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Automatic detection system for real-time assessment of human work postures during hammering operation

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Abstract
A fast detection system that detects ergonomic criticalities for immediate intervention purposes is highly desirable for human work posture assessment. This paper presents the validation of a developed real-time ergonomic assessment knowledge-based system for use in the real-time evaluation of work postures on the shop floor and the provision of feedback to workers. The system is developed using a cost-effective, automatic-detection 3D motion sensor. The developed intelligent system utilizes the knowledge from health and safety guidelines, a set of rules and an inference engine, to automatically capture and assess workers' postures and provide real-time feedback to the worker through an easy-to-understand user interface. Results of testing the developed system showed that the system can detect manual handling tasks such as hammering activity and give real-time feedback to the operator on the task detection, as confirmed by the 'True' value displayed for hammering, with detection confidences of approximately 0.4, 0.5 and 0.7. Results also showed that the system can assess work postures and provide real-time feedback to workers simultaneously with task detection. The system is beneficial to workers on the manufacturing shop floor as it can correct their work methods and alert them to adjust awkward postures that can lead to Work-Related Musculoskeletal Disorders.

Keywords: Microsoft Kinect; Work-Related Musculoskeletal Disorders; Awkward postures; Manual Handling; Expert Systems.

1. Introduction

Hammering activity is a leading cause of shoulder pain that can lead to work-related Musculoskeletal Disorders (WMSDs) (Pranav et al., 2023). WMSDs result in work-related illnesses and lead to lost working days (HSE, 2016). From 2009 – 2016, manual handling was rated as the highest cause of WMSDs among the other risk factors, accounting for up to 40% of the work-related upper limb disorders and 53% of the reported work-related low back disorders. This is followed by awkward work postures which accounted for up to 25% of the reported low back disorders and 14% of the reported work-related upper limb disorders in Great Britain (HSE, 2016). Moreover, awkward work postures have been identified as an ergonomic risk factor resulting from manual handling (Valero et. al., 2016). Designing for ergonomics during the initial design of workplaces can help to reduce awkward postures (Maurya et al., 2019). However, to mitigate the risk posed by the adoption of awkward postures by operators during manual handling operations, a real-time automatic Health & Safety posture assessment feedback system assesses workers' postures and prompts them to adjust any awkward posture that has been held over a period, is required.

Adequate risk assessment has been recommended by Health & Safety professionals to identify and assess awkward postures. However, such an assessment is normally carried out by observing several operations and carrying out an analysis afterwards. Although some improvements can be identified for the operations, this cannot alert operators and prevent them from adopting awkward postures in time. A health and Safety-compliant system that not only observe the worker's tasks but also automatically captures the worker's joint data, process and convert this data into posture data, assess the posture and provide real-time feedback through an easy-to-understand user interface, is of great importance in a flexible system in which immediate response to changes are always required. The knowledge from the health and safety recommendations on manual handling can be utilised to form the knowledge base of the system.

This study presents the validation of a system developed by (Mgbemena, Oyekan, et al., 2018) for ergonomic evaluation of work postures and real-time feedback to operators using a hammering task.

A Knowledge-Based System (KBS), is an intelligent system that utilises a knowledge base to solve problems (Aziz et al., 2017). The requirements of a KBS which include the hardware, the knowledge base and the user interface requirements are extensively described in Pavlovic-Veselinovic, et. al. (2016). Human knowledge of ergonomic risk assessment can be written in the form of rules and utilized in the knowledge base of an intelligent system to solve complex ergonomic problems (Aziz et al., 2017). KBS has been developed to solve ergonomic problems in various industries like healthcare where it is used to provide correct working conditions from a knowledge base built using ergonomic methods like OWAS (Bartnicka, 2015). In product design in which a knowledge base is built using data from expert knowledge on recommended design goals, and coded in the form of production rules into a KBS called OSCAR, to enable more improved ergonomic product design. In the automotive industry in which a knowledge base is built with occupational ergonomics data collected through interviews and questionnaires to provide decision-makers with a framework that predicts ergonomic risk factors during product and process design in the automotive manufacturing shop floor (Aziz et al., 2017). These aforementioned are only prototypes and frameworks and are therefore incomplete systems.

A more flexible KBS, known as SONEX, which allows the user to define their questions to the system, has been developed to identify risks that can lead to WMSDs among workers and recommend ways to avoid them. The system's knowledge base is built with data extracted both from the literature review and from expert's experience of ergonomic issues (Pavlovic-Veselinovic et al., 2016). The system takes about 10 minutes to evaluate the risk of each worker and provide feedback and recommendation to the user (Pavlovic-Veselinovic et al., 2016). Again, the system depends on the data manually provided by the user as answers to its questions, to make its assessment.

These systems are expert systems that utilize some rules to build the knowledge base for ergonomic recommendations towards improved workplace assessment and consist of a knowledge base, an inference engine and a user interface. However, the limitations of the KBS tools include a lack of automatic posture assessment and a lack of effective real-time feedback to alert workers in time. A survey of the Literature reveals a gap in the utilization of rules from the Health & Safety database, to build a knowledge-based system which is capable of assessing human work postures and providing real-time feedback that alerts the workers to adjust awkward postures which if held for prolonged periods This paper presents a Kinect-based expert system that extracts data from a knowledge built with rules collected from Health & Safety database (Mgbemena et al., 2017; Mgbemena et al., 2017; Mgbemena et al., 2018, 2016). This ensures more accurate ergonomic work posture assessment by acceptable Health & Safety guidelines. The system is capable of assessing human work postures and providing real-time feedback that alerts the workers to adjust awkward postures which if held for prolonged periods, can result in injuries and losses. The system is a knowledge-based system with knowledge extracted from Health & Safety database, an inference engine which reasons the knowledge and draws conclusions, an interface through which the user interacts with the system, and hardware based on the Microsoft Kinect V2 Sensor.

2.0 Material and methods

The developed system is an automatic posture assessment system designed to automatically detect a worker's awkward postures as well as provide immediate intervention to help the worker adjust any awkward posture that can lead to WMSDs. These functionalities will be tested in this study using a case study, to determine the system's effectiveness. The task chosen for this study is manual handling involving the hammering of IKEA table components. In the study, the ability of the system to provide real-time feedback to operators on the shop floor is tested as they hammer the IKEA table components during assembly tasks. The task was carried out in the laboratory under controlled conditions. The case to be investigated are selected, as tabulated in Table 1.

Table 1 Case Study Description

CASE STUDY	FEATURES	CHALLENGES
Hammering of IKEA table components. The capability of the developed tool to detect manual handling tasks and simultaneously assess	Different experiments are carried out to determine the following: i. If the system can detect manual handling tasks and give real-time feedback to the operator on the task detection.	Setup delays may arise. Again, participants may be reluctant to carry out a hammering task.

the worker's posture and provide real-time feedback to the worker will be tested in this case study.	ii. If the system can assess work postures and provide real-time feedback to workers simultaneously with task detection.

2.1 Experimental Setup

The hammering task was chosen because the task has been identified as a high-risk task that usually leads to WMSDs if not correctly assessed (Cheng et al., 2013; Lee & Han, 2013; Valero et al., 2016). Again, incorrect use, as well as repetitive use of the hammer, can lead to muscle and tendon injuries on the hand (Buchanan et al., 2016).

The experimental setup for this study is represented in Figure 1.

a) Experimental setup **b) Positive x, y, z coordinates**

Figure 1 Experimental Setup

In Figure 1a, the arrow represented by 1.2m is the height of the Kinect from the floor while the 3m arrow represents the depth z distance to the operators as depicted by Figure 1b. Figure 1b represents the Kinect positive coordinates facing the direction of the Kinect (MSDN, 2016), in which z is equal to 3m, with the x and y coordinates representing the value and location of a pixel in the colour and depth frame.

A large table is used as the workstation. As the IKEA table components are assembled, the part is hammered using a hammer. Kinect, placed at a 3m distance from the operators and mounted on a tripod stand of height 1.2m, is used to capture the skeletal data of each of the operators, convert it to posture data and assess the postures and display the results in real-time to the operators.

Participants

A total of fifteen operators, seven males and eight females, participated in this task. The operators are all young and healthy volunteers who were briefly trained on the task before experimenting. Inclusion criteria for selecting the participants include male and female participants that are aged between 23 to 41 years, who can perform tasks while standing, right-handed and with heights ranging from 1.5m to 1.92m. Exclusion criteria include participants with sensory or visual impairment, history of low-back or shoulder pain, and musculoskeletal disorders. These inclusion/exclusion criteria were chosen because the task involve hammering activity and only healthy participants are required to participate. The participants were given a consent form to sign before the experiment. The forms were meant to inform the participants on what to expect during the experiments, the aim and objectives of the study, as well as intimate them on their rights to either withdraw or continue their participation in the study.

The study was approved by the Cranfield University Research Ethics System (CURES) and all the participants were briefly trained on the tasks they were to perform.

Figure 2 shows the age distribution of the participants.

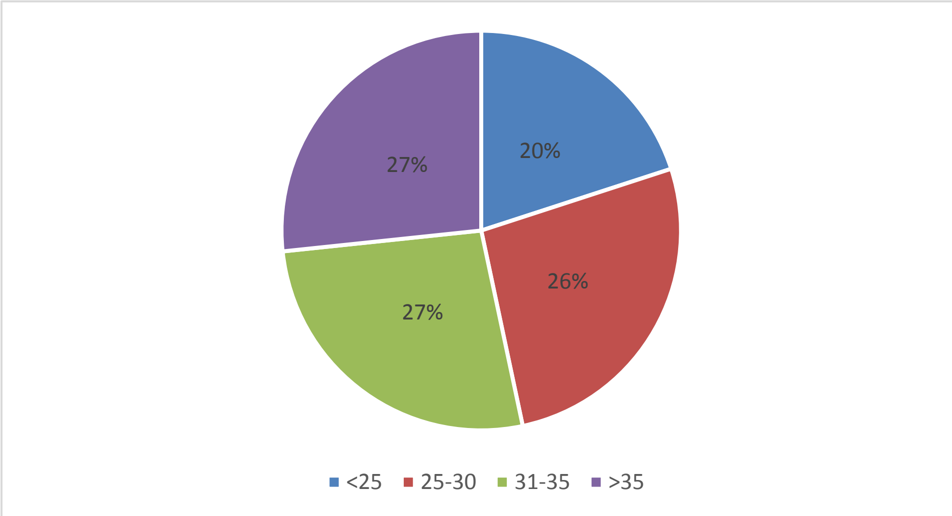


Figure 2 The Age Distribution of Participants.

The neutral positions of the participants were first tracked before starting the experiments. Figure 3 shows Participant 11 tracked at his neutral position before the commencement of the experiment.

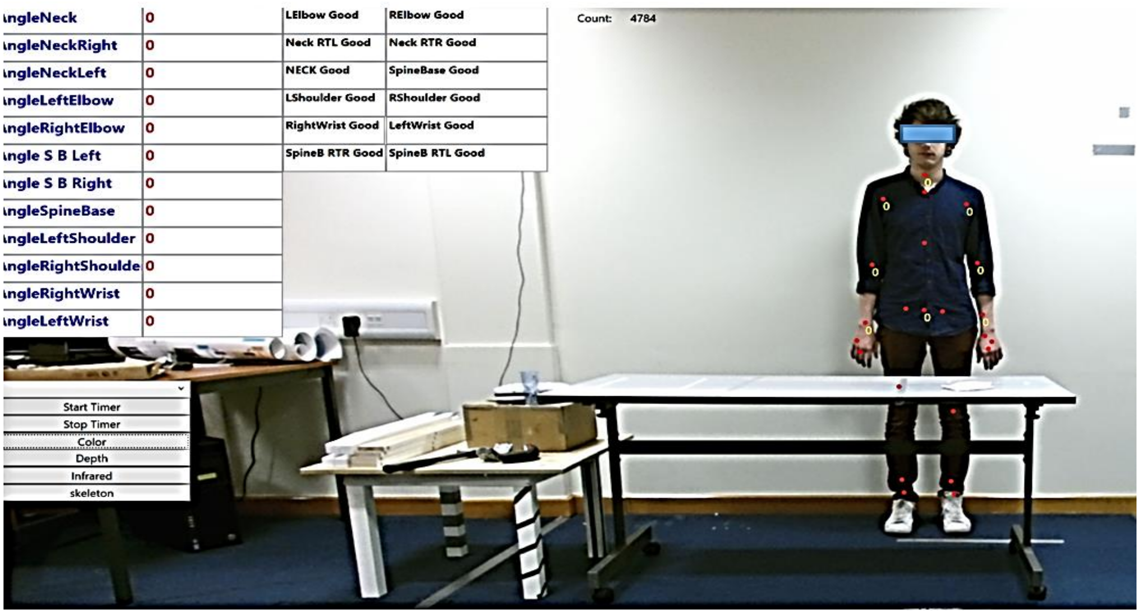


Figure 3A Participant tracked at Neutral Positions

2.2 Setup Precautions

During the initial setup, the following precautions were taken.

- The sensor was placed and maintained within the recommended position in the field of view for the duration of the case study to avoid depth measurement errors.
- The operators ensured they avoided errors due to self-occlusion and obstacles.

2.3 General Task Rules

There are some rules which the operators were acquainted with while performing the task. These rules include:

- The task must be performed in such a way as to depict what is obtainable among operators performing the same task on the shop floor.

- The operators are required to face the sensor while performing the tasks. This helps to reduce measurement errors and occlusions.

2.4 Task Description

The task requires an operator to hammer the IKEA table components while the system captures his body, and his upper arm posture and possibly detects the task. The detection is necessary to enable the operator to ascertain if the tracking of his joint data is progressing satisfactorily. It is also necessary to know if the task is to be completed correctly. Hence, the operator checks if the task is detected by the system even while adjusting his posture.

The steps involved in the study include:

Step 1: Assessment of the operator's upper arm postures during a hammering activity.

Step 2: The operator checks to see if the system detects the task

Step 3: Feedback from the system on the task detection status

To check for task detection, the operator while selecting the colour button in the Knowledge-Based System, is given an option through a dialogue box, whether to run detection or not. Selecting the run detection button opens the detection window on which the detection results are displayed.

3. Results and Discussion

The result of the real-time task detection with feedback and the corresponding posture assessment of the participants are presented in this section.

3.1 Feature i: A Test to ascertain if the system can detect manual handling tasks and give real-time feedback to the operator on the task detection.

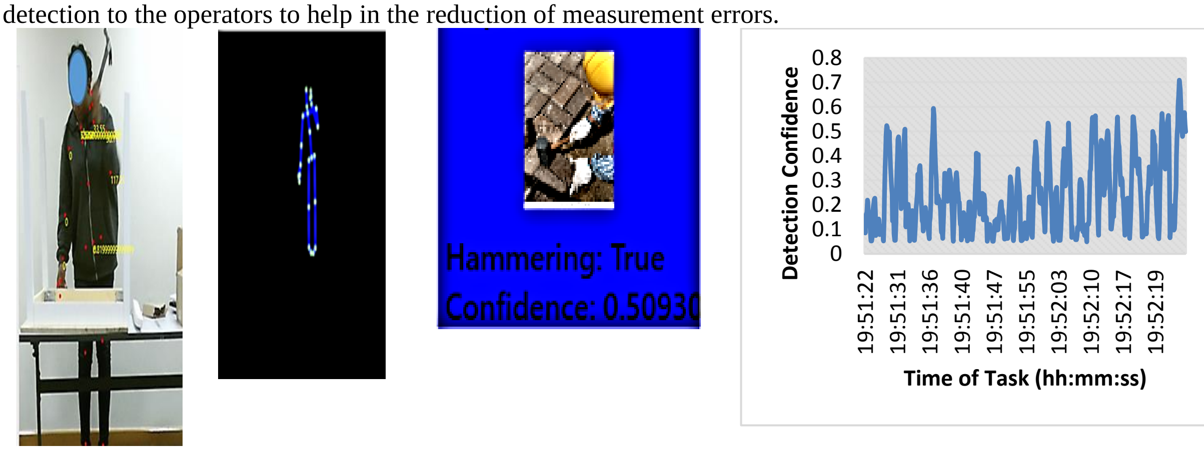
There was successful task detection when the operators checked for task detection during the hammering activity, as presented in Figure 4.

In the figure, the participant's tasks are displayed in real-time. The hammering task was detected as confirmed by the 'True' value displayed for hammering, with a detection confidence of 0.5 at the time of capture (figure 4a). Figure 4b depicts the detection confidence rate of the participant during the entire task duration.

Similarly, the true value was displayed for hammering when the remaining fourteen participants were detected, with detection confidences of approximately 0.4, 0.5 and 0.7, respectively at the time of capture. This indicates that the system detects the tasks performed by the participants and successfully displays the detected task result to them in real time.

The participant's response on whether real-time feedback was provided to them concerning their tasks, which agrees with the results of Figure 4, is presented in Table 2.

We can, therefore, infer that the developed Knowledge-Based System can also provide real-time feedback on task detection to the operators to help in the reduction of measurement errors.



a. Real-time task detection display to Participant

b. Detection Confidence Rate for Participant

Figure 4Real-Time Task Detection by a Participant

3.2 Feature ii: A test to ascertain if the system can assess work postures and provide real-time feedback to workers simultaneously with task detection.

The upper arm posture of the participants was assessed as they performed hammering operations on the IKEA table. Results obtained revealed that real-time feedback of the posture assessment was provided simultaneously with the real-time task detection results, as presented in Figure 5. Because all the participants are right-handed, only the right shoulder assessment result is of interest in this study.

Figure 5 **Task detection and posture assessment feedback to Participant 2**

Participants' responses on whether there was real-time feedback of the upper arm posture assessment and task detection results are also presented in Table 2. Therefore, results reveal that the system can assess work postures and provide real-time feedback to workers simultaneously with task detection.

Table 2 Operator's response to real-time feedback of task detection and posture assessment results

Participants	Hammering Task Detected?	Real-Time Feedback Provided for Task Detection?	Shoulder Posture Assessed?	Simultaneous Real-Time Feedback Provided for Posture Assessment and Task Detection?
1	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	Yes
3	Yes	Yes	Yes	Yes
4	Yes	Yes	Yes	Yes
5	Yes	Yes	Yes	Yes
6	Yes	Yes	Yes	Yes
7	Yes	Yes	Yes	Yes
8	Yes	Yes	Yes	Yes
9	Yes	Yes	Yes	Yes
10	Yes	Yes	Yes	Yes
11	Yes	Yes	Yes	Yes
12	Yes	Yes	Yes	Yes
13	Yes	Yes	Yes	Yes
14	Yes	Yes	Yes	Yes
15	Yes	Yes	Yes	Yes

Hence, it can be deduced from Figures 4, 5 and Table 2, that the developed system is capable of detecting manual handling tasks such as a Hammering operation, assessing human work postures, and providing simultaneous feedback of posture assessment and task detection to operators – all in real-time.

4.0. Conclusion

This paper presents the validation of the developed real-time knowledge-based ergonomic evaluation and feedback system during a hammering task activity. The study was conducted to ascertain if the developed expert system can provide real-time feedback to operators concerning their ergonomic behaviour in terms of postural loading. Results of the study have proved that the developed system can provide real-time posture assessment feedback and effectively reduce the awkward work postures of operators by prompting them to adjust any awkward postures that can be detrimental to their health. The system can successfully detect a hammering task activity, assess the worker's posture and provide real-time feedback on both the task detection and posture assessment to the operator. This supports the findings in literature by (Mgbemena et al., 2016; Posner et al., 2023), the Kinect can detect gestures and tasks in real-time.

This study is beneficial to operators on the shop floor as it can help them adjust awkward postures that can be detrimental to their health. It can also help to correct the worker's methods.

The limitations of the study is the occlusions which generally affect that tracking of data by Kinect. Any occlusions within the field of view of the Kinect makes it impossible for the system to detect and assess data. Hence, for accurate detection, the operator must be working within the field of view of the Kinect, facing the Sensor.

5.0 Recommendation

Further work is recommended in the development of the system to detect manual tasks involving the lower limbs of the human body.

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