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OCCUPATIONAL WRIST POSTURAL ASSESSMENT AND MONITORING SYSTEM: DEVELOPMENT AND INITIAL VALIDATION

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Abstract

Identification and quantification of poor wrist postures at the occupational setting are generally challenging due to rapid changes in wrist movement. A system prototype was developed to capture and assess wrist postural behaviour at the workplace. This manuscript describes the development and initial validation process of the system prototype. The system prototype utilizes wearable glove attached with Inertia Measurement Unit (IMU) sensors to capture wrist postural behaviours. The postural angle data from sensors were extracted and processed through a customized programming software for visualization purpose. The real-time wrist postural angle data at work is benchmarked and normalized to personal maximum wrist Range of Motion (ROM) data. Preliminary validation compared the wrist postural angle readings between system prototype and traditional goniometer, at 30° for ulnar, radial, flexion, and extension wrist positions. Overall, the results from one sample t-test across 31 subjects indicate statistically no significant differences between the system prototype and goniometer readings at alpha level 0.05 (p-value > 0.05). The results from this preliminary validation activity demonstrate a degree of accuracy in terms of capturing wrist postural angle when being compared to goniometer.

Keywords: Ergonomics, Postural assessment, Range of motion, Wrist posture.

1. Introduction

Poor wrist posture has been identified as one of the main factors contributing to occupational sprain and strain. The US Bureau Labour of Statistics (BLS) reported with an incidence rate of 3.8%, where an approximated total of 42, 000 workers had experienced wrist injuries or illnesses in 2015 [1]. Among the wrist injuries or illnesses, Carpal Tunnel Syndrome (CTS) is known as one of the most common wrist injuries in the workplace. There has been a total of 139,336 CTS cases in California between 2007-2014, which amounted to an incidence rate of 6.3 cases per 10,000 full-time workers [2]. Washington State Compensation System reported that CTS cases compensation-related cost accounted for 10.2% of the total state fund allocated for work-related musculoskeletal disorders [3]. A recent study focusing on CTS cases, conducted across 5 different hospitals in Finland concluded that in a lifetime, over 3% of people will undergo surgery due to CTS [4]. Adoption of poor wrist posture at work can be due to many factors such as workstation design, tool design, and work habit. Proper identification of poor postures at work would be a first step in avoiding the development of wrist injuries.

Poor wrist posture is one of the established risk factors to CTS [2]. Frequent and extreme deviation from neutral wrist posture has shown association to alter carpal tunnel pressure, contributing to the onset development of CTS [5]. Identification and quantification of wrist postures at work are challenging due to rapid movements in real-life occupational scenarios. However, as the trend on the application of the integrated system in workplaces gains momentum, the technological advances applied to the field of occupational ergonomics may provide a more comprehensive and efficient way to manage the issue. As an example, human postures can already be detected through motion capture technologies, widely used in gaming and film making industry. Applying the technologies to identify poor postures at work helps to expand the usefulness of the technologies beyond the entertainment realm. The application of technology that promotes a cyber-physical system also aligns with the emerging concept of Industrial Internet of Things (IIOT) and Industry 4.0 in general [6, 7].

Industrial Internet of Things (IIOT), in which, technologies have been utilized as a platform for “big data” storage and analysis have been trending in manufacturing industries [8]. Identification of poor posture has traditionally been done manually through observation and goniometer. With the advent of technologies such as an accelerometer or Inertial Measurement Units (IMU), the postural angle can be identified through sensors, and the captured data can be digitalized through a cyber-physical system enabler. The real-time data obtained from sensors provide a wealth of data that can be analysed for specific trends and patterns. This concept of wearable Intelligent Health Monitoring System (IHMS) to deliver and track information regarding health status has recently gained attention from researchers [9-12]. However, existing IHMS has been primarily focused on health care and consumer sectors. There has been a limited application of IHMS in industrial settings. Digitalizing postural angles at occupational settings, and treating the real-time data captured as a “big data” for the purpose of monitoring trends of poor working posture is in line with the general direction of IIOT.

An automated assessment system has been envisioned to identify, quantify, and monitor wrist postural behaviour at work. Detection of wrist posture behaviours in real-time would provide a tool for engineers and managers to identify poor wrist posture at work, assess its consequences, and consequently becomes a basis for intervention and improvement such as workstation/tool redesign or workers' training program. The study specifically aims to describe the system prototype development of a wrist postural assessment and monitoring system, as well as preliminary validation process of the captured wrist behaviour data.

Wrist postural assessment and monitoring system

Few studies by Moore and Garg [13] and Kilbom et al. [14] have documented the challenges to identify and quantify wrist postural behaviours in workplace settings. Among the challenges include high work pace, limited and restricted area to observe and a combination of different movements and tasks resulting in difficulties in observing wrist motions [15]. Current tools to assess postural behaviour are limited in terms of specificity, sensitivity and have limited consideration of individual differences in postural capabilities and limitations, as described in the authors' other manuscript. A new tool system was developed in an attempt to address these issues.

With the breakthrough in technology, utilization of wearable devices to capture real-time and objective wrist postural data may allow for a better overview of wrist postural behaviour assessment at work. Utilization of Inertia Measurement Unit (IMU) sensors would allow capturing several data parameters on wrist posture, consequently interpreting those data to assess wrist postural behaviour at work. Instead of using absolute angle data over time to assess and monitor wrist posture behaviour, it is proposed that the data be represented in normalized value for data interpretation. This normalization of wrist angle over the maximum range of motion angle may account for individual differences in postural capabilities and limitations. Workers' with onsets of injury of musculoskeletal disorders (MSDs) will have a lower maximum range of motion value compared to normal healthy workers, so their normalization will result in higher value for the same task compared to their healthy counterparts. Assessment that uses normalization of an assessed task against maximal capacity is not new, as being used in measuring muscle activities using electromyography (EMG) [16-18].

Current works on using IMU to detect postural behaviours has gained some attention from researchers. IMU that is traditionally used in gaming and film-making industries has been utilized in capturing postural angles by researchers in the field of ergonomics. The ability of IMU to capture real-time postural angle would allow objective-based ergonomics assessment. Vignais et al. [19] developed an assessment system that uses IMU to capture postural data, and feeding them back to the system to calculate Rapid Upper Limb Assessment (RULA) scores. Li et al. [20] integrated IMU in a safety helmet to detect possible fatigue and sleepiness from head gesture motion data. Chen et al. [21] developed an assessment system integrating IMU with Microsoft Kinect to capture motion data for construction workers. This preliminary work concludes that IMU has a great potential in overcoming the accuracy limitation of the Kinect system. Similarly, Tian et al. [22] investigated the fusing of IMU and Kinect data to improve the accuracy and robustness of trajectory tracking. Peppoloni et al. [23] proposed the integration of IMU with Electromyography (EMG) system to look into the possibility of using motion and muscle activity information of the upper limb to conduct an ergonomics risk assessment. Similar to Vignais et al. [19], the IMU estimated the postural angle as input for RULA scores. A more recent study by Yan et al. [24] proposed a warning system that makes use of IMU to capture postural angles at neck and lower back to provide information on postural behaviours for construction workers. The similarity of these systems is that they use the IMU system to capture postural motions for ergonomic assessment purpose. However, none of them specifically looks into wrist postural behaviour in details. None of these systems was designed to be normalized to the individual maximum range of motion (ROM), which is the concept used for the system proposed in this study. In addition, the IMU sensors used in the proposed system is relatively smaller compared to previous studies, due to the advances in technology.

2. Methodology

The development of the system prototype described in this study consisted of three steps. The first step involves system architecture development. A system prototype, consisting of physical hardware and a custom-programmed software was then developed based on the proposed architecture. The system prototype undergoes a preliminary validation process to ensure the accuracy and reliability of measures.

2.1. System architecture development

A system architecture, as shown in Fig. 1, was developed to represent the conceptual framework of the proposed system. The physical part of the system consists of a wearable glove with Microelectromechanical system (MEMs)-based Inertia Measurement Unit (IMU) sensors. The worker to be assessed will wear the glove, and perform a series of calibration activities before performing maximum voluntary ROM on wrist ulnar, radial, flexion, extension deviations.

The angle value of the maximum ROM is captured by the software and will be stored in the system software as baseline data. After the benchmarking activity, the worker will be asked to perform or simulate occupational task while the system captures the real-time wrist motion behaviour. The wrist postural data will then be normalized to the maximum voluntary wrist ROM captured earlier. A graphical User Interface (GUI) was created to display data and assist assessor to interpret the data. The detailed description of the architecture development has been documented in the authors' other manuscript.

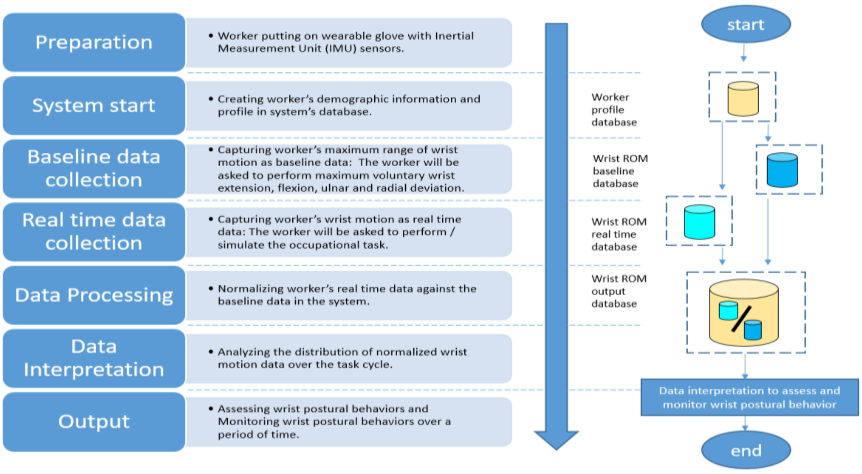

Fig. 1. Conceptual architecture of wrist range-of-motion (ROM) assessment system to assess and monitor wrist postural behaviours at workplace.

2.2. System prototype development

A system consisting of physical hardware and a custom programmed software was developed to capture wrist behaviour (Fig. 2). System hardware consisted of a computer and MEMs based IMU sensors to capture physical posture parameters from generated motion. IMU sensors that consisted of accelerometers captured raw acceleration data from the sensors’ movement. The acceleration data of each sensor were converted to velocity data, and further to positional data to allow mapping of each sensor’s coordinate in 3-dimensional space through x, y, and z axes. The customized algorithm in the developed prototype software maps the relative positioning and coordinates of two sensors, before calculating the angle through positional differences between the sensors.

The IMU sensors from commercially available motion capture system (Perception Neuron by Noitom Ltd, Miami, FL, USA) were integrated into the system. The sampling rate of data from the IMU system can be set up to 120 frames per second. The data captured from IMU can be communicated and transferred wirelessly to the running software in the computer, allowing complete freedom of movement of the hand. The data will be converted to a Biovision Hierarchy (BVH) file format for further processing. BVH is a standard file format containing ASCII text to store data of standardized points of skeletal structure based on human skeleton landmark. Data from system hardware will be imported to a computer. The computer provides processing power to compile, process, and visualize data.

A custom-developed programme, known as ROM BVH reader was developed using a Java-based open-source computer programming language ‘processing’. This reader serves the purpose of extracting BVH data from the system hardware. Data from BVH files will then be imported to ROM BVH reader, and the reader will extract data points on the wrist region. The extracted BVH data will be organized based on positional data and categorized in different axis. Each data is sorted by frame. The data extracted is in text format compatible with Microsoft Excel for external storage and detailed analysis.

Fig. 2. System prototype consisting of hardware and custom software.

2.3. System prototype preliminary validation

The next stage involves initial validation of the developed system prototype, where the values of wrist postural angles captured using the system prototype were compared to the manual readings from goniometer. The purpose of this preliminary validation is to check for accuracy of the system prototype to capture wrist postural angle in ulnar, radial, flexion and extension deviation positions.

2.3.1. Subject

In this initial validation stage, the study recruited 32 healthy subjects, without prior history of MSDs. The subjects consisted of 15 males and 17 females. Subjects recruited were young adults (Mean age = 24, *SD* = ±6.71). Among the inclusion criteria is that all subjects should be right-handed and were free from any wrist injuries or diagnosed MSDs for the past six months. Subjects with current and recent cases of wrist related injuries and musculoskeletal disorders may directly affect their motions and consequently, affect the reading. Right handedness was required as the prototype of system hardware and software were set up to only capture data from the right hand.

2.3.2. Protocol

Before data collection started, all subjects were given a briefing about the purpose of the study. Subjects were informed of their rights, including the decision to withdraw from the study at any time. Subjects were given an opportunity to ask any question that they may have before the commencement of data collection. Subjects were then asked to complete consent and demographic form. The dimensions of their hands were measured. The subject was set up with a glove and wearable IMU sensors on their right hand. They were then instructed to do a series of calibration activities to ensure proper data readings from the IMU system. Once the system is calibrated, the subjects were asked to sit down in a testing rig. The testing rig set-up consisted of a chair, desk, goniometers, camera stands were arranged as shown in Fig. 3. Videos of the wrist motions were recorded from top and side views throughout the data collection process.

(a) **(b)**

Fig. 3. Experimental set-up for study: (a) Side view. (b) Top view.

Subjects were asked to adjust the chair height to allow the elbow to be rested on the upper-limb support rig at an angle of 90°. The shoulder and upper arm should be in a neutral and relaxed position. The researcher would check if the shoulder is raised, or the upper arm is abducted, and make arrangements of the rig to modify the posture accordingly. Once the subjects were in the right position, a wrist support jig is applied to keep the wrist location in one place. The researcher would check if the wrist support jig restricts the subject's wrist movement and would take necessary action to allow for the subject's free motions of the wrist area. A few preliminary trials were conducted to get subjects to familiarise with the specific motions of the wrist to be performed in this study, specifically ulnar, radial, flexion and extension deviations.

Subjects were then instructed to perform a series of wrist motion deviations with reference to the goniometer on the test rig as the system prototype begins, recording the data. The subjects started with a neutral, pronated wrist position, which they have to maintain for a duration of 5 seconds. They were then instructed to move their wrists to an ulnar position at 30° from a neutral position.

A reflective lining on top of the glove provides a visual indicator to subject on the angle they have to get to. At 30° ulnar deviation, the subject was asked to maintain the position for a duration of 5 seconds, before returning to neutral wrist position. This activity was repeated in which, the subject was instructed to maintain the position for radial deviation at 30° angle. The rig was then modified by the researcher for flexion and extension deviation setup, while the subject remains seated in position. Once the setup was ready, the subject would begin with sustaining a neutral pronated wrist position for a period of 5 seconds, before being instructed to move their wrist in wrist flexion and extension at 30° angle from a neutral position. Similar to previous activities, the subjects were required to sustain their wrist position for 5 seconds once their wrist was angled at 30° flexion and extension positions. Data collection protocol is summarized in Fig. 4.

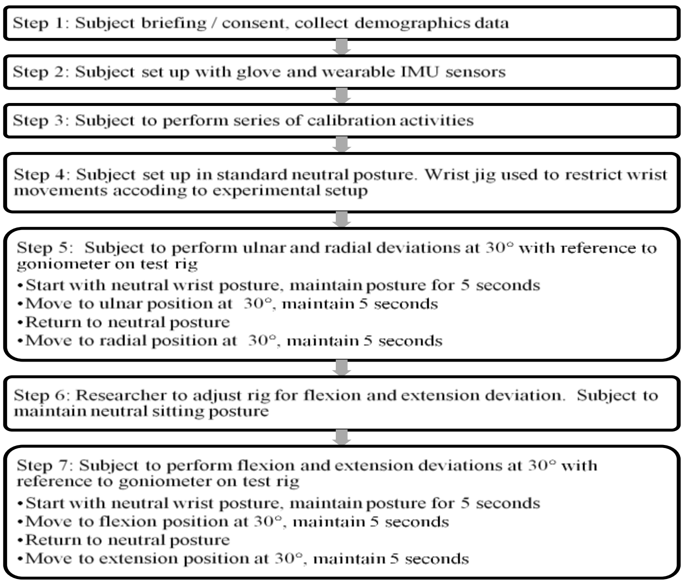

Fig. 4. Data collection protocol.

2.3.3. Data processing and analysis procedure

The raw BVH data from IMUs were run through the BVH reader software, and frame-by-frame wrist data were extracted into a text file. Microsoft Office Excel 2016 was used to plot the data to visualize wrist motion angles at ulnar, radial, flexion and extension deviations. As subjects sustained their posture deviated at 30° while performing each of the wrist motions, the average value of data angles for 5 seconds duration recorded was calculated for comparison purpose. Statistical analysis was conducted using SPSS software. Distribution of data was checked using a normality test. Descriptive statistical analysis was conducted to get an overview of differences between subjects' wrist angle data captured through goniometer and system reading. Outliers were identified using boxplot. T-test analysis comparing wrist angle datasets from system and goniometer were conducted to evaluate differences in wrist angle values.

3. Results

3.1. System prototype development

The developed system prototype allows tracking of wrist postural angle data through a wearable glove with IMU sensors. The system prototype starts with a series of calibration activities, and inputs of demographic information of the assessed user through a GUI. The assessed user will be asked to perform a series of maximum voluntary ROM on wrist ulnar, radial, flexion and extension deviations as a benchmarked data. The system will save these maximum wrist postural angle values in a baseline database. After the benchmarking process, the system prototype is ready to be used to capture real-time wrist postural behaviour data. Through performing or simulating the actual task, the system prototype will extract real-time wrist angles in ulnar or radial, and flexion or extension positions. The captured wrist angle data will be normalized to the benchmarked maximum wrist range of motion data. Visualisation of human hand motion can be viewed through the custom-developed system Graphical User Interface (GUI). Another GUI provides a graphical visualization of wrist postural angles over the recording period. The graphical visualization of the wrist postural patterns, as shown in Fig. 5 can be exported out of the system for references. Monitoring of wrist postural behaviour at work can be conducted through a periodic application of the system prototype over a period.

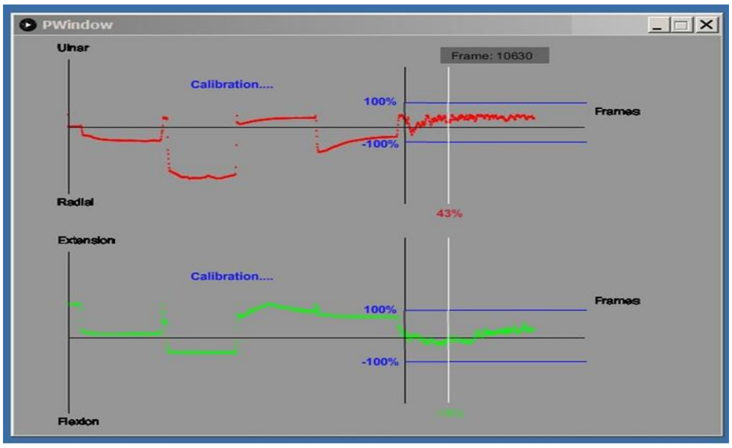

Fig. 5. Visualization of hand motion and wrist postural angle data from the system prototype.

3.2. System prototype preliminary validation

A total of 32 subjects' data were recorded comparing four wrist motions at a specified angle of 30° with reference to goniometer readings. However, data from one subject was eliminated from the analysis due to the inconsistency in readings of the recorded data from the system. The tabulated data from this specific subject also showed extreme outliers when compared to data from other subjects. Thus, the analysis will only involve data from 31 subjects.

Examples of comparisons based on goniometer and system readings for flexion, extension, ulnar and radial deviations from subject S09 are shown in Figs. 6 and 7. The sample demonstrated that the system readings for flexion, extension, ulnar and radial deviations are close to 30° angle, which is comparable to 30° angle reading from goniometer. In general, the wrist angle data captured by the system were similar to goniometer readings, across all 31 subjects.

Descriptive statistics tabulated in Table 1 shows the comparison reading values between goniometer and system prototype methods. Comparing to wrist positions of ulnar, radial, flexion and extension deviations at 30° angle using goniometer, the mean wrist angle captured by the system across all 31 subjects were 29.83° (*SD* = 1.19°), 30.16° (*SD* = 0.91°), 30.19° (*SD* = 1.24°), and 29.85° (*SD* = 1.22°) respectively. The results indicate comparable reading values between goniometer and system prototype methods.

It should be noted that normality checking was conducted on the dataset. The histogram on the distribution of flexion dataset shows a slight skew to the left, as shown in Fig. 8. Radial's distribution also has a slight negative skew, while extension and ulnar are having a normal distribution. Quantile-quantile (Q-Q) plot was also generated from the dataset. Data points of flexion generally fall close to the normal line, as shown in Fig. 8, while data points of extension, ulnar and radial generally fall mostly on the normal line.

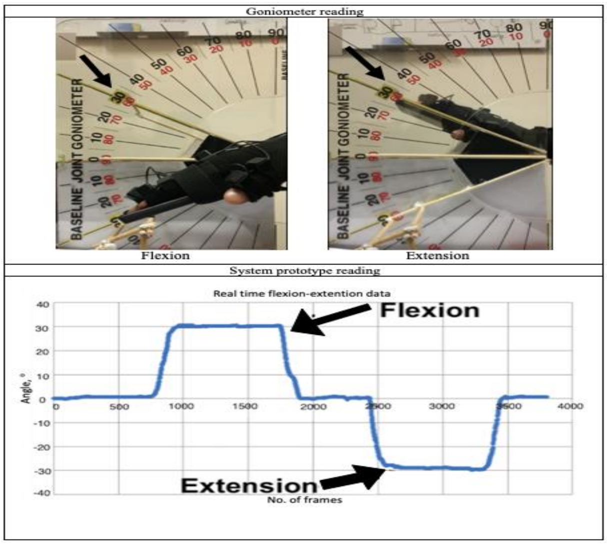

Fig. 6. Sample of flexion and extension readings by goniometer and the system for S09.

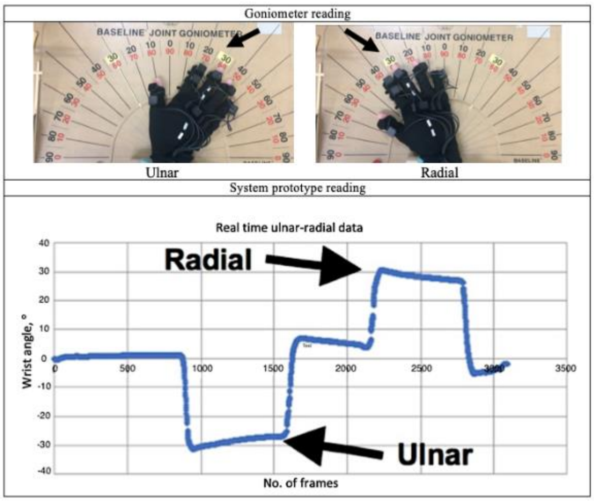

Fig. 7. Sample of ulnar and radial readings by goniometer and system for S09.

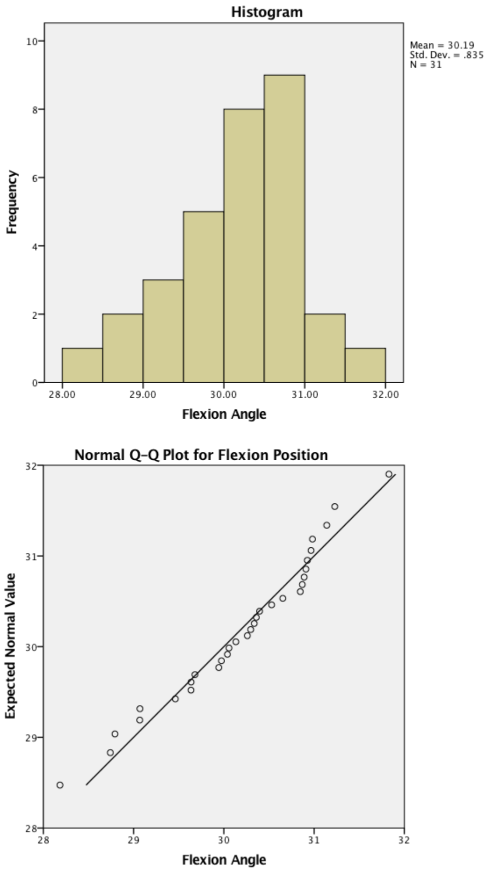

Fig. 8. A sample of histogram and normal Q-Q plot for wrist flexion data.

Table 1. Descriptive statistics of wrist postural angle (°) deviation from system prototype, as compared to 30° reading from goniometer.

	Wrist postural angle (°) reading from system prototype, compared to 30° reading from goniometer, $n = 31$			
	Ulnar	**Radial**	**Flexion**	**Extension**
Mean	29.83	30.16	30.19	29.85
Standard deviation	1.19	0.91	1.24	1.22
Variance	1.41	0.82	1.55	1.49
Minimum	27.32	27.55	28.18	27.71
Maximum	32.07	31.92	31.83	31.99

In testing the assumption of normality, as tabulated in Table 2, Shapiro-Wilks test with the alpha value of 0.05 was taken to be compared with the significant value of the four wrist motions. The results demonstrate that the dataset of the four wrist motions readings from the system prototype does not show a significant departure from a normal distribution. As such, the data can be assumed to be normal.

Boxplot for flexion and extension (Fig. 9) are symmetrical, this means that the angles of the subjects fall equally in the range between 27.3° to 32.1° for ulnar and 27.6° to 31.9° for radial. Subjects' result for flexion is in the range of 28.2° to 31.8° whereas extension is in the range of 27.7° to 32.0°.

In the comparison of mean between the system prototype and goniometer readings using a one-sample test, the dataset from the system prototype were tested with a test value of 30° angle. Overall, the results from one sample t-test across 31 subjects indicate no statistically significant differences between the system prototype and goniometer readings at alpha level 0.05 (p-value > 0.05). Result of one sample t-test for all the four wrist motions is presented in Table 3.

Table 2. Test of normality for four wrist motions ($n = 31$).

	Shapiro-wilk		
	t	***df***	***Sig* (p-value)**
Ulnar	.970	30	.525
Radial	.966	30	.425
Flexion	.968	30	.469
Extension	.973	30	.604

*Note: *t* is *t*-Statistics, *df* is degree of freedom, *Sig* is Significance value at alpha 0.05

Table 3. Result of one-sample t-test for the four wrist motions ($n = 31$).

	Test value = 30					
	t	***df***	***Sig* (2 tails) (p-value)**	**Mean difference**	**95% confidence interval of difference**	
					Lower	**Upper**
Ulnar	-0.598	30	0.554	-0.13357	-0.5895	0.3224
Radial	-0.690	30	0.496	-0.15113	-0.5986	0.2964
Flexion	0.958	30	0.346	0.15592	-0.1766	0.4885
Extension	-1.386	30	0.176	-0.29501	-0.7298	0.1398

Note: *t* is *t*-Statistics, *df* is degree of freedom, *Sig* is Significance value at alpha 0.05

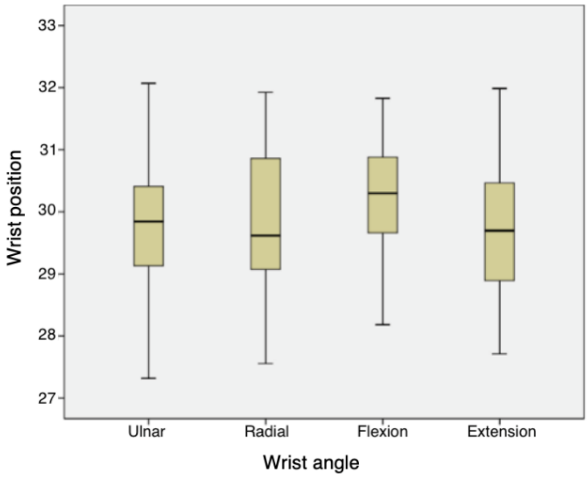

Fig. 9. Boxplot summarizing data distribution of wrist angle readings in ulnar, radial, flexion and extension positions from system.

4. Discussions

The current study describes the development and initial validation of a system prototype to capture and assess wrist behaviour at work. The system prototype was developed based upon system architecture created with input from ergonomists. Generally, the ergonomists gave positive feedback on the concept of the proposed system. Among the main concerns from them, including the accuracy and reliability of the system. Across 31 subjects recruited in this study, comparison of wrist angle at 30° between readings from the system prototype and goniometer shows that differences are not statistically significant. This indicates a level of accuracy and reliability from the system, as compared to the traditional method of assessment using standard goniometer. However, as this study uses goniometer as the reference in performing wrist motions, the identification of 30° angle for each of the wrist posture performed was based on the researcher and subject's naked eyes. There is a tendency where the subjects' wrist motions would fall slightly above or below the expected angle of 30°. As such, one of the protocols in this validation stage is to have each subject maintain each wrist position for 5 seconds before moving to the next wrist position sequence. This 5-second duration will allow for correction and stability of wrist readings, as a subject may tend to over- or under-shoot the 30° mark on the goniometer as they initially reached the mark. Hence, it is possible to have the result's tolerance to be a plus-minus of 1° to 2° in validating the system in this study.

Accuracy and reliability of the system prototype to capture wrist postural angle are important requirements for the whole premise of the proposed system, whereby the postural angle due to work requirements will be normalized to the maximum voluntary ROM of the subject. The capability of the system prototype to capture the postural angle accurately will allow for assessment at an individual level, potentially contributing to the overall sensitivity of the system prototype. As the misfit between a work requirement and worker happens at a personal level, there is a need to compare the captured data to a personal benchmark. As this system prototype capture wrist postural angle, it is proposed that the benchmark would be the wrist angle at an individual's maximum voluntary ROM condition. This concept is inspired by the well-established method of ergonomics assessment to measure physical exertion using electromyography (EMG). Individual's physical exertion can be assessed through normalization of the work requirement exertion against maximum voluntary exertion values [16-18]. There have been few studies that propose capturing postural angle using IMU systems, such as from Li et al. [20], Chen et al. [21], Peppoloni et al [23], Vignais et al. [19], and Yan et al. [24]. However, these studies did not propose to normalize captured data against a benchmark, as proposed in this system prototype.

The angle of slope in the "wrist angle vs. time" graph obtained from the system's generated data provides an indicator for acceleration or deceleration of the wrist. The data trend that shows sharp angle changes over time indicates higher wrist acceleration when moving from one position to another, and vice versa. All subjects generally show sharp incline in their datasets when moving between each wrist positions, indicating accelerated wrist motions. It is expected that those with the onset of wrist related disorders may have lower wrist motion acceleration when changing between wrist positions, indicated by the lower incline of data over time. This information may indirectly provide preliminary information on the health condition of subject's wrist, provided proper protocol has been observed (e.g., standardized instruction for subject to switch to different wrist position on a normal, comfortable pace). This premise can be further explored in a future study comparing between healthy subjects and subjects with onset of MSD symptoms on the wrist region. A comparison study with this system prototype will provide visual data evidence on the wrist acceleration patterns between the two populations of the subject.

Future work would include a comparison between usability testing of the system prototype. In the current system, two graphs (ulnar vs. radial, and flexion vs. extension) of wrist postural angle were simultaneously generated to provide a visual overview of wrist postural behaviours over time. Current graphical user interface (GUI) design requires the system prototype user to look at the two graphs simultaneously to determine if the subject is in ulnar or radial position, in combination with flexion or extension position, at a specific time frame. Other studies by as Yan et al. [24] uses only one graph with multiple colours indicating the postural angle data from the different axis. The design of GUI to assist interpretation of data requires further in-depth usability study. In addition to the wrist postural data being displayed, the current GUI design also displays lines representing a maximum degree of voluntary ROM at ulnar, radial, flexion and extension positions. The system prototype user can get an overview of the relative relationships between postural wrist angle at work and maximum personalized value through the patterns generated by the graphs.

Further validation of the system will include field studies to compare between the assessment results of the developed system prototype with other wrist postural assessment tools such as Strain Index [25] and ACGIH-HAL [26]. A comparison study will allow a better quantification of the advantages and disadvantages of the proposed system prototype compared to other established wrist assessment tools used by ergonomists and industrial practitioners. Future study should also include a wider range of subject populations, such as elderly or individuals with pre-existing wrist issues. In addition, feedback on the comparison outcomes, as well as additional inputs from ergonomists and industrial practitioners will be sought as part of the validation process.

5. Conclusions

In summary, the prototype system developed in this study has shown some degree of reliability and accuracy in detecting wrist postural angles, as being compared to readings from goniometer. Across ulnar, radial, flexion, and extension wrist positions, the dataset shows normality values in all positions (p-value > 0.05 for Shapiro Wilk), even with relatively small sample size. In addition, the data from the system prototype also showed a level of accuracy when comparing against traditional goniometer values on all wrist positions tested (p-value > 0.05 for *t*-test). The detection of real-time wrist postural angles would provide a tool for safety practitioners, engineers, and managers to assess and monitor wrist postural behaviours at work. Quantifying poor wrist postural behaviours may provide evidence that can become a basis for ergonomics intervention or improvement initiatives. It is expected that this research endeavour bridges gap between academic research and practice. The developed prototype shows early promises of a system that may eventually assist industrial practitioners to perform an ergonomic evaluation, and ultimately improving the overall occupational safety and health of workers.

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Nomenclatures

df	Degree of freedom
M	Mean
n	Number of subjects
Sig	Significance
t	Statistics

Abbreviations

ACGIH-HAL	American Conference of Governmental Industrial Hygienists - Hand Activity Level
BLS	Bureau of Labour Statistics
BVH	Biovision Hierarchy
CI	Confidence Interval
CTS	Carpal Tunnel Syndrome
EMG	Electromyography
GUI	Graphical User Interface
IHMS	Intelligent Health Monitoring System
IIOT	Industrial Internet of Things
IMU	Inertia Measurement Unit
IOT	Internet of Things
IT	Information Technology
MEMs	Microelectromechanical systems
MSD	Musculoskeletal Disorder
Q-Q	Quantile-Quantile
ROM	Range of Motion

RULA	Rapid Upper Limb Assessment
SD	Standard Deviation
SPSS	Statistical Package for the Social Science

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