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Mgbemena, C.E., Oyekan, J., Hutabarat, W. et al. (2018) Design and implementation of ergonomic risk assessment feedback system for improved work posture assessment. Theoretical Issues in Ergonomics Science, 19 (4). pp. 431-455. ISSN: 1463-922X

https://doi.org/10.1080/1463922X.2017.1381196

DESIGN AND IMPLEMENTATION OF ERGONOMIC RISK ASSESSMENT FEEDBACK SYSTEM FOR IMPROVED WORK POSTURE ASSESSMENT

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ABSTRACT

Ergonomic risk factors which include force, repetition and awkward postures, can result in Work-Related Musculoskeletal Disorders (WMSDs) among workers. Hence, systems that provide real-time feedback to the worker concerning his current ergonomic behaviours are desirable. This paper presents the design and implementation of a human-machine interface posture assessment feedback system whose conceptual model is developed through a model-driven development perspective using the UML and Interface flow diagrams. The resulting system provides a shop floor with a simple, cost-effective and automatic tool for real-time display of worker's postures. Testing the system on volunteer participants reveals that it is easy to use, achieves real-time posture assessment and provides easy-to-understand feedback to workers. This system may be useful for reducing the rate of occurrence of awkward postures, one of the contributing factors to risk of WMSDs among workers.

KEYWORDS: Awkward postures; Ergonomics; Manual Handling; User Interface; Real-Time Feedback.

1. Introduction

Operators in a manufacturing shop floor are often required to undertake manual handling activities. These activities, which include lifting, lowering and carrying (Shoaf et al. 1997), if not ergonomically executed, can result in risks that may lead to WMSDs and greatly limit worker's life and health (Valentin et al. 2015; Savino, et. al., 2016). Such ergonomic risks are caused by factors such as forceful exertion, task repetition and awkward postures (Tak et al. 2011; Chander and Cavatorta 2017). Critical postures that increase the rate of development of WMSDs, especially when held for prolonged periods exceeding 45% of the workday (Stuebbe et al. 2002), may be adopted by operators while working (Johnson and Fletcher 2014). Hence, there is need for postural assessment which has been recommended as an ergonomic risk prevention strategy that helps to reduce worker's discomfort as well as minimise costs (Stuebbe et al. 2002).

Awkward postures have been defined by H&S professionals as the posture that occurs when a part of the body deviates from its natural alignment or its neutral position. The neutral position is defined as a position where the joints are naturally aligned with the trunk and head upright, the arms by the side, forearms hanging straight and the wrists not bent or deviated

(OSHA - Hazard Index 2016; Steinberg 2012a; EU-OSHA:E-Fact 45 2016; HSE 2002). To minimise the rate of occurrence of awkward postures, a good ergonomic posture assessment tool with easy-to-use and easy-to-understand feedback interface system is of great importance. Hence, we aimed to design and develop a real-time ergonomic posture assessment feedback system for use in workplaces.

Feedback interface design involves modelling of specific use cases which indicates to users what they have done, where they have been, and where they currently are (Palmas et al. 2014). Attributes of good feedback systems include simplicity, legibility, transparency, and customizability (Claypoole, Schroeder, and Mishler 2016). Interestingly, research suggests that established feedback systems such as the Ovako Working Posture Analysis System (OWAS), were not designed in an easy-to-understand, ergonomic-friendly way (Valentin et al. 2015). In the assessment of ergonomic risk factors on the shop floor, a natural and interactive interface that provides good feedback to the users is of utmost importance (Aromaa and Väänänen 2016) and the design of this interface should capture the most important elements of the system so that both the expert and the novice staff would have a greater capacity to participate (Hoarau, Charron, and Mars 2014). For awkward posture assessment, systems that provide real-time feedback to the worker concerning his current ergonomic behaviours are highly beneficial as they can prompt the worker to optimally adjust postures and result in improved ergonomic workplace conditions. Such systems are also convenient and save time (Johnson and Fletcher 2014; Klippert, et. al., 2012).

Existing work posture assessment tools can be classified as either observation-based or instrument-based. Observation-based tools such as OWAS, Rapid Upper Limb Assessment, RULA, Quick Exposure Check, QEC, and the Rapid Entire Body Assessment, REBA (Vignais et al. 2013), uses visual perception to evaluate the rate at which the body moves away from the neutral position. A comparison of these tools has been made and strengths as well as limitations have been previously described (Savino, Mazza, and Battini 2016; Kale and Vyavahare 2016). The tools enable the user to capture data while observing several operations and perform offline analysis of the data afterwards. The use of the RULA observation tool, for example, requires sufficient training to select for assessment, the most difficult posture. Instrument-based tools assess work postures using instruments (Kee and Karwowski 2007). Currently available instrument-based postural assessment feedback systems require workers to wear inconvenient measurement devices which interfere with work methods (Valentin et al. 2015; IFA-CUELA 2016; Manghisi et al. 2016; Plantard et al. 2015), fail to provide real-time feedback (WSH Institute 2016), requires substantial user training (Center for Ergonomics), or are difficult to use as they require experts to perform time consuming posture analysis (Manghisi et al. 2016). Again these tools are not suitable for many work places due to space, cost and calibration limitations (Haggag et al. 2013). These limitations can be overcome by employing a cost-effective, easy-to-use, non-invasive, portable and calibration-free tool, which possesses the capability to provide real-time feedback that can inform the worker to adjust awkward postures in time. The Microsoft Kinect (hereafter called the Kinect) has been recommended by many researchers as an easy-to-use, markerless and cost-effective alternative for ergonomic work-posture assessment (Plantard et al. 2015; Dai and Ning 2013; Mgbemena et al. 2016). Kinect has been proved to generate accurate kinematic information needed for ergonomic assessment (Plantard, et. al., 2015), can accurately measure human joint angles (Clark et al., 2012; Diego-Mas and Alcaide-Marzal, 2014; Fernández-Baena, et. al., 2012), and provide real-time feedback to users (Martin et al. 2012; Delpresto et al. 2013). Manghisi et al. (2016) has proved that Kinect is suitable for the detection of awkward postures and can yield moderately accurate posture data.

Our newly designed postural assessment feedback system will therefore use the Kinect as its hardware component to address the limitations of existing tools by providing the workplace with a tool that: i) provides real-time automatic feedback to workers to enable them to adjust awkward postures in time. ii) is easy-to-use, with easy-to-understand feedback to overcome the limitation posed by tools that are difficult, and those that require experts and training iii) is non-intrusive and therefore more convenient as it does not interfere with work methods. iv) is portable, cost-effective and calibration-free.

The system is designed to adopt a similar method as seen in the design by Liu and Lee (2014), with screens which support flexible visualisation methods that enable the user to define their own data for each case study (Palmas et al. 2014).

2. Methodology

The first step in designing the proposed system was to identify the functional requirements through some basic questions, including: a) who are the external users? b) what information does the external user need to give or receive? and c) what format is the information provided?

We used the UK Health and Safety recommendations for personnel involved in risk assessment to identify the external users of the proposed system (Health and Safety Executive 2016).

2.1. Description of the Functional Requirements of the Proposed System

The functional requirements of the proposed system include a system that: a) supports new staff registration, captured in the ‘staff accounts’ use case, b) provides and retains staff details, which also reflects in the ‘staff accounts’ use case, c) reflects workplace information, captured in the ‘workplace reports’ use case d) displays joint information of staff, which reflects in the ‘Display joint’ use case e) retains information on the size of the load handled by the operator as captured in the ‘Load attribute’ use case f) supports viewing, searching and editing of required manual handling tasks, captured in the ‘Select task’ and ‘Select task order’ use cases g) alerts the worker whenever the motion becomes awkward, reflected in the ‘Prompt staff’ use case h) updates the posture assessment information of all operators, which is captured by the ‘Display posture’ use case and updated in the system database i) allows the worker to view previous posture assessment results. This is captured by the ‘Display posture’ use case j) supports change from one task to another, captured by the ‘Select task order’ use case and k) allows update of worker’s activities on the shop floor, captured by the ‘workplace reports’ use case and updated in the system database.

Details of these requirements are outlined on table 1.

2.2. Posture Assessment categories and Scoring method

In the definition of awkward postures as presented in section 1, two posture categories, the neutral (good) and awkward categories, were utilised in the tool’s initial development. A designation of ‘Good’ indicates postures beyond the neutral position range, equivalent to the existing tool’s neutral to mild category or the green colour band for posture classifications using colour bands. The ‘Awkward’ category indicates postures beyond the neutral position range, equivalent to the existing tool’s moderate and severe categories and corresponding to the amber to red colour categories. This decision was made to enable the tool to provide simple, easy-to-understand real-time feedback without the complexities of having several categories of postures that may confuse the workers especially when working in flexible manufacturing systems where immediate response to posture changes is required.

Hence, for ergonomic assessment involving joint angles of the upper body, the neutral figures denote the reference point for each joint and therefore is represented by the ‘zero’ score.

Therefore, each of the joints of the upper body is set at zero and the definition is programmed for each joint such that any deviation from it beyond the recommended limits results in awkward posture.

The Back posture is scored as Good = 0° – 20° and Awkward = >20° , based on the definition extracted from the UK HSE, that the back posture is classified as awkward when the back is bent or twisted more than 20 (HSE - Awkward Postures). The Nec*k* posture is scored as Good = 0° – 10° and Awkward = >10°, based on the RULA scores (McAtamney and Nigel Corlett 1993). The Elbow posture is scored as Good = 0° – 90° and Awkward = >90°, based on some countries’ H&S definitions that the elbows become awkward when held above chest height or bent more than 90°, but neutral when hanging straight by the side or in handshake position (OSHA:Supplemental Information 2017; HSE - Awkward Postures; WSH Council 2014; Steinberg 2012b). The Shoulder posture is scored as Good = 0° – 20° and Awkward = >20°, based on the RULA scores (McAtamney and Nigel Corlett 1993). The Wrist posture is scored as Good = 0° and Awkward = >0°, based on some countries’ H&S definitions that the wrists should not be bent but should be maintained at straight or neutral position or be assessed as awkward if an obvious angle is observed (OSHA - Hazard Index 2016; HSE - Awkward Postures; WSH Council 2014).

2.3. Detailed System Design

The step by step methods adopted for this design and implementation include;

I. Detailed System Design. This involves the following; a) identification of the system’s external users. b) Modelling the usage requirements, set of actions and performance of the external users using the UML use case diagram. c) modelling the flow and format for information among the external users within the system. d) development of model for the logic captured by the use case model using the UML activity diagrams and e) developing the model for the system’s widgets using the user interface flow diagram/storyboards. This is modelled with the information provided by the UML Activity diagram models and shows at a glance, the various widgets of the designed system and depict the final design of the feedback system. The system widgets include the buttons, screens and icons and this is presented in figure 6.

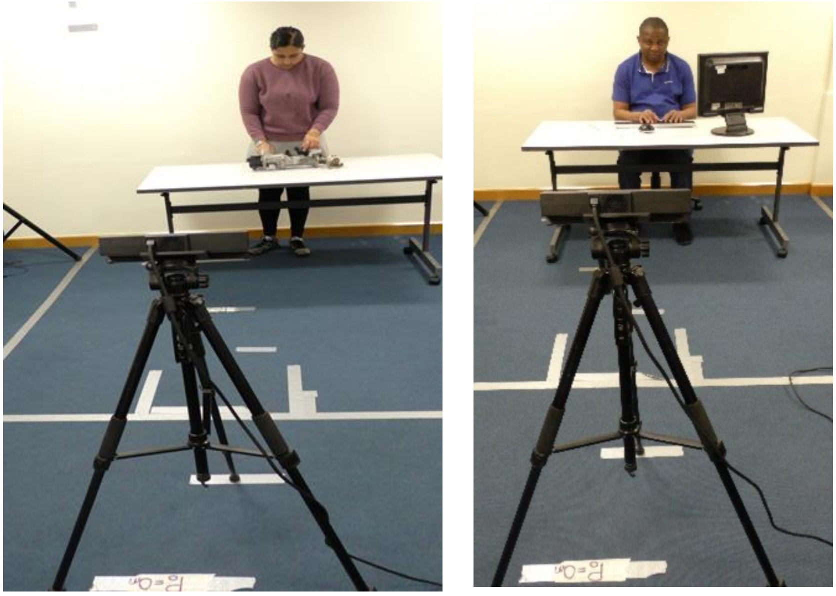
II. System demonstration. This involves the development of the designed system widgets some of which are presented in figure 7. These widgets are developed using C# programming language in the WPF application of the .NET Framework 4.5 of the visual studio.

III. System implementation using real-life examples. This involves testing the developed system on some participants to test the system functionalities.

2.4. Experimental Setup for testing the developed System.

To test the functionalities of the developed system, experiments were conducted on two case studies. These are the manual assembly of EGR Valve of a Jaguar diesel engine by six operators and the posture assessment of four PhD researchers while studying. A total of 10 participants aged between 25 to 40 years, participated in the study. The 3D motion sensor utilised in this system is the low-cost Microsoft Kinect sensor (hereafter called the Assessor) which costs approximately £90/$112 and is readily available in the market. This sensor can capture the skeletal data of workers who are within 0.5m to 4.5m depth range from the sensor, at horizontal and vertical fields of view of 70° and 60° respectively. The developed system requires very little set up time as it only requires the user to place the sensor within the sensor's field of view and to start the system by pressing the start button. The sensor is programmed to simply inform the operator when the posture is good or awkward. This is done by real-time display on the screen and speech communication to the operator on the postures that have been held over prolonged periods. The system is easy-to-implement because the screens are designed in a simple and interactive way.

For this experiment, the sensor is placed at 1.2m Height and 3m object distance from the sensor as obtained from Mgbemena et al. (2017), and shown in Figure 1.



a. Operator Assembling engine valve **b. Researcher studying**

Figure 1 Experimental Setup for testing the developed system.

2.4.1. Experimental Procedure

The participants were asked to setup the system, login and register their various tasks, while the setup times for each participant was recorded. Then their upper body postures were captured and assessed by the system during task execution. Each participant was asked to complete an assessment form to evaluate the system using the following criteria; i) ease of use ii) ease of understanding iii) ability to provide real-time feedback and iv) convenience. By convenience, we meant to assess if the participants were comfortable and satisfied with the feedback provided by the system.

Case 1: Posture Assessment of Operators Assembling Jaguar Engine Valve.

According to the UK HSE's definitions 'The back posture is considered awkward if more than 20° of twisting or bending is observed' ('HSE - ART tool: Awkward postures,' n.d.). In this case study, we examine the system's capability to assess back postures in compliance with HSE guidelines and provide feedback. The upper body postures of six volunteers were captured and assessed with the developed feedback system during the assembly of valve engine components.

These volunteers, employed as cleaners in different workplaces in the United Kingdom, were briefly trained on how to assemble the engine valve. Each volunteer assembled the valve component once – under controlled laboratory conditions - while the system captured his motion data, assessed his posture and provided real-time feedback.

Case 2: Posture Assessment of Seated Researchers

Again, according to the UK HSE, 'The arm is considered to adopt an awkward posture if the elbow is raised around chest height' ('HSE - ART tool: Awkward postures,' n.d.). Hence, the system's capability to assess arm postures in compliance with HSE guidelines and provide feedback to four PhD researcher volunteers was examined during a simulated studying task. This case study was selected to test the generalizability of the developed system for use in workplaces involving non-manual handling tasks.

3. Results

The results obtained from the design, development and implementation of the feedback system, are presented in this section.

3.1. System Design Results

Figure 2 displays the external users (system actors) of the system.

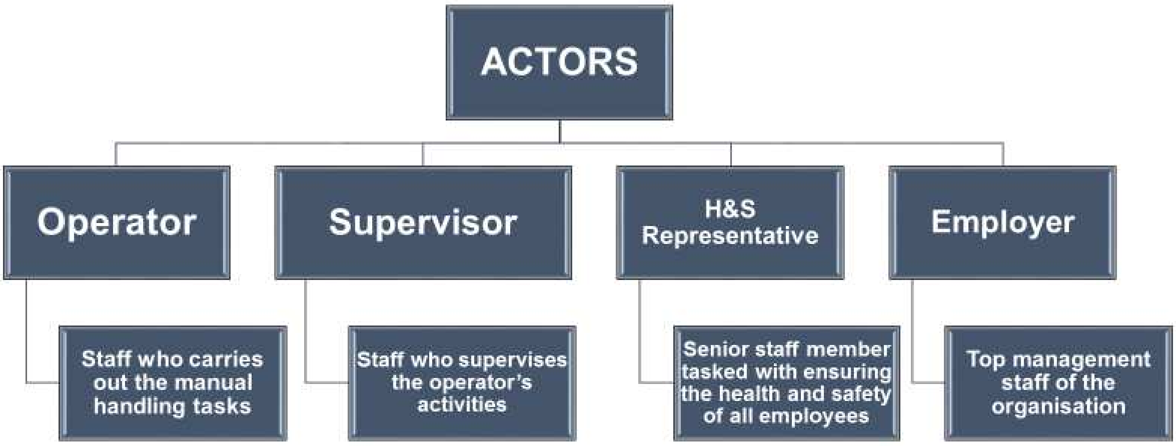


Figure 2 System Actors

The result obtained by modelling the usage requirements of the system, the set of actions on the system, as well as the performance of the external users of the system are represented by the UML use case diagram shown in figure 3. This diagram shows the user's interaction with the system.

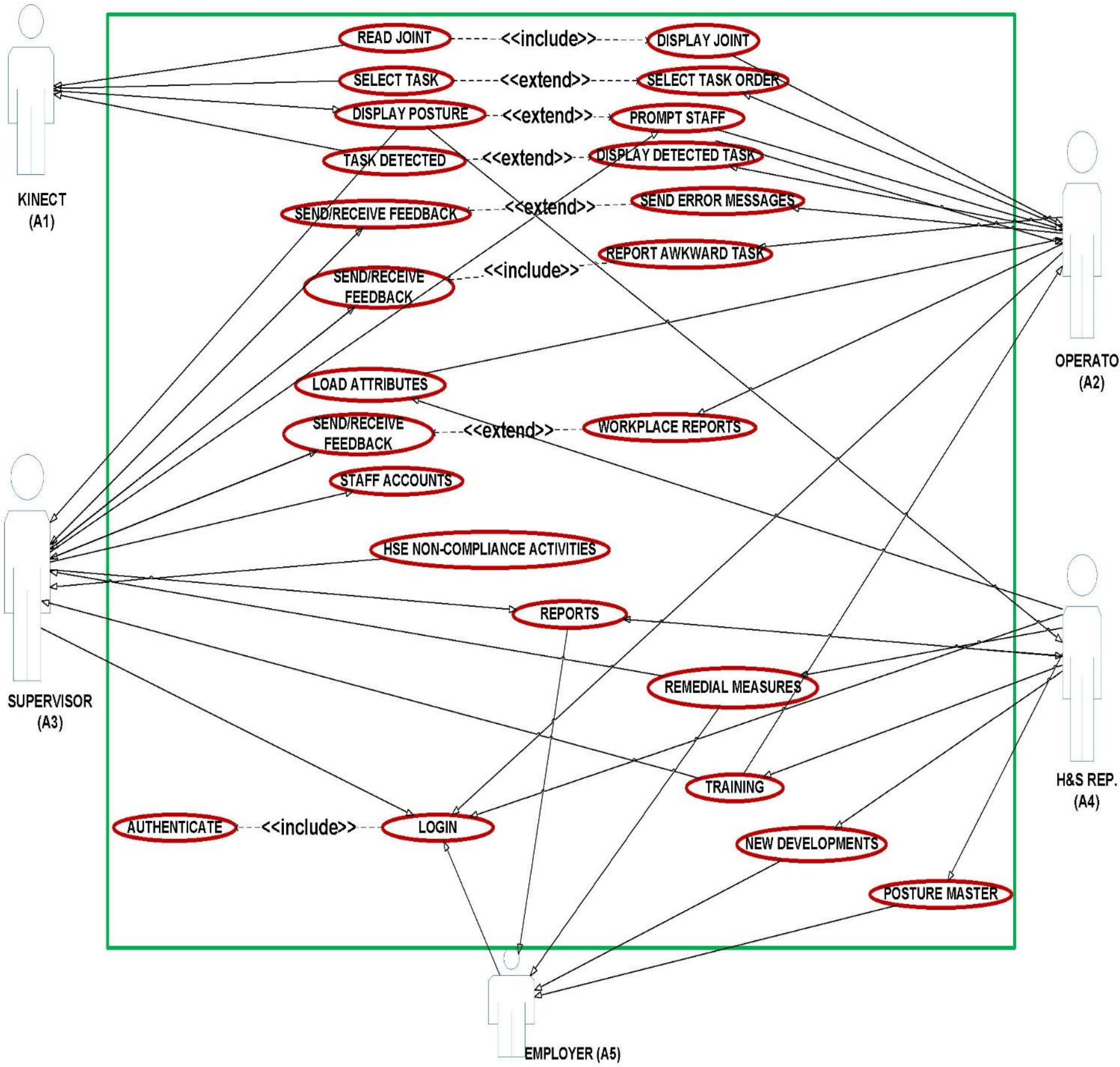
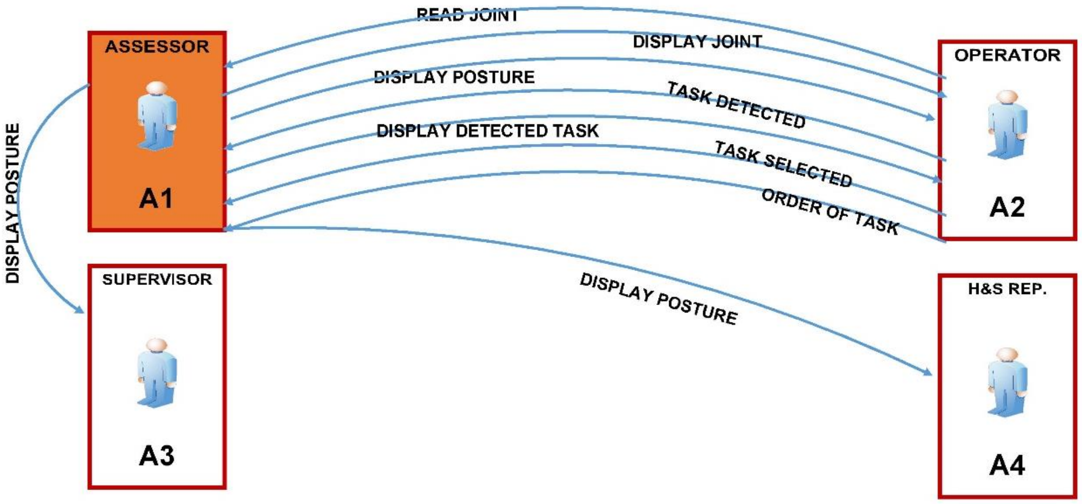
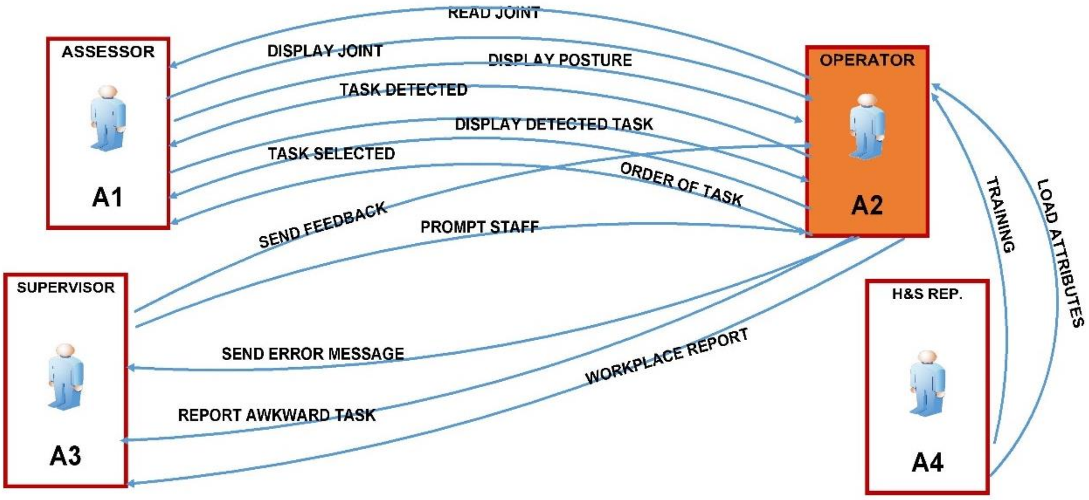


Figure 3 Model of the System using the UML Use Case Diagram

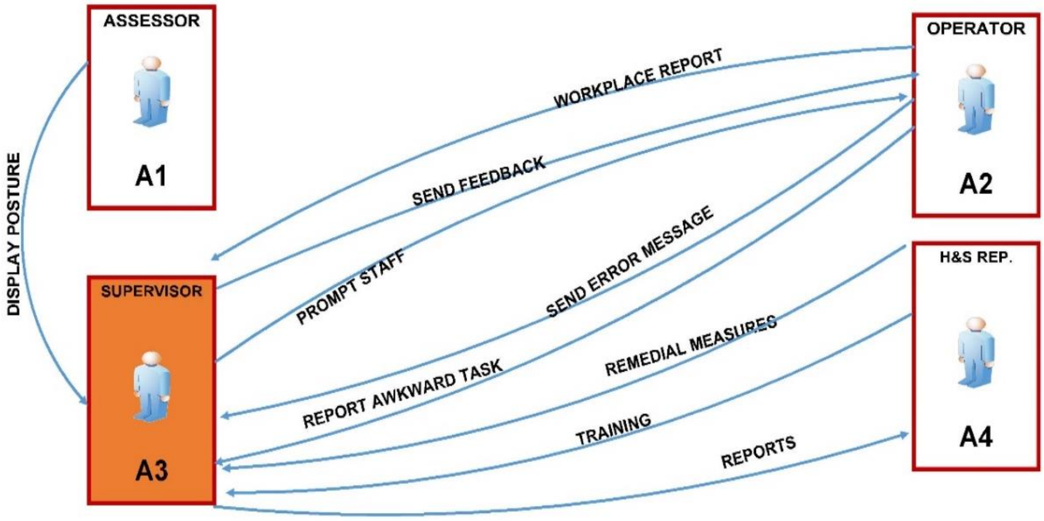
Information flow among external users is depicted in figure 4 with arrows indicating whether information is given or received by each specified actor.



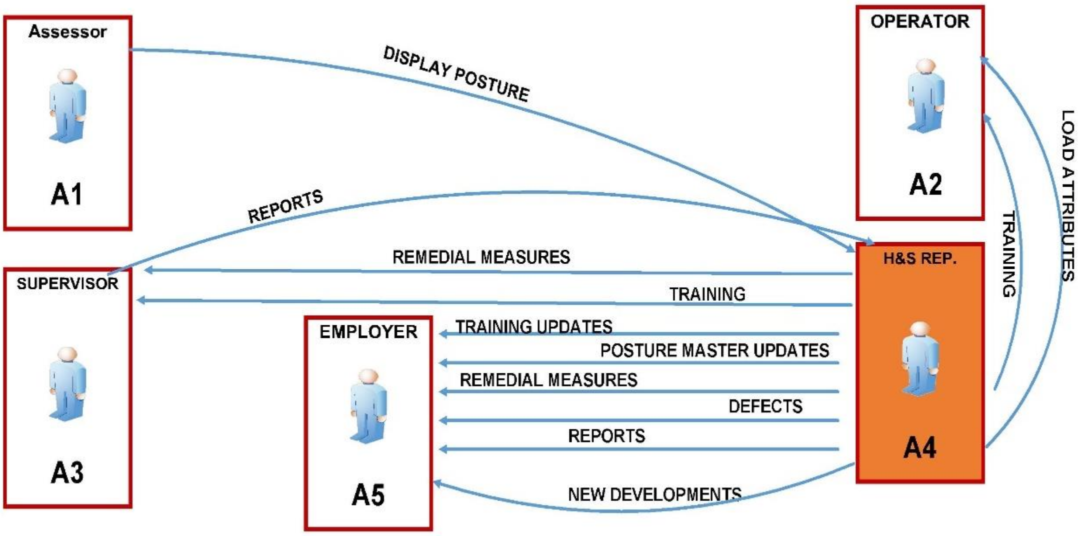
a. **Assessor's interaction with other actors**



b. **Operator interaction with other actors**



c. **Supervisor interaction with other actors**



d. H&S Rep. interaction with other actors

e. Employer interaction with other actors

Figure 4 Actor Interaction Flow Diagram

Figure 4 illustrates the flow of information from one actor to another. Table 1 summarises in greater detail the information flow and formats for delivery to each external user. Row 3 of table 1 for example, shows how the posture status of the operators is to be displayed by the assessor in real-time both by display on the screen and by voice alert from the system.

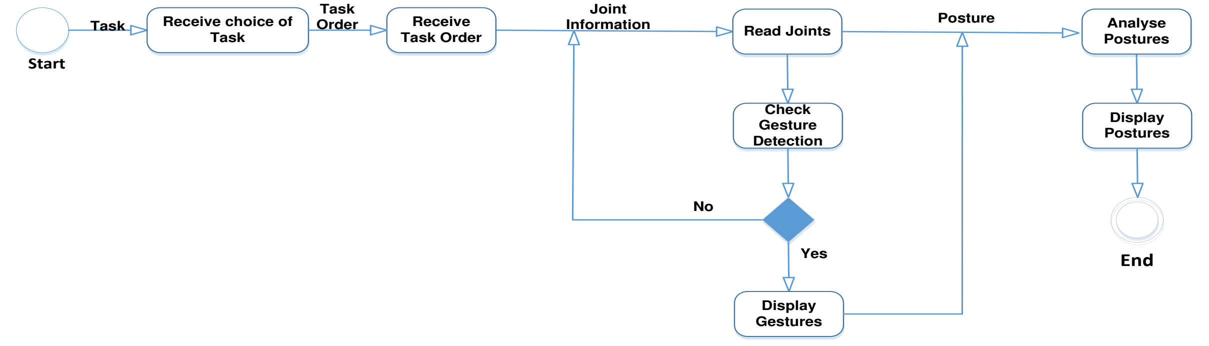
Table 1 Information flow and format among the actors

Information	**Description of Information**	**Nature of Information**	**Flow**	**Format**
Joint Information	a) The Assessor receives information on the joints of a worker within its field of view. b) It processes the data and display output	a) Real time b) Real time	a) A2 – A1 b) A1 – A2; A1 – A3	Tracked body joints displayed as numerical values in X, Y, Z coordinates.
Posture Status	a)The Assessor displays the posture output to Staff. b) Operator, Supervisor, H&S Rep. receive feedback of Operator’s posture from the Assessor. c)Supervisor & H&S Rep. prompts operator to adjust risky postures	a)Real time b) Real time/ offline c)Real-time /offline	a) A1 – A2 b) A1 – A2/A3/A4 c) A3/A4 – A2	a) Display of Posture updates on screen and voice alert b) Choice of update from database c) Text entry via chat
Gesture	a) The Operator checks if task is	a) Real time	a) A2 –	Matched to manual

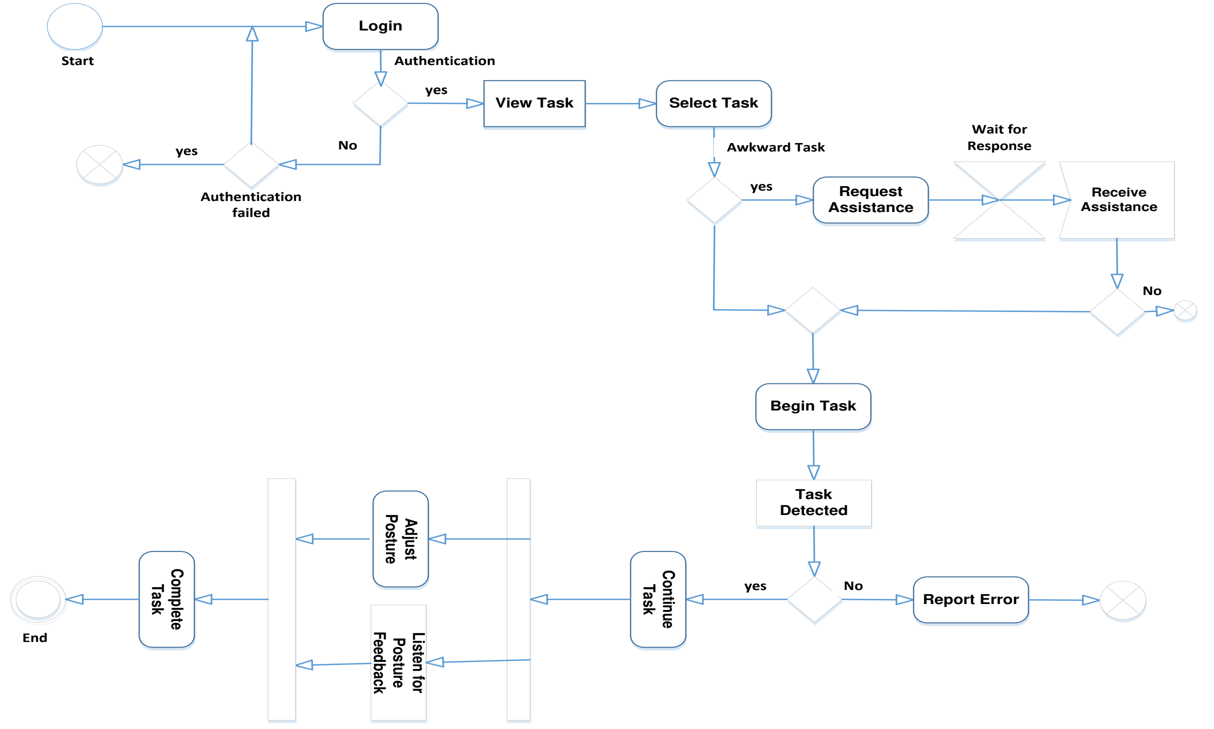
detection	detected by the Assessor. b)The Assessor responds.	b) Real time	A1 b) A1 – A2	handling motions.
Task Selected	a)The Assessor receives information from the Operator on the choice of task. b)Operator sends information to the Supervisor requesting help with awkward tasks c)Supervisor sends help	a) Real time b) Real time c) Real-time	a) A2 – A1; A2 – A1 b) A2 – A3 c) A3 – A2	a)Choice of task from a library of task b)Message to signal awkward task c)Text via chat
Login	Login by all actors except the Assessor using assigned Username and Password.	Real time	-	Text input
Workplace	a) Operator notifies the supervisor if the workplace has any ergonomically unacceptable issues such as poor lightning which can lead to altered posture assessment results. b) Supervisor sends feedback c) Operator receives the feedback	a) Real time or offline b) Real time or offline c) Real time or offline	a) A2 – A3 b) A3 – A2 c) A2 – A3	a) Text entry via the chat window. b) Text response via chat. c) Text entry via chat.
Staff Account	Supervisor registers new User and updates existing users.	Offline.	-	Text entry
Error Reports	a) Operator notifies the supervisor when the sensor starts generating erroneous feedback which is informed by failure of the sensor to detect the operator's task. b) Supervisor receive the information and send feedback to the operator.	a) Real time b) Real time or offline	a) A2 – A3 b) A3 – A2	a)Text via chat b)Text via chat
Training	a)H&S Rep. organises training for all staff b)All other staff receives training on the use of the system.	a) Offline b) Offline	a) A4 – A2/A3 b) A2/A3 – A4	Choice of suitable training from library of training log
Reports	a) Supervisor generates and sends report to H&S Rep. b) H&S Rep. receives reports and send to Employer c) Employer receives the report	Offline	a) A3 – A4 b) A4 – A5 c) A4 – A5	Chat or by paperwork.
Archive	Registered staff can assess the past posture updates of Operators any time.	Offline	-	Choice of posture output from the database
Posture Master	a) Employer receives feedback from the H&S Rep., effectiveness of the system and system upgrade.	Offline	a) A4 – A5	a) Text entry via chat or by paperwork

The internal logic of the complex operations involved in the design of the system as modelled by the UML activity diagram is presented on table 2. This shows the activities of each of the users and provides the possible navigation paths and connections to other key data elements necessary for state changes. The models clearly communicate the system functionality, processing and user interface flows for each external user. The Kinect activity diagram describes how the Kinect receives information and displays results. The operator’s activity diagram flow explains his activities from when he logs in to when he completes his task. The supervisor’s activity diagram flow also shows him logging into the system, how he can register new staff and monitor operators for awkward posture updates and feedback. The H&S Rep.’s activity diagram depicts the activities of the H&S Rep. at the operator’s desk, supervisor’s desk and at employer’s desk. The employer’s activity diagram shows the employer activities. While the use case model shows why and when the users should follow particular paths in the system, the activity diagrams models the roadmap of the user functionality which shows the paths followed by the users (Lieberman 2004).

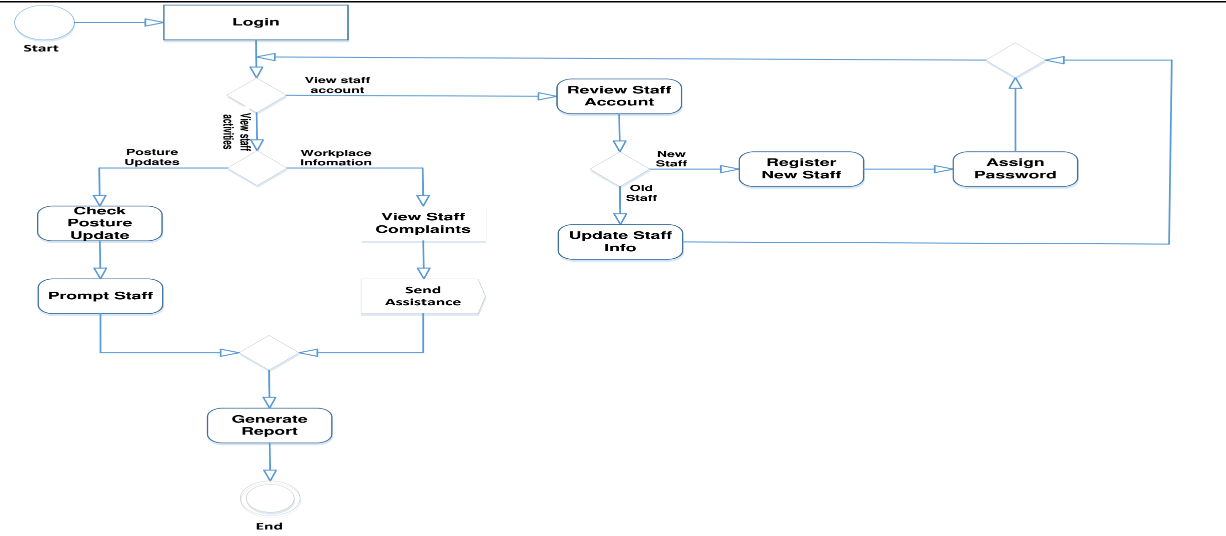
Table 2 Modelling of the Actor’s Activities using UML Activity Diagrams



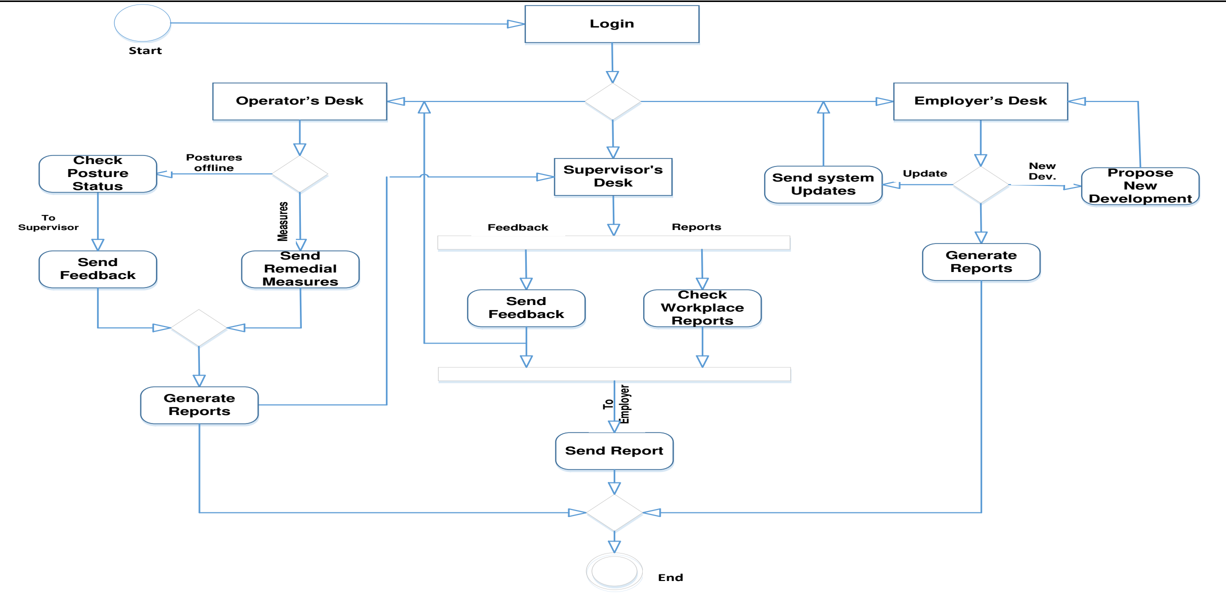
a. Assessor’s Activity Diagram



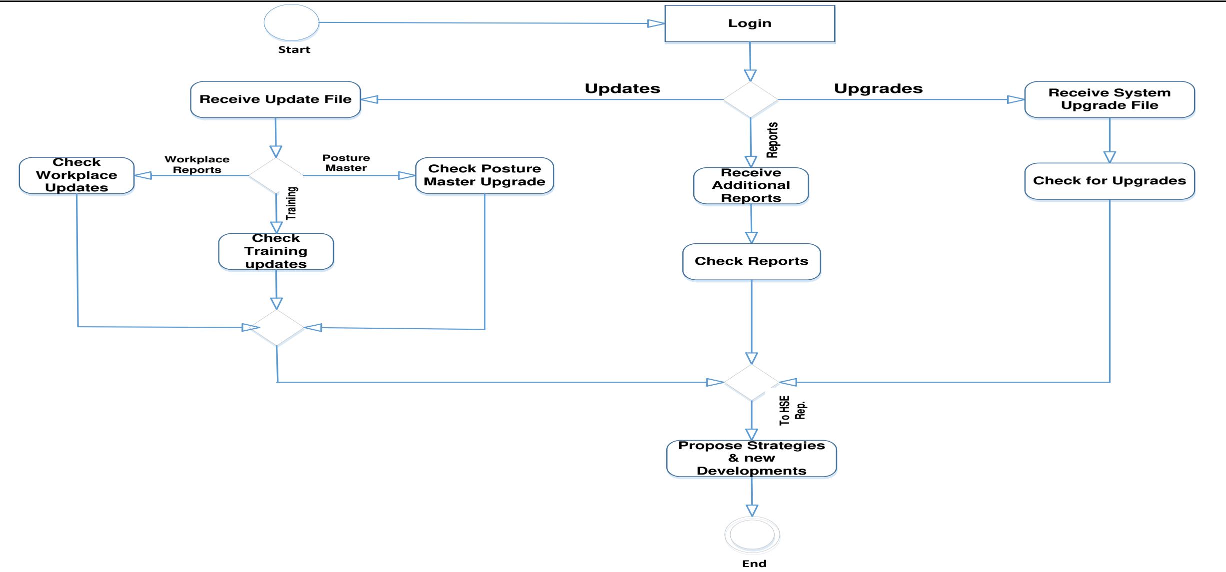
b. Operator’s Activity Diagram



c. Supervisor's Activity Diagram



d. H&S Rep's Activity Diagram



e. Employer's Activity Diagram

Furthermore, the system's site map of figure 5 describes the system's screens and sub screens and summarises the user interface flow diagram.

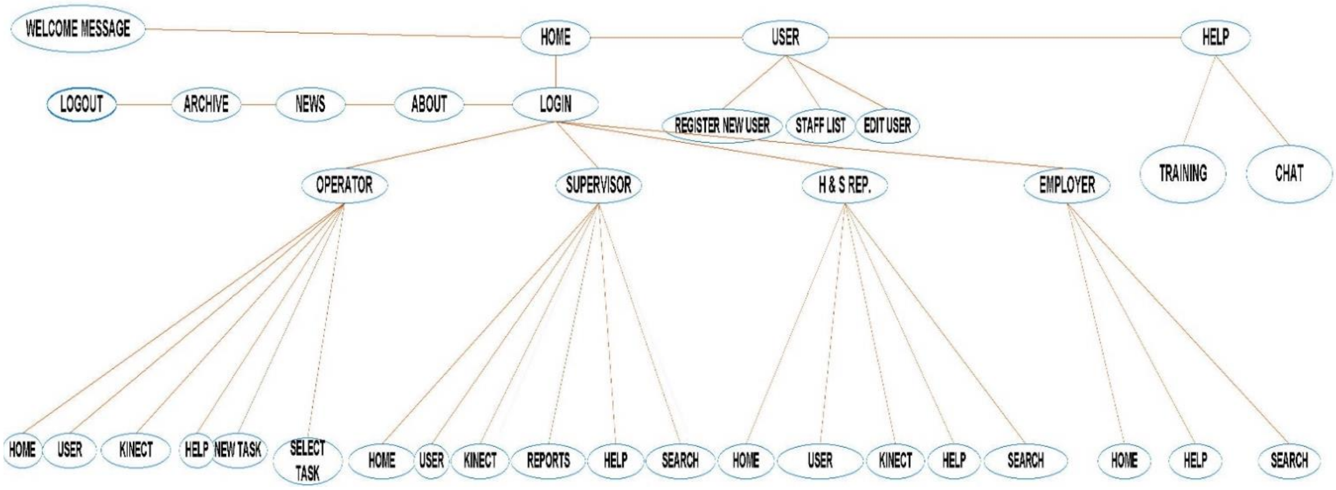


Figure 5 The Site Map of the proposed system

The User Interface Flow Diagram, also known as the Storyboards, employed to model the high-level relationships between the major user interface elements, shows a high-level overview of the feedback system design and is the architectural view of the system as it represents the complete interface system along with its controls as seen in figure 6.

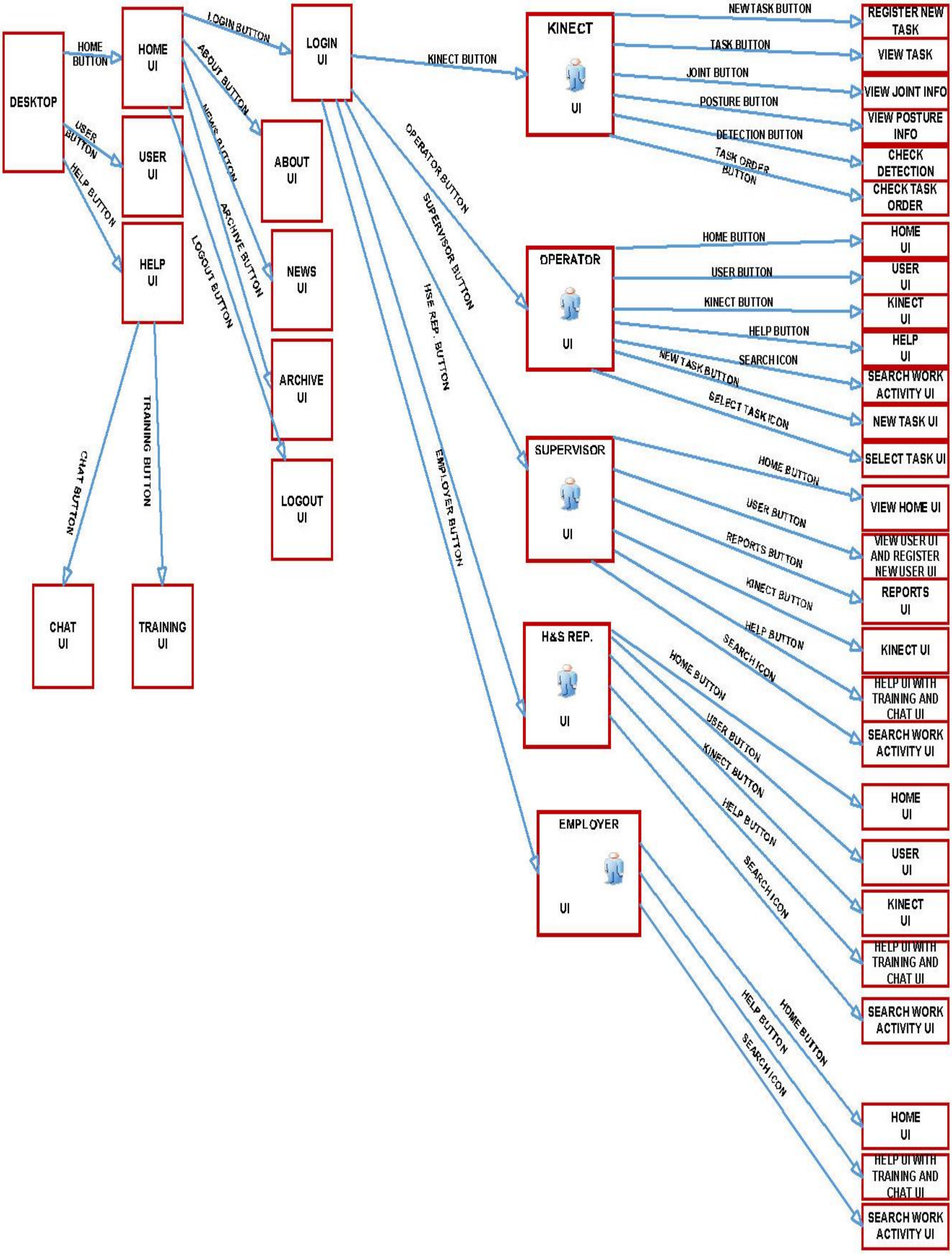
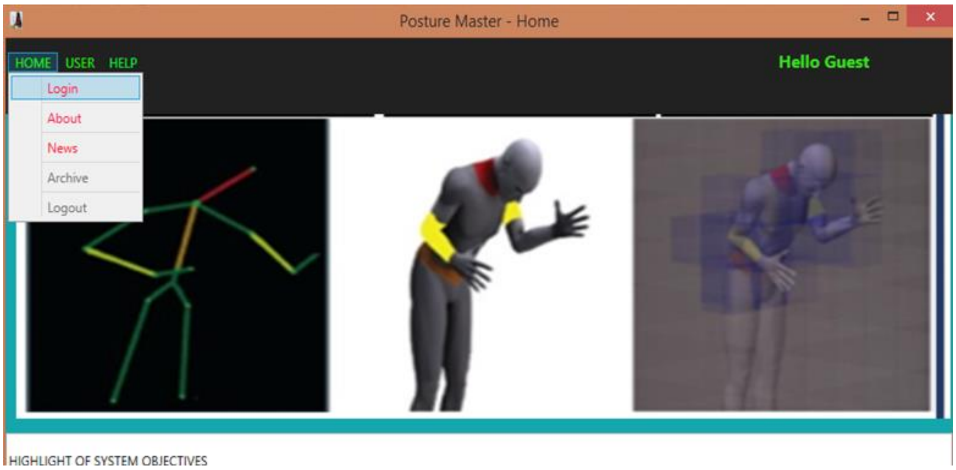


Figure 6 User Interface Flow Diagram (Storyboards) of the proposed Feedback System.

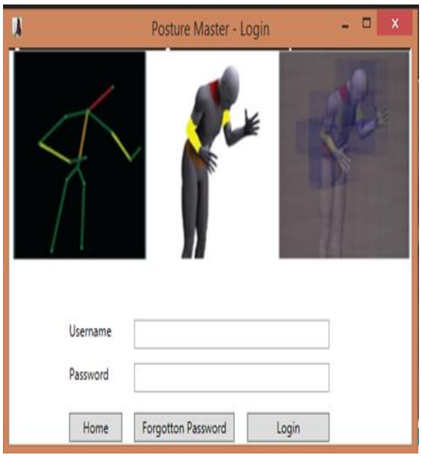
3.2. System Development Results.

The first level screen the user is expected to see after launching the system is the 'Home Screen' which contains the 'Home', 'User' and 'Help' menu buttons as shown in figure 7a. Some of the implemented screens, described on table 3, are represented in figure 7.

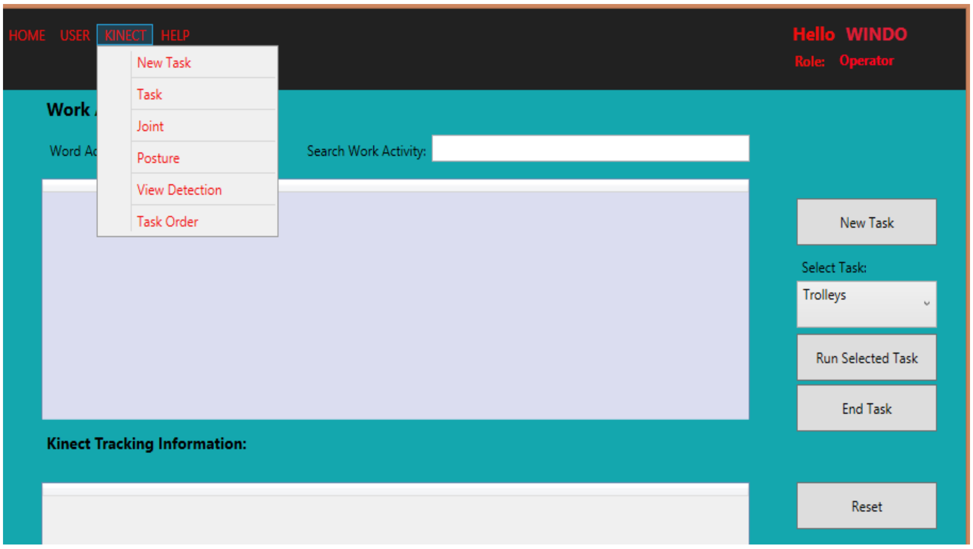
Figure 7 shows some developed screens of the posture assessment feedback system.



a. Home screen displaying the 'Home' Button facilities

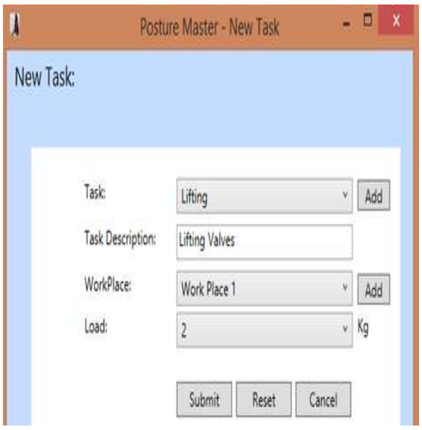


b. Login Screen



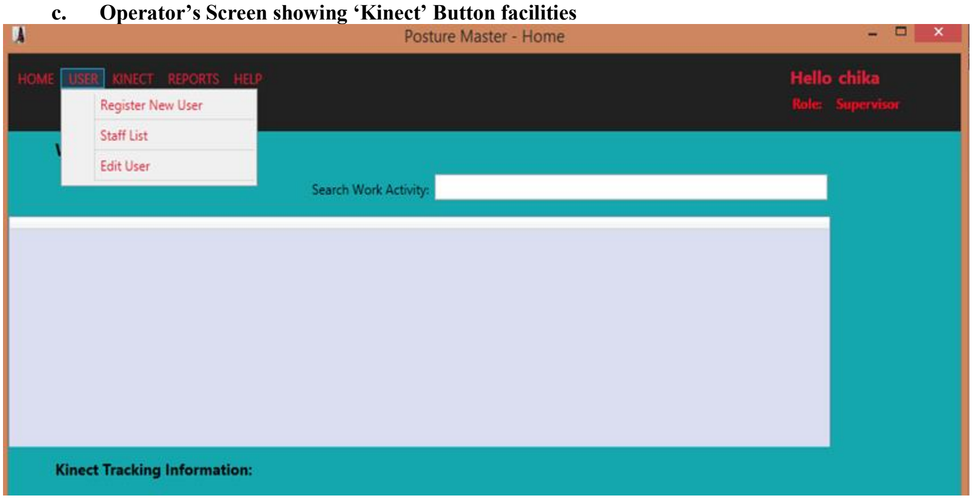
Select Task: Trolleys

c. Operator's Screen showing 'Kinect' Button facilities



Task: Lifting
Task Description: Lifting Valves
WorkPlace: Work Place 1
Load: 2 Kg

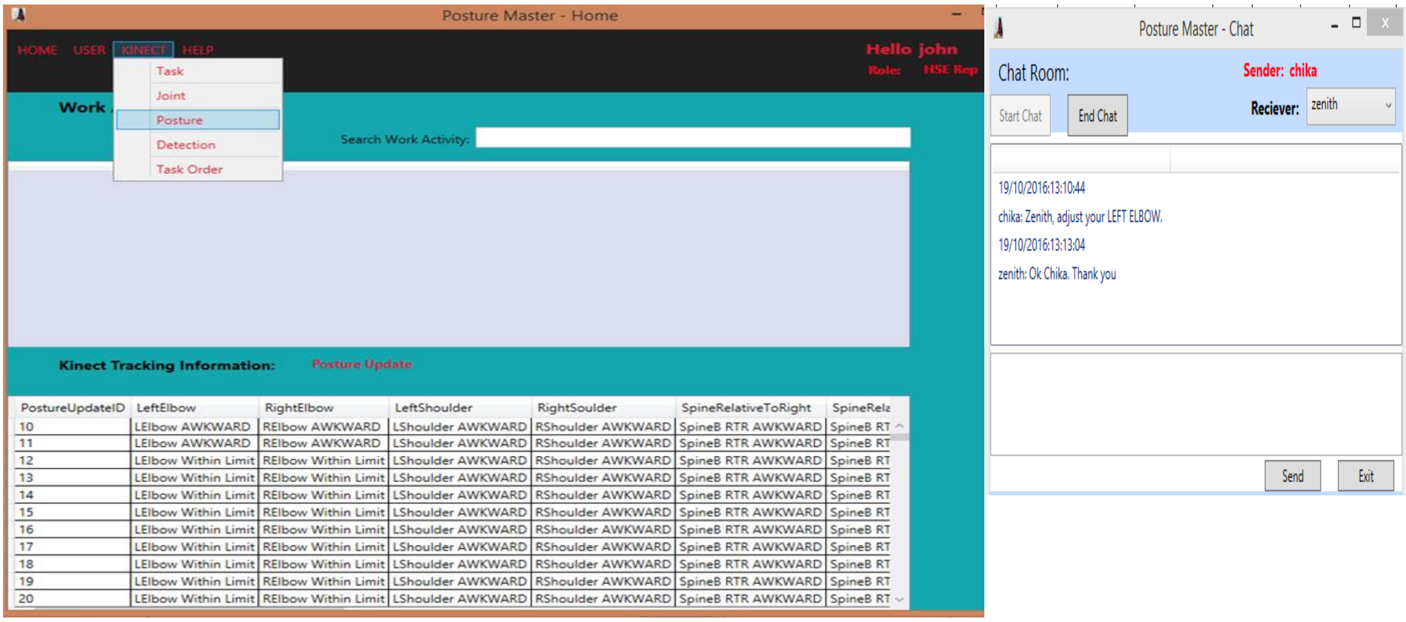
d. Operator's New Task Screen



e. Supervisor's Screen showing the 'User' button screen

Department: Operator

f. Supervisor's Registration Screen



Hello john
Role: HSE Rep

PostureUpdateID	LeftElbow	RightElbow	LeftShoulder	RightSoulder	SpineRelativeToRight	SpineRela
10	LElbow AWKWARD	RElbow AWKWARD	LShoulder AWKWARD	RShoulder AWKWARD	SpineB RTR AWKWARD	SpineB RT
11	LElbow AWKWARD	RElbow AWKWARD	LShoulder AWKWARD	RShoulder AWKWARD	SpineB RTR AWKWARD	SpineB RT
12	LElbow Within Limit	RElbow Within Limit	LShoulder AWKWARD	RShoulder AWKWARD	SpineB RTR AWKWARD	SpineB RT
13	LElbow Within Limit	RElbow Within Limit	LShoulder AWKWARD	RShoulder AWKWARD	SpineB RTR AWKWARD	SpineB RT
14	LElbow Within Limit	RElbow Within Limit	LShoulder AWKWARD	RShoulder AWKWARD	SpineB RTR AWKWARD	SpineB RT
15	LElbow Within Limit	RElbow Within Limit	LShoulder AWKWARD	RShoulder AWKWARD	SpineB RTR AWKWARD	SpineB RT
16	LElbow Within Limit	RElbow Within Limit	LShoulder AWKWARD	RShoulder AWKWARD	SpineB RTR AWKWARD	SpineB RT
17	LElbow Within Limit	RElbow Within Limit	LShoulder AWKWARD	RShoulder AWKWARD	SpineB RTR AWKWARD	SpineB RT
18	LElbow Within Limit	RElbow Within Limit	LShoulder AWKWARD	RShoulder AWKWARD	SpineB RTR AWKWARD	SpineB RT
19	LElbow Within Limit	RElbow Within Limit	LShoulder AWKWARD	RShoulder AWKWARD	SpineB RTR AWKWARD	SpineB RT
20	LElbow Within Limit	RElbow Within Limit	LShoulder AWKWARD	RShoulder AWKWARD	SpineB RTR AWKWARD	SpineB RT

Sender: chika
Reciever: zenith

19/10/2016:13:10:44
chika: Zenith, adjust your LEFT ELBOW.
19/10/2016:13:13:04
zenith: Ok Chika. Thank you

g. HSE Rep.'s Screen showing the 'Kinect Posture' button functionality **h. Chat window**

Figure 7 Screenshots of Developed Screens of the Feedback System

Table 3 Description of screens presented on Figure 7

Figure No.	Description of the Figures
Figure 7a	Home Screen showcasing the 'Home', 'User', and 'Help' buttons as well as the system objectives & home button menus. The 'Home button' contains the 'Login button' which when pressed, displays the login screen to all users, the 'About button' which displays information about the system, the 'News button' for display of current news to the users, the 'Archive button' for accessing database updates and the 'logout button' for logging out of the system.
Figure 7b	The Login screen used by all users to sign into the system using assigned Username or password. Forgotten passwords can also be reset and the user can go back to the home screen using the 'home button'.
Figure 7c	Operator's Screen showing Kinect button menus. Its right-hand side contains the 'Task' buttons and icons where new tasks are registered, tasks are selected and 'run' by the Operator. The Kinect button consists of the 'New task button for registering new task, the 'Task button' for viewing all task updates, 'joint button' for viewing the joint information updates from the database, 'posture button' for viewing the posture updates of any of the operators, the 'view detection button' for viewing the task detection updates and the 'Task order button' which shows the order of task for multiple tasks.
Figure 7d	New task screen showing where the Operator registers new tasks. This usually takes less than 15 seconds to complete and submit.
Figure 7e	Supervisor's home screen showing all the buttons and icons especially the User button menu
Figure 7f	Registration page used by Supervisor to register new user, view staff list and edit new user.
Figure 7g	Kinect task button capability of H&S Rep.'s screen showing how he culls previous posture updates of Operators from database
Figure 7h	Chat window showing how the users can send and receive information through chat.

3.3. System Implementation Results

In this section, the results of testing the designed and developed feedback system are presented.

Tables 4 and 5 show the response of the participants on the assessment form.

Table 4 Researcher's Responses

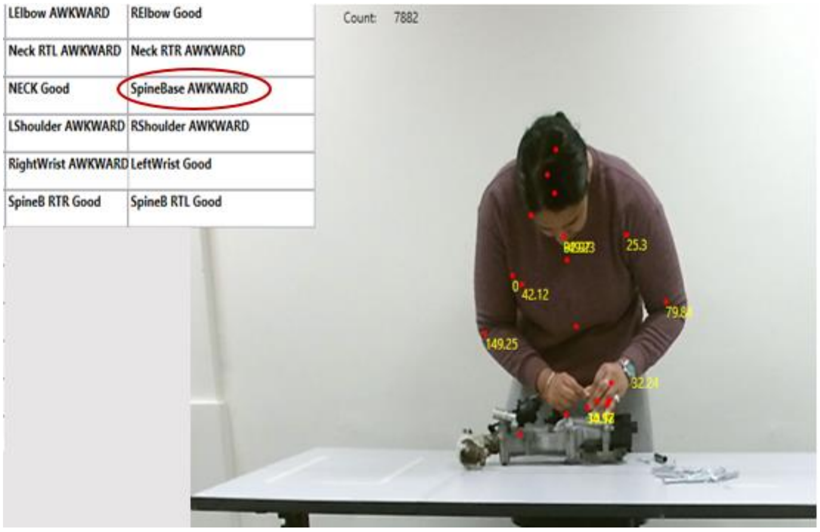
PARTICIPANT Parameter	RESEARCHER 1 (MALE)	RESEARCHER 2 (MALE)	RESEARCHER 3 (MALE)	RESEARCHER 4 (FEMALE)
Age	**30**	**34**	**35**	**25**
Set-up Time including new task registration time (s)	**32**	**30**	**37**	**39**
Is the system convenient to use?	**Yes** ☐ **No** ☑ **Maybe** ☐	**Yes** ☑ **No** ☐ **Maybe** ☐	**Yes** ☑ **No** ☐ **Maybe** ☐	**Yes** ☑ **No** ☐ **Maybe** ☐
Ease of Use	**Very Easy** ☑ **Easy** ☐ **Difficult** ☐	**Very Easy** ☑ **Easy** ☐ **Difficult** ☐	**Very Easy** ☐ **Easy** ☑ **Difficult** ☐	**Very Easy** ☐ **Easy** ☑ **Difficult** ☐
Is the system easy understand?	**Very Easy** ☑ **Easy** ☐ **Difficult** ☐	**Very Easy** ☑ **Easy** ☐ **Difficult** ☐	**Very Easy** ☑ **Easy** ☐ **Difficult** ☐	**Very Easy** ☑ **Easy** ☐ **Difficult** ☐
Was real-time feedback provided concerning awkward postures?	**Yes** ☑ **No** ☐ **Maybe** ☐	**Yes** ☑ **No** ☐ **Maybe** ☐	**Yes** ☑ **No** ☐ **Maybe** ☐	**Yes** ☑ **No** ☐ **Maybe** ☐
Which feedback format did you find easier to understand?	**Voice Alert only** ☐ **Screen display only** ☐ **Both by voice alert and screen display** ☑	**Voice Alert only** ☐ **Screen display only** ☐ **Both by voice alert and screen display** ☑	**Voice Alert only** ☐ **Screen display only** ☐ **Both by voice alert and screen display** ☑	**Voice Alert only** ☐ **Screen display only** ☐ **Both by voice alert and screen display** ☑

Table 5 Operator's Responses

PARTICIPANT Parameter	OPERATOR 1 (FEMALE)	OPERATOR 2 (MALE)	OPERATOR 3 (FEMALE)	OPERATOR 4 (MALE)	OPERATOR 5 (MALE)	OPERATOR 6 (FEMALE)
Age	**28**	**35**	**29**	**30**	**40**	**55**
Set-up Time including new task registration time (s)	**38**	**30**	**31**	**32**	**30**	**37**
Is the system convenient to use?	**Yes** ☑ **No** ☐ **Maybe** ☐	**Yes** ☑ **No** ☐ **Maybe** ☐	**Yes** ☑ **No** ☐ **Maybe** ☐	**Yes** ☐ **No** ☑ **Maybe** ☐	**Yes** ☑ **No** ☐ **Maybe** ☐	**Yes** ☐ **No** ☐ **Maybe** ☑
Ease of Use	**Very Easy** ☑ **Easy** ☐ **Difficult** ☐	**Very Easy** ☑ **Easy** ☐ **Difficult** ☐	**Very Easy** ☑ **Easy** ☐ **Difficult** ☐	**Very Easy** ☐ **Easy** ☑ **Difficult** ☐	**Very Easy** ☑ **Easy** ☐ **Difficult** ☐	**Very Easy** ☐ **Easy** ☐ **Difficult** ☑
Is the feedback from the system easy understand?	**Very Easy** ☑ **Easy** ☐ **Difficult** ☐	**Very Easy** ☑ **Easy** ☐ **Difficult** ☐	**Very Easy** ☑ **Easy** ☐ **Difficult** ☐	**Very Easy** ☐ **Easy** ☑ **Difficult** ☐	**Very Easy** ☑ **Easy** ☐ **Difficult** ☐	**Very Easy** ☐ **Easy** ☑ **Difficult** ☐
Was real-time feedback provided concerning awkward postures?	**Yes** ☑ **No** ☐ **Maybe** ☐	**Yes** ☑ **No** ☐ **Maybe** ☐	**Yes** ☑ **No** ☐ **Maybe** ☐	**Yes** ☑ **No** ☐ **Maybe** ☐	**Yes** ☑ **No** ☐ **Maybe** ☐	**Yes** ☑ **No** ☐ **Maybe** ☐
	Voice Alert only ☐ **Screen display only** ☐ **Both by voice**	**Voice Alert only** ☐ **Screen display only** ☐ **Both by voice alert and screen display**	**Voice Alert only** ☐ **Screen display only** ☐ **Both by voice**	**Voice Alert only** ☐ **Screen display only** ☐ **Both by voice**	**Voice Alert only** ☐ **Screen display only** ☐ **Both by voice**	**Voice Alert only** ☐ **Screen display only** ☐ **Both by voice**

	alert and screen display ☑	☑	**alert and screen display** ☑	**alert and screen display** ☑	**alert and screen display** ☑	**alert and screen display** ☑

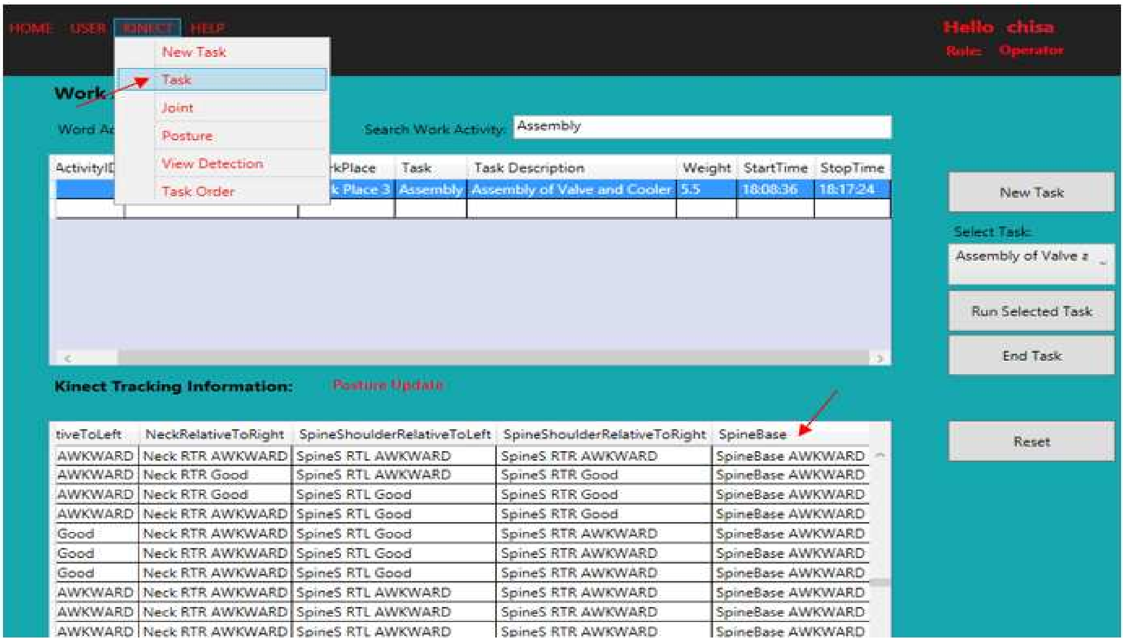
Figures 8 and 9 present the posture assessments of an operator and a researcher carrying out their assigned tasks. This data is retrieved from the system database and plotted in SPSS software to analyse the frequency of the back-posture quality. Frequency is computed as the rate at which the joint is held either awkward or good at a time.



LElbow AWKWARD	RElbow Good
Neck RTL AWKWARD	Neck RTR AWKWARD
NECK Good	SpineBase AWKWARD
LShoulder AWKWARD	RShoulder AWKWARD
RightWrist AWKWARD	LeftWrist Good
SpineB RTR Good	SpineB RTL Good

Count: 7882

a. Real-Time tracking/feedback to an Operator showing awkward back posture assessment during assembly task



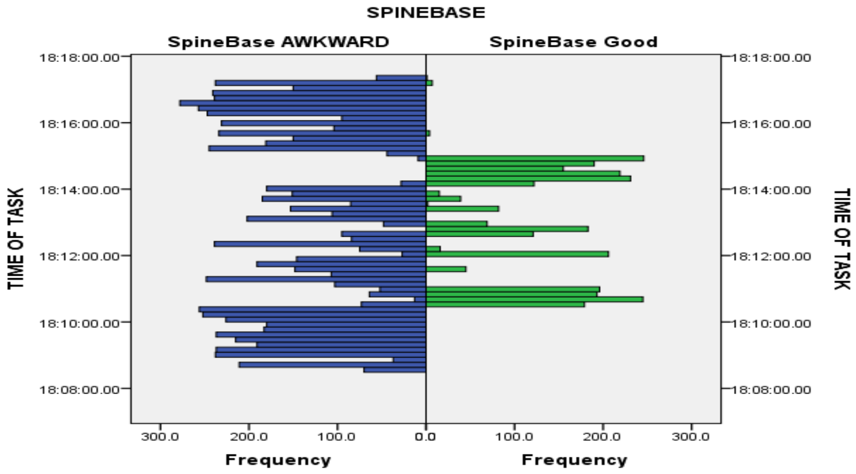
Search Work Activity: Assembly

ActivityID		kPlace	Task	Task Description	Weight	StartTime	StopTime
		k Place 3	Assembly	Assembly of Valve and Cooler	5.5	18:08:36	18:17:24

Select Task: Assembly of Valve a

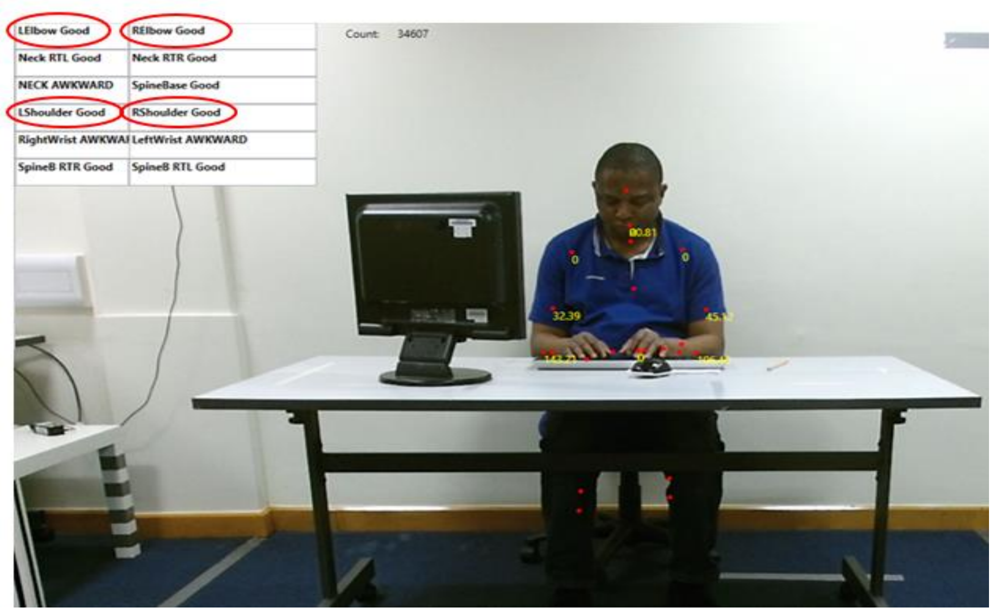
tiveToLeft	NeckRelativeToRight	SpineShoulderRelativeToLeft	SpineShoulderRelativeToRight	SpineBase
AWKWARD	Neck RTR AWKWARD	SpineS RTL AWKWARD	SpineS RTR AWKWARD	SpineBase AWKWARD
AWKWARD	Neck RTR Good	SpineS RTL AWKWARD	SpineS RTR Good	SpineBase AWKWARD
AWKWARD	Neck RTR Good	SpineS RTL Good	SpineS RTR Good	SpineBase AWKWARD
AWKWARD	Neck RTR AWKWARD	SpineS RTL Good	SpineS RTR Good	SpineBase AWKWARD
Good	Neck RTR AWKWARD	SpineS RTL Good	SpineS RTR AWKWARD	SpineBase AWKWARD
Good	Neck RTR AWKWARD	SpineS RTL Good	SpineS RTR AWKWARD	SpineBase AWKWARD
Good	Neck RTR AWKWARD	SpineS RTL Good	SpineS RTR AWKWARD	SpineBase AWKWARD
AWKWARD	Neck RTR AWKWARD	SpineS RTL AWKWARD	SpineS RTR AWKWARD	SpineBase AWKWARD
AWKWARD	Neck RTR AWKWARD	SpineS RTL AWKWARD	SpineS RTR AWKWARD	SpineBase AWKWARD
AWKWARD	Neck RTR AWKWARD	SpineS RTL AWKWARD	SpineS RTR AWKWARD	SpineBase AWKWARD

b. Back posture updates of the Operator from the database



c. Back Posture Quality vs frequency for Assembly Task

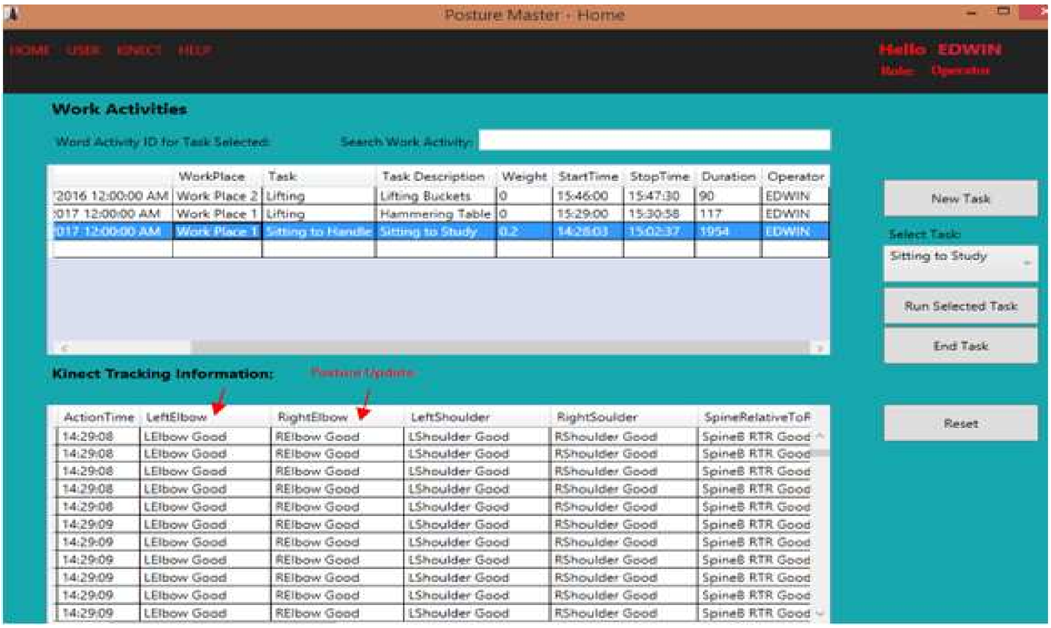
Figure 8 Feedback System Implementation on Assembly Task Operator



LElbow Good	RElbow Good
Neck RTL Good	Neck RTR Good
NECK AWKWARD	SpineBase Good
LShoulder Good	RShoulder Good
RightWrist AWKWAI	LeftWrist AWKWARD
SpineB RTR Good	SpineB RTL Good

Count: 34607

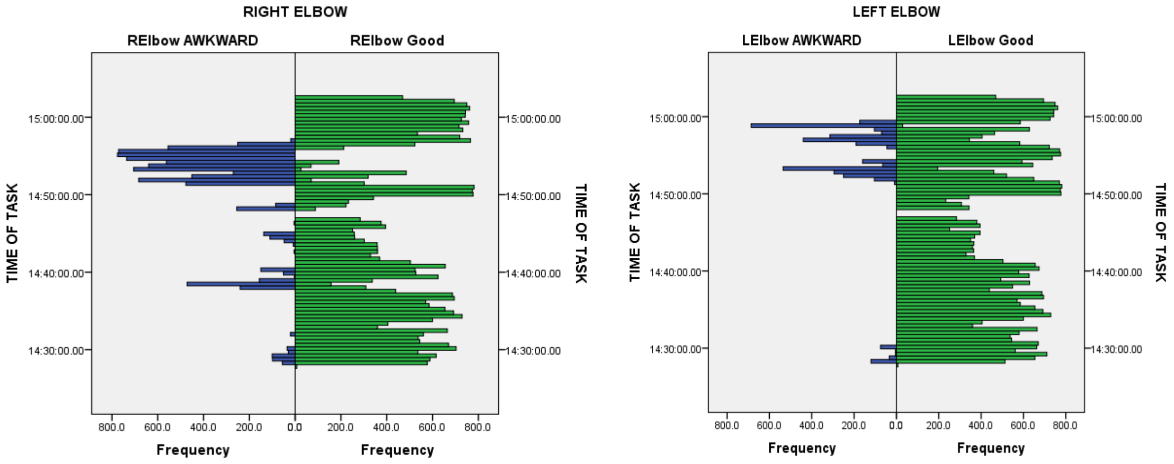
a. Real-Time tracking/feedback to Researcher showing good arm posture assessment



	WorkPlace	Task	Task Description	Weight	StartTime	StopTime	Duration	Operator
'2016 12:00:00 AM	Work Place 2	Lifting	Lifting Buckets	0	15:46:00	15:47:30	90	EDWIN
017 12:00:00 AM	Work Place 1	Lifting	Hammering Table	0	15:29:00	15:30:58	117	EDWIN
017 12:00:00 AM	Work Place 1	Sitting to Handle	Sitting to Study	0.2	14:28:03	15:02:37	1954	EDWIN

ActionTime	LeftElbow	RightElbow	LeftShoulder	RightSoulder	SpineRelativeToF
14:29:08	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:08	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:08	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:08	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:08	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:09	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:09	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:09	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:09	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:09	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good
14:29:09	LElbow Good	RElbow Good	LShoulder Good	RShoulder Good	SpineB RTR Good

b. Researcher's posture update showing the elbow postures



c. Right Elbow posture quality vs frequency for Researcher 3 **d. Left elbow posture quality vs frequency for Researcher 3**

Figure 9 Feedback System Implementation on Seated Researcher

4. Discussion of Results

This paper describes the design and implementation of a human-machine interface feedback system that displays the real-time ergonomic posture assessment updates to a worker and provide a manufacturing shop floor with a simple, low-cost, easy-to-implement, feedback mechanism.

The system design was initiated by the establishment of some basic questions which helped to establish the external users of the system, information flow from one user to another and the format the information is delivered to the end user. The UK HSE's recommended requirements on personnel to involve in risk assessment was used to identify the various users in the system. The system's models were developed using the UML use diagrams as well as the user interface flow diagram.

Testing of the developed system's functionalities on ten volunteers provides evidence that the system delivers useful, real-time postural feedback. For example, all the participants were found to receive their posture assessment feedback both by display on the screen and by voice alert which helped prompt them to adjust awkward postures. As an additional mechanism to prompt workers to adjust awkward postures, the chat screen could be used by supervisors and/or H&S reps.

Figure 8a shows the real-time feedback of the back-posture assessment feedback of one of the operators. As shown, the back posture was assessed as represented by 'SpineBase Awkward' and displayed to the operator on the Kinect window, at the time of capture.

Figure 8b shows how the operator may view his posture update and task information using the 'Kinect menu button'. The task display window depicts information on all previously captured tasks carried out by the operator. Detailed information for those tasks can be displayed in the posture update window by pressing either the Kinect 'task' button or the Kinect 'posture' button. Similarly, pressing the Kinect joint button displays the angular joint data for each of the joints (not shown). Availability of this information via the stored database may help inform future ergonomic interventions and actions.

Figure 8c depicts the analysis of the back-posture quality data in accordance with its frequency of occurrence. As illustrated, the 'SpineBase Awkward' occurred with much higher frequency than the 'SpineBase Good' during assembly tasks. Further analysis showed the operator maintained risky back postures for 78% of the assembly task duration. This result in an actual work environment would indicate the need for immediate ergonomic interventions and possible workplace re-design and training.

Figure 9 depicts the real-time tracking/feedback to researcher showing good arm posture assessment. Note that both the right and left elbows were displayed as 'Good' in 9a and held for a long time as 'Good' in Figure 9b when viewed offline by the researcher. Figure 9c shows that the right elbow been held as 'Good' for longer periods of up to 80% of the task duration while in figure 9d, the left elbow was held as 'Good' for longer periods of up to 91% of the task duration. This indicates that the researcher does not require any immediate ergonomic intervention.

The analysis of these experimental results illustrates the potential utility of our newly developed real-time ergonomic postural assessment feedback system to document occurrence and frequency of risky postures during task performance and thereby inform ergonomic interventions. Such information will enable both H&S representatives and workers to recognize and correct awkward postures in a timely manner.

Assessments completed by the participants revealed that eight of the ten rated the system as convenient to use. Six participants found the system very easy to use, two found it easy while one rated it as a difficult system. Eight participants found the feedback from the system very easy to understand while two rated it as easy. All the participants agreed that the system provided real-time feedback by both voice alert and screen display. When asked why they thought that the feedback was easy to understand, the participants stated that the voice alert that enabled the system to communicate verbally to them concerning their posture, was very simple and very easy to understand. The operator who found the system difficult to use said that she was not used to being monitored while working and did not like to be distracted. Operator 4 and researcher 1, who rated the system as not convenient, said the prompting by the system made them lose concentration. The average setup time required, including starting the system and registering a new task was 33.6 seconds.

Limitations of this system include its inability to assess other ergonomic risk factors and the occlusion issues associated with the Microsoft Kinect. To use the system, the worker must be facing the sensor.
Future work will focus on assessing the reliability of this newly developed system.

5. Conclusion

In this paper, we designed and implemented a human-machine interface feedback system whose function is to capture, analyse, classify and display the postures of workers in real time. This is made possible with the aid of a Microsoft Kinect sensor which is cost-effective, readily available and convenient to use. The developed system enables ergonomic posture analysis of the operator with real-time display in an easy-to-understand and simple interface thereby prompting the worker to adjust any possible awkward posture that may occur during any manual handling activity in the workplace.

During the design, the Health and Safety requirements were studied to establish the personnel requirements in risk assessment and three basic questions were answered to establish the conceptual models of the system as well as the system requirements. These models were developed using the UML use case diagrams, the UML activity diagrams, and the Interface prototype was modelled using the User Interface Flow Diagram (Storyboards).

The designed system provides feedback visualisation Interface with screens designed to support the visualisation of posture outputs. The developed system showed real-time posture analysis and feedback to workers when tested on different participants during manual handling tasks. The generalizability of the system to workplaces involving non-manual handling tasks was tested on desk-based seated researchers with results showing the potential for use among seated industrial workers.

Workplaces will most likely benefit from the developed system because it can inform workers about their posture while working. This may help reduce the rate of occurrence of awkward postures and the risk of WMSDs among workers in the workplace.

Acknowledgment

The authors would like to acknowledge the Petroleum Technology Development Fund, PTDF Nigeria for sponsoring the PhD of the lead author from which this paper is derived.

Disclosure statement

No potential conflict of interest was reported by the authors.

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