline subject-scenario body movement during control activities for each controller is needed in order to clearly isolate signs of high mental task load or distress.

Keywords: *Air Traffic Controller; Movement Patterns; Procedural Control Activities.*

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Introduction

Air Traffic Control (ATC) is a service provided for the safe, orderly and expeditious flow of traffic [1]. In 2018, Malaysia's passenger movements saw a lower growth increase of 2.5% to 99 million passengers as compared to an 8.5% increase in 2017, with domestic and international movements increasing by 0.4% and 4.5%, respectively [2]. This was the result of a lower than anticipated traffic movement and weak consumer sentiment. This year, Malaysia Airports Holdings Bhd. (MAHB) forecasted that domestic passenger traffic would grow by 7.6% and international traffic by 2.4% [3].

Numerous studies have shown that the number of air traffic movements has an effect on Air Traffic Controller (ATCo) task load or workload, as it would create more complex and difficult scenarios [4-11]. However, understanding workload is no longer about establishing the maximum workload that can be handled by the ATCo but also on workload transitions and how things interrelate, interconnect and interact at a certain time of day in certain sectors [12].

ATCo Workload

Workload of the ATCo is the major limiting factor in increasing the sector capacity. Numerous solutions have been proposed and implemented to help alleviate ATCo workload, such as re-sectorization of the airspace, imposing ground delay to aircraft and also the introduction of new controller support tools. However, quantifying whether an ATCo's workload is too high or too low is still an ongoing question.

Song Zhuoxi et. al. defined ATCos' workload as abstract time spent on accomplishing each control task by using the ATCo's professional knowledge, wisdom and physical strength. It is also acknowledged that the factors which could affect the controllers' work include objective factors (e.g. the number of aircraft, the number of crossing air routes) and human factors (e.g. physical pressure, mental pressure) [13].

Three main categories of cognitive load measurements are subjective measures, performance measures, and psychophysiological measures [14]. This study looks at the possibility of using the psychophysiological measures in capturing signs of distress or high workload. It is believed that changes in various bodily processes and states have also been reported with changes in mental workload [14].

Body Motion Measurement System

Full-body human motion measurement system is generally used in areas concerning but not limited to biomechanical analysis, rehabilitation, ergonomics, and also in sports performance science. Motion measurement analysis is common in research within the area of injury prevention systems [15-17], active computing of body tracking [18-20], human activity mapping [21], human machine interfaces [22,23] et cetera.

In Air Traffic Management (ATM) research-related areas, human motion measurement is still not widely used, as the task complexity and variability is wide. Thus, to look at the possibility of using human motion measurement, a controlled, demanding environment was presented to subjects, that is through a human-in-the-loop experiment of procedural control activity in ATC during varying traffic feed intensity.

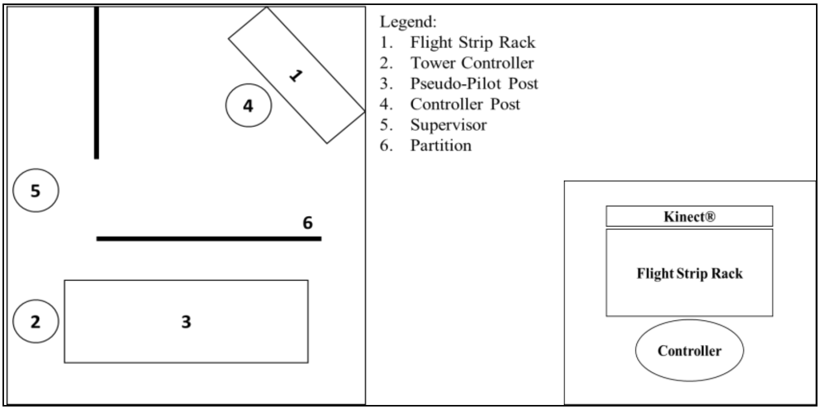
HITL Experiments

An ATCo is trained in both radar and procedural control. During radar control, aircraft is monitored through a radar screen. However, in the event that radar is unavailable, procedural control system will take place. In the procedural control system, a controller is required to use flight progress strips to build a 3 dimensional picture of air traffic in his / her mind. Aircraft separation is instructed based on the aircraft's position reports and altitude, gained from flight plans and from talking with the pilot in flight [24].

The procedural control method depends largely on the mental capacity of the ATCo to imagine the position and trajectory of the aircraft based on each aircraft's flight progress strip, which contains its route, altitude and estimated times over reporting points. The information is then compared with every aircraft in the sector to determine if there are any possible future separation infringements. When required, ATCo will issue altitude, speed or routing changes (when needed) to separate aircraft from each other.

This study was conducted to identify the possibility of measuring body movement frequency or extremity during ATC activities. It was hoped that by having the baseline values, irregularity in a controller's body movement could be used as a method for capturing signs of distress. In this study, 40-minute human-in-the-loop (HITL) experiments involving five experienced ATCos from the Civil Aviation Authority of Malaysia (CAAM) Subang were conducted to monitor the physical response of the ATCo, specifically upper body movements during control activities. Each session was conducted with one controller (referred to as "subject"), one tower controller (manually simulated), two to three pseudo-pilots (manually simulated), and one supervisor/observer. The experiment seating arrangements were as shown in Figure 1 (a).

The recording equipment, which was Kinect®, was placed facing the subject (ATCo) above the flight strip rack in order to capture body movements, specifically upper body movement during the course of the experiment (Figure 1(b)). Communication between subject and pseudo-pilots were done using a two ways communication radio to add in realism to the situation. The experiment flight plan setup was designed by an active controller based on airways in Sector 4 (oceanic areas) of Kuala Lumpur Flight Information Region (KLFIR). Each subject needed to manage the same flight plan.



(a) (b)

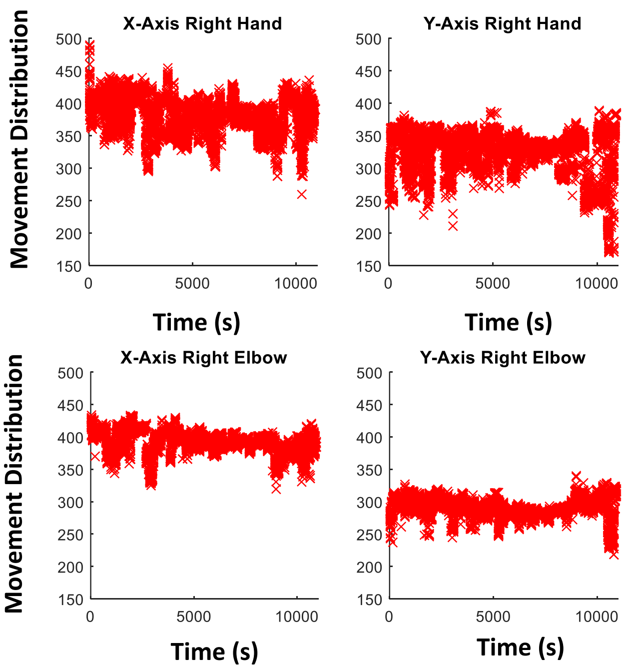
Figure 1: Experiment Settings. (a) Experiment Seating Arrangement (b) Recording Equipment Positioning

Results and Discussions

During the duration of the whole experiment, voice and movement were tracked using Kinect® placed in front of the subject. As the subjects were in seating position, Kinect® was only used to track upper body movement. Figure 2 shows an example of upper body movement tracking by Kinect® displayed through Matlab®. The dots in the picture represent the position of the controller's upper body skeletal point as fixed in Kinect®. These are hip centre, spine, shoulder centre, head, left and right shoulder, elbow, wrist and hand. These data points were stored every second to capture subject's movement pattern.

Figure 2: Upper Body Movement Tracking by Kinect®

Upon analyzing the data, hand movement was seen as the most prominent due to the necessity of the subject to manage the flight strip on the flight strip rack. Based on the movement pattern, hand (either left or right) was shown to have the biggest movement range compared to shoulder and elbow as shown in Figure 3. Figure 3 shows examples of hand, elbow and shoulder movement distribution for a single subject. Hip, spine, wrist and head also showed minimal movement patterns. Further analysis of hand movement pattern is elaborated on in the subsequent sections.



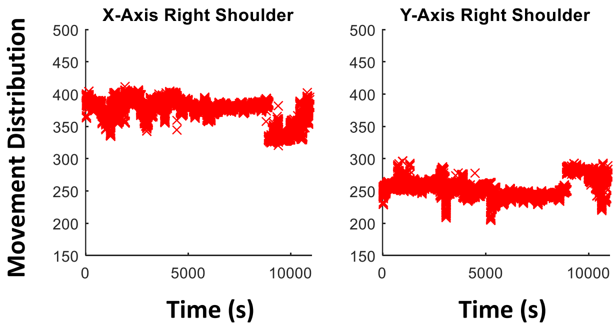
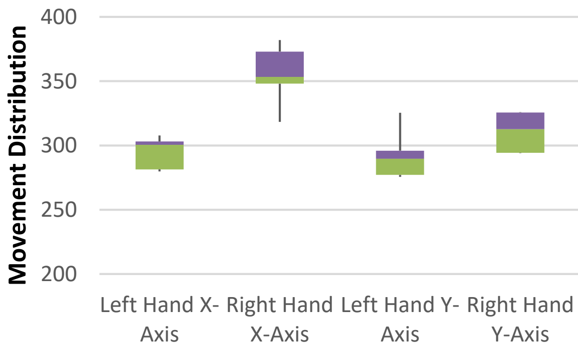
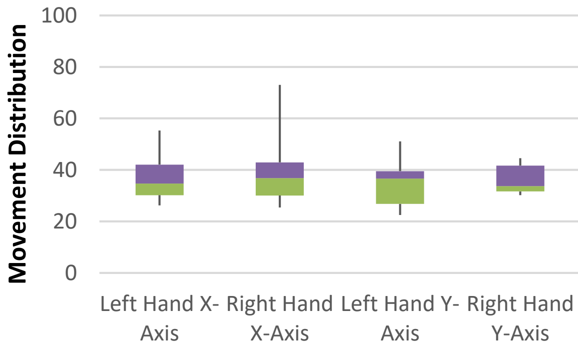


Figure 3: Movement Patterns in X and Y Axis.

The distribution of data varied between subjects. Whilst difference in average x-axis data between left and right hand represented positioning of the hand with respect to the recording device, the difference in y-axis data represented movement extremity of the left and right hands while arranging the flight strip on the procedural console rack. It can be seen in Figure 4 (a) that the right hand showed larger range of average movement than the left hand, together with a higher positioning (in y-axis) of right hand as compared to left hand. Figure 4 (b) shows almost the same degree of data distribution for both the left and right hands.



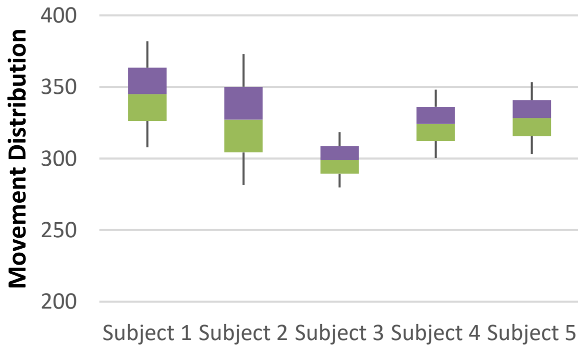
(a)



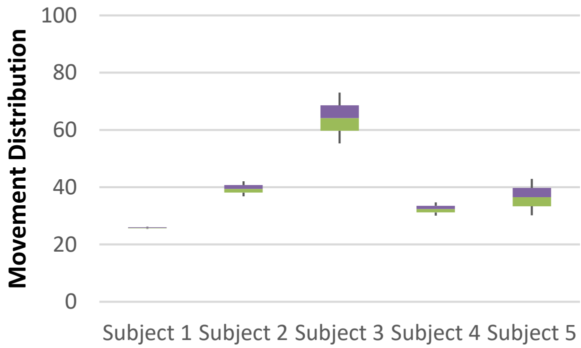
(b)

Figure 4: Average Movement Distribution. (a) Distribution. (b) Standard deviation

Further analysis based on each subject revealed that indeed both x-axis and y-axis hand movement median and range are different from one subject to another. For example subject 2 showed the highest degree of range for average x-axis (Figure 5 (a)) and y-axis (Figure 6 (a)) movement compared to the other subjects, whereas subject 3 and subject 1 showed the lowest range of average x-axis (Figure 5 (a)) and y-axis (Figure 6 (a)) movement, respectively. Also, the distribution of data per subject varied as shown in Figures 5 (b) and 6 (b). Thus, individual subject physical response or body movement analysis was needed in order to gather subject-scenario baseline value.



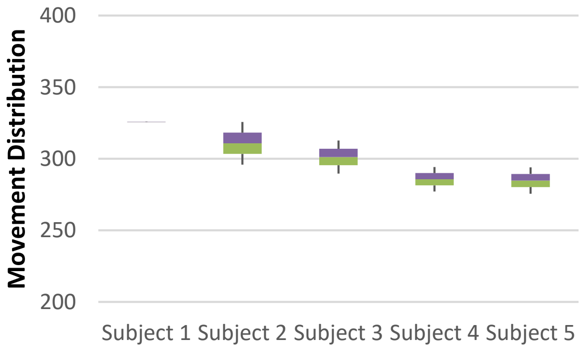
(a)



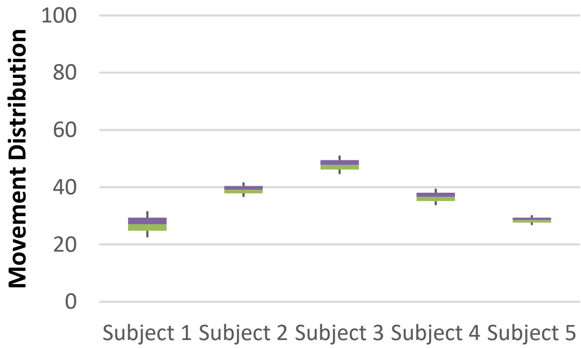
(b)

Figure 5: X-Axis Hand Movement Distribution. (a) Distribution. (b) Standard Deviation.

By having a subject-scenario baseline value, it is hypothesized that extremity in body movements during procedural control activities can be captured and analyzed, to investigate its association to the subject's increase or decrease in mental task load while working on a specific sector or assigned airspace. Figures 7 (a) and (b) show examples of Subject 1 and 3 right hand y-axis movement during the course of the experiment, respectively. Both sets of data represented the minimum (Subject 1) and maximum (Subject 3) distribution patterns as shown in Figure 6 (b).



(a)



(b)

Figure 6: Y-Axis Hand Movement Distribution. (a) Distribution. (b) Standard Deviation.

(a)

(b)

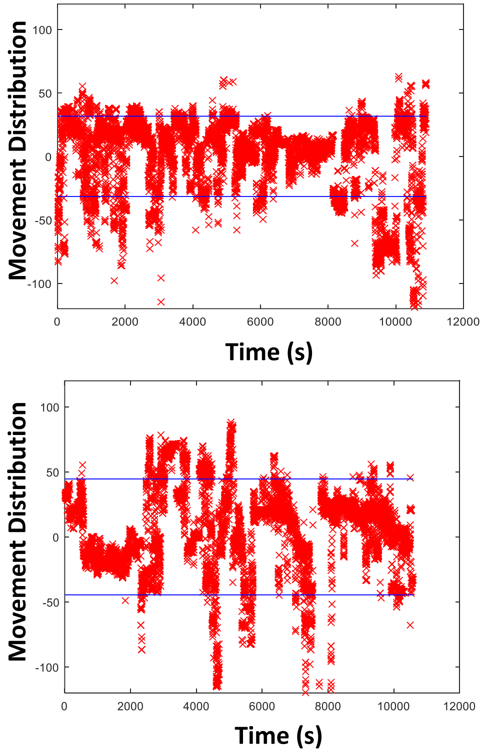


Figure 7: Right Hand Y-Axis Movement Distribution. (a) Subject 1. (b) Subject 3.

The results illustrated in Figure 7 shows the subject's hand movement in y-axis with two horizontal blue lines representing the standard deviation of the movement distribution. Procedural control practices repetitive movement throughout their control activities. Large concentration of data indicates their normal movement behaviour in executing their task, while multiple smaller scattered data represents uncommon hand movement behaviour. So, for Subjects 1 and 3, uncommon hand movements outside of the normal range can be considered as additional effort needed during control activities. However, this data alone is not sufficient to indicate high or even low mental task load. What can be deduced is working behaviour pattern and also physical effort invested in monitoring traffic. It is concluded that a longer experimentation duration is needed to conclude any signs of unusual behaviour / movement irregularities.

Conclusions and Recommendation

Body movement analysis is more commonly used in the fields of medicine, sport science and robotics, to name a few. In the medical field, its main purpose has been to understand human gait in order to understand disease / disorder, to make decisions about treatment, or to evaluate treatment effects. Whereas in sport science, body movement analysis was performed to analyze an athlete's body efficiency in motion or to prescribe corrective movement techniques and also optimizing body mechanics. In robotics, on the other hand, understanding body movement would enable development of a more realistic humanoid robot. This preliminary study utilized body movement analysis in a different field, specifically it looked at its application during procedural control activities of an ATCo.

Based on the results, it is concluded that each controller has their own repetitive behaviour, which can be classified into two: normal movement range and uncommon movement range. Areas of large concentration of data indicated their normal movement range in executing their task while multiple small group scattered around the graph was uncommon movement behaviour. It is hypothesized that these uncommon movements constituted additional physical effort needed to monitor traffic. However, these could not be conclusively determined as high mental workload situations.

To obtain a subject-scenario baseline value, a larger pool of data is needed per subject. Apart from that, other body movement tracking options such as on-body sensor or post-experimental data collection through video recording and analysis could be applied in order to investigate the possibility of using a higher sensitivity device towards better movement tracking. The data can then be validated through either subjective task load assessment such as Instantaneous Self-Assessment (ISA) workload rating and NASA

Task Load Index (TLX) to name a few. Another objective task load assessment such as heart rate variability (HRV) collected from an electrocardiogram (ECG) can be used to assess its correlation with body movement analysis.

This preliminary study has shown promising results in tracking and localizing ATCo body movement. It is envisioned that through a more elaborate study on body movement during control activities, a subject-scenario profile could be gathered and could be used to isolate signs of high mental task load or distress in ATCo.

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