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Vision-Based Real-Time Ergonomic Detection for SMEs

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Abstract

As highlighted in this paper, the project development was a real-time ergonomic risk detection system with an eye on small and medium-sized enterprises (SMEs). The ultimate purpose of the study is to develop an inexpensive, visual sensor-based surveillance system that could improve the working environment safety through identification of unfavorable postures that can cause working-related musculoskeletal disorder (WMSD). The system integrates webcam data with Python-anchored pose-estimation software to locate body points and compute body joint angles. Deviations in posture get measured and in case the angle of extension surpasses 20 o angle with the neutral, warnings can be seen and heard in real time to trigger corrections. Attention to ergonomic conflict score is further done through Rapid upper limb assessment (RULA) basis of scoring and results saved in CSV format which thereafter analyzed. The prototype system was logically developed, set up and tested under an SME-like construct. The experimental data showed that the system can recognize unsafe postures correctly and the feedback was timely as well as effective at encouraging employees to correct themselves in behavioral patterns. The data recorded also indicated the trend of ergonomic risk during working time periods and this proved the effectiveness of the system. The work is planned to be enhanced in the future to fine-tune operation under lighting conditions changes, be capable of detection multiple workers simultaneously, and test the algorithm on more diverse SME configurations. This paper shows the possibility of inexpensive, real-time, vision-based solutions in enhancing ergonomic operations and boosting the safety and security of employees in SMEs.

1. Introduction

Work-related musculoskeletal disorders (WRMSDs) are a widespread issue that is burdensome on the working population of different working sectors (Wang, 2021). These are the injuries that are caused by long exposure to unfavorable ergonomic situations, such as unnatural postures, movement, and force exertion. Besides making employees feel uncomfortable and suffer health complications such hazards result in more absenteeism and low productivity. It is necessary to take care of the ergonomics so that workers could be healthier and industrial activities could be sustainable. Nevertheless, though the significance of ergonomic safety is well acknowledged, most working environments, particularly small and medium-sized enterprises (SMEs), find it difficult to incorporate effective tools that can assess the level of safety in their working environments. Thus, in the absence of proper evaluation and measures, WRMSDs hazards will have the potential to cause harm to the health of workers and to organizational productivity (Ahmed, 2019).

Over the past few years, a significant breakthrough has been achieved in the use of tech advancements like computer vision and machine learning toward ergonomic risk assessment (M. Kunz, 2022). Through scientific researches, it has been made clear that these technologies may be used to aid automatic and constant monitoring of the postures of workers using cameras. Computer vision algorithms, which interpret visual data by identifying key anatomical landmarks like joints and limb positions have shown promise in detecting maladaptive postures that may lead to musculoskeletal disorders (Lor, 2023). Large datasets trained to Machine learning models can be used to classify postures to either safe or risky so that it can inform real-time decisions and cut on human judgment of the same. Such systems can revolutionize the method of assessing ergonomics by resulting in increased accuracy, efficiency, and scalability (M. Kunz, 2022).

However, even with the highly advanced studies, there are still huge lapses in implementing the innovations in actual industrial conditions especially in the case of SMEs (Wang, 2021). Most systems in the normal environment are tested under controlled conditions or on tasks, which do not reflect the realities of the production lines that are normally complex (Kruger, 2015). Also, most of the systems use costly computing equipment, large computing requirements or technical skills that are not practical to resource-limited SMEs (Wang, 2021). These constraints deter wide usage and majorly express the necessity of affordable, flexible, and usable final products that would easily fit in everyday operatives (Ahmed, 2019). Closing of this research gap may empower SMEs to proactively deal with ergonomic risks without significant costs or operation interruptions

This study was devoted to the creation of a practical, cost effective and scalable vision based ergonomic assessment system that is specifically suitable to a SME manufacturing setting. The major research questions in the study are as follows: What are some of the ways of integrating computer vision and machine learning in order to real-time monitor the postures of workers? Is it possible to locate the ergonomic hazards on heavy production lines through the system? They proposed the following hypothesis: A resource-constrained webcam vision system would have been able to detect postures that led to musculoskeletal risks reliably and deliver instantaneous feedback to workers and minimize the chances of musculoskeletal injuries. The research involved designing the system architecture, implementing image processing algorithms such as Mediapipe to detect anatomical points, and integrating machine learning models to evaluate ergonomic risks continuously.

The approach was the systematic design of a vision-based ergonomic monitoring tool, with hardware-software integration, setup, and experimental verification in an SME-like laboratory setting. To estimate the pose the system used Webcam and pose estimation in Python to estimate the postures in real time and to estimate the joint angles. Any deviation beyond 20 o above the neutral posture would produce a visual and audible warning. Logging data into the CSV file allowed further processing of the ergonomic trends, which helped with assessing the long-term risks and setting up the better positioning of the workers. The quality of the system was evaluated based on how accurate the posture could be identified, the reaction speed of the feedback mechanism, and its ability to give practical ergonomic advice.

2. Methodology

2.1 System Design and Setup

Selected and integrated hardware and software were the initial steps to the development of the system. It was based on placing strategically located high-resolution webcams that could take images of the movement of the worker on different positions. These cameras were connected to a computer system running Python, along with libraries like OpenCV and Mediapipe, for processing and analyzing the video data. The cameras were installed in such a way that they could cover every workstation in the production process and this enabled the system to keep a constant check on the posture of the workers.

The software installation was based on real-time detection of a posture relying on computer vision algorithms to measure the deviation angles of the major anatomical markers like shoulders, hips, and neck. The information provided an opportunity to prompt the system against any postural deviation that exceeded acceptable ergonomic limits. The system itself was made in such a way, that it could fit into different production environments, so it could be easily deployed and the monitoring be efficient even in dynamic environments of SME companies. Figure 1 System Flowchart shows the visual representation of the working system flow of video capture to video alert generation to make comprehensible the posture analysis stepwise process of the system.

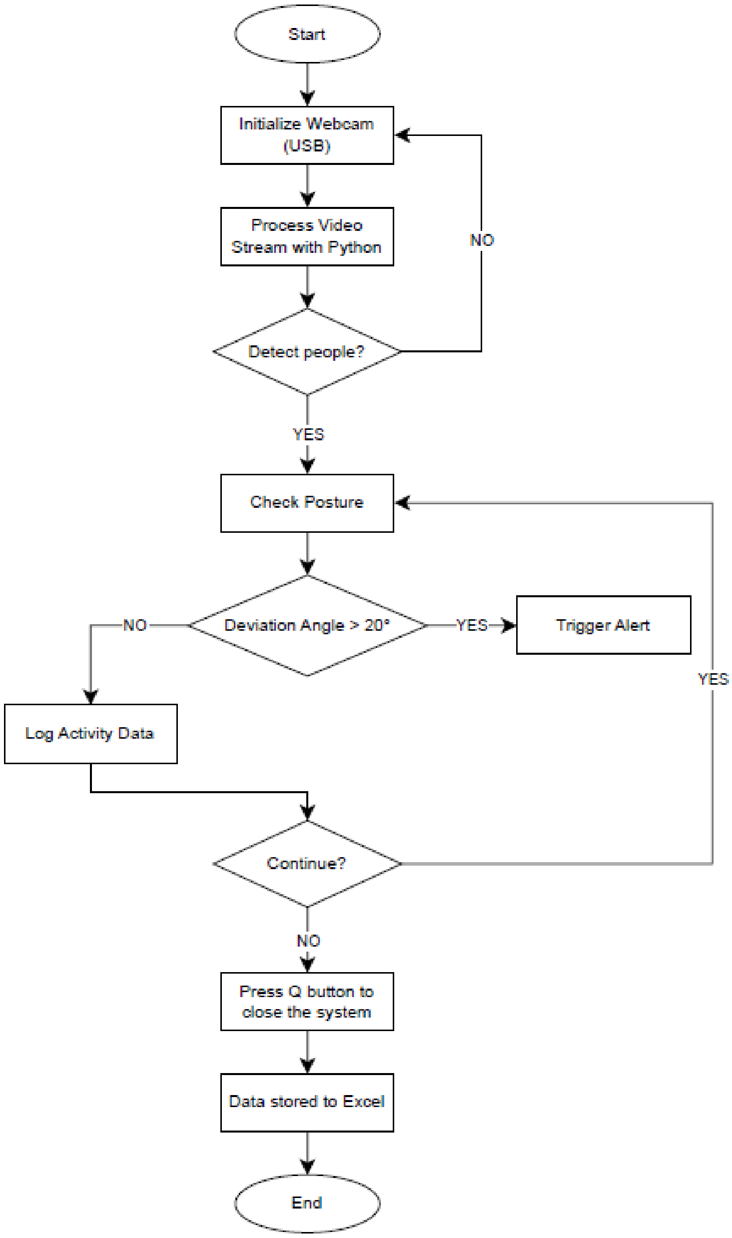
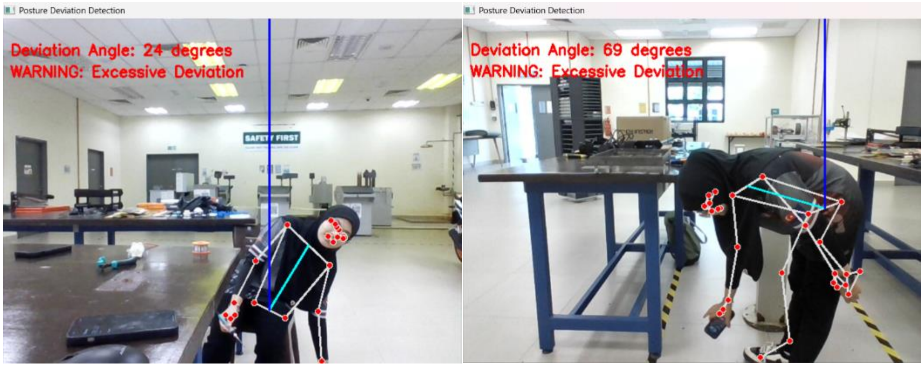


Fig. 1 *System Flowchart*

2.2 System Design and Setup

The posture detection algorithm was built using the Mediapipe library, which detects key landmarks on the human body. Such landmarks are shoulders, hips, knees and ankles on which deviation angle is calculated. Measurement of the angles amongst these body parts and quantification of the ergonomic risk the deviation of posture was the main concern of the system. Figure 2 indicates the posture classification procedure in which the basic posture of an individual assumes different posture like upright or leaning depending on the identification of body landmarks accurately by the system.



(a) **(b)**

Fig. 2 *Posture classification (a) Front view; (b) Side view*

In case the posture of a particular worker exceeds a certain threshold angle (here 20 that is set), a system will cause a visual and auditory feedback. The deviations are computed with the help of angles that are taken out of the skeleton (see Figure 2). The result of this warning will eliminate musculoskeletal disorders (MSD) as the worker or the supervisor will be informed about the risk. The algorithm was made with the ability to be robust, to accommodate complex postural actions like bending, twisting, and reaching, which ergonomic risks are usually concerned with.

Threshold for Posture Deviation: To trigger the warning alert when a deviation exceeds 20°, the formula used to assess the severity could be expressed as shown below where θ is deviation angle calculated from the body landmarks:

$$Alert\ Trigger = \begin{cases} 1, & if\ \theta > 20^\circ \\ 0, & if\ \theta \leq 20^\circ \end{cases} \quad (1)$$

2.3 Data Collection and Real-Time Monitoring

To collect data, the system video-taped the webcams constantly and evaluated each frame in order to measure the worker posture. The video processing was performed in real-time, to derive information on body poses of the worker and thus calculated angles of postural deviations. This information was noted down together with timestamps in order to do subsequent analysis. The system had this data record to a CSV file, which is easy to track and review the past postural deviation of the worker. The experimental set up, as presented in Figure 3 explains how the cameras and sensors were placed in the production line to record the video in order to carry out real-time analysis.

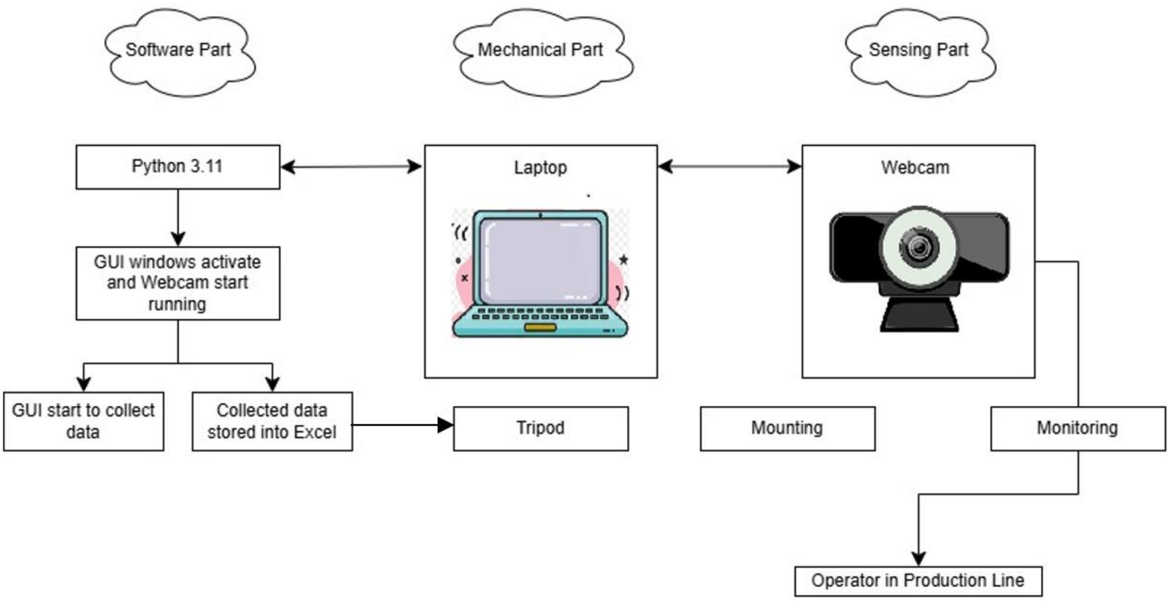


Fig. 3 *Experimental Setup*

The continuous feedback that was given to the workers as a result of the real time monitoring ensured that the workers did not take more than a moment to remedy an unsafe posture. The ease with which ergonomic conditions of the workers during different activities at different times of the day could be compared also provides with the possibility to use the data collecting procedure during the research. Values of deviation angles and timestamps among others were recorded and stored to proceed with the analysis as shown in Figure 4 of how the data was organized and stored in an excel file.

2.4 Test Scenarios and Validation

A number of test conditions were incorporated into controlled SME environments to test the validity of the efficiency of the system. These tests replicated typical activities in the workplace, which were identifying with lifting, bending, and sitting in one position long enough and various environmental factors such as light in the room, and also the presence of other workers within the camera view. Such scenarios were meant to reproduce practical problems of the production environments. Figure 5 shows the 3D layout of the workstations, where the cameras had been arranged to cover the areas the best at the stage of validation.

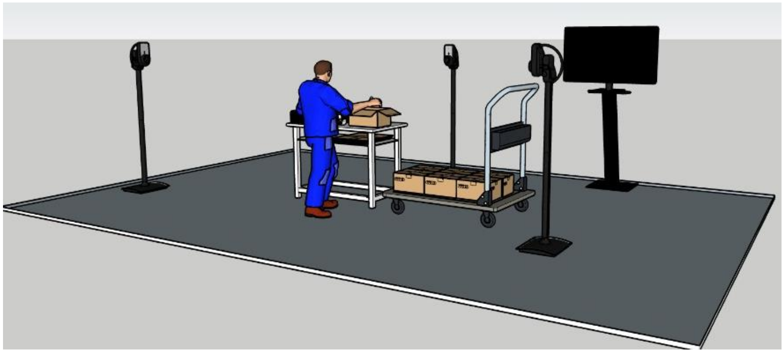


Fig. 4 *Layout Design*

The results of each test situation were thoroughly analyzed so as to determine whether the system could identify postural deviations and produce correct alerts on varying situations. The validation was done by comparing the system-determined deviations to that of expert ergonomic analysis so that it was possible to establish that the system could successfully recognize posture and was consistent with established ergonomic principles. The measurements of these tests were depicted in Figure 4 and the data was encoded in a formatted pattern so that they could easily be retrieved and evaluated.

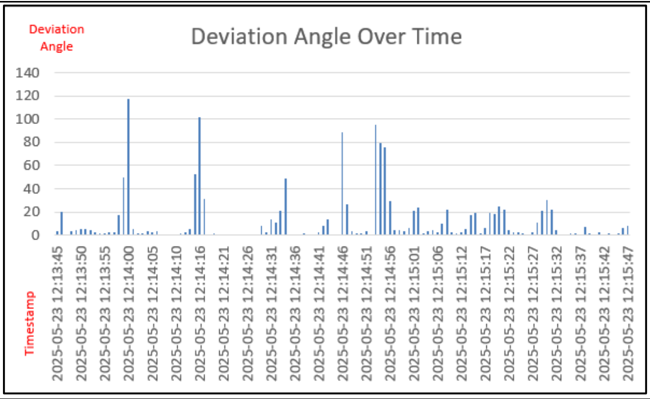
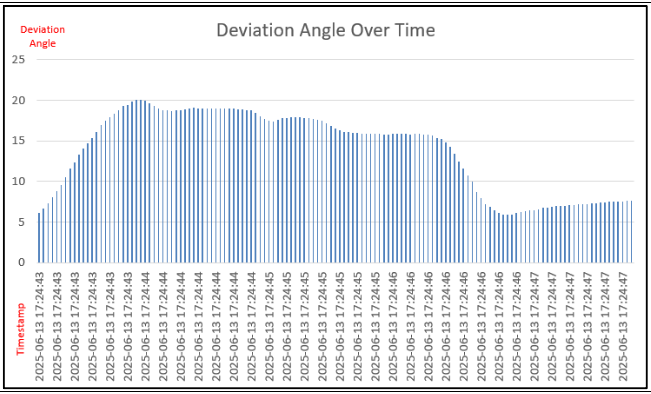
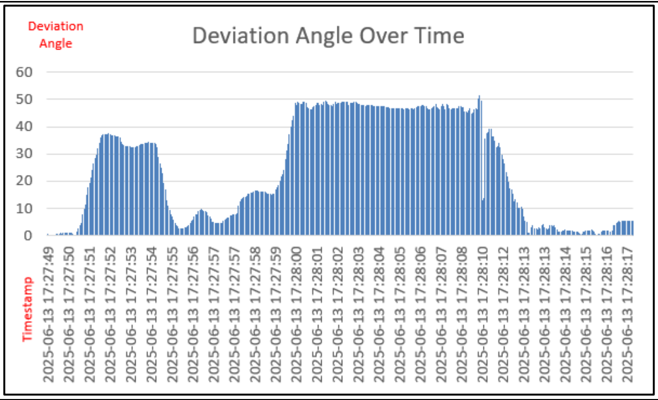
2.5 Data Storage and Analysis Technique

The system stored the data collected in a CSV file and this was retrieved and used with ease to perform further analysis thereof. The dimension measurements were deviation angles and timestamps to each measurement. Excel and other statistical applications were used to analyze this data and find trends with respect to time in regard to posture and ergonomic risk. The table 1 has been provided with an example of collected data about three volunteers in order to demonstrate the way posture deviations were recorded during testing.

The postures of the workers were analyzed to find how and why some tasks and some times of the day contained more ergonomic risks than others. Below depicts a graph that is used to spot the patterns of cumulative posture detection to visualize the changes in the presence of ergonomic risks with time where they vary over time in one work session.

Table 1 *Deviation Angle of Three Volunteers*

Volunteers	Deviation Angle Graph

1st	
2nd	
3nd	

2.6 Performance Metrics and System Evaluation

In order to assess the system functionality, two main criteria have been provided, the so-called The Work Session Duration and Deviation and the Workplace Ergonomics Score. Such measures were used to monitor the changes in posture deviations throughout the working hours of a worker to determine high-risk moments when a worker was more likely to feel discomfort or injury. Table 2 shows the data of the performance of the system during functional testing, where it was more important how effectively the system identified ergonomic hazards and responded to them.

The standard of evaluating the overall ergonomic well-being of a worker was the sum total of individual elements such as average deviation angle and deviation frequency at the work place. This score assisted in the quantification of success of the system in detecting and managing ergonomics related risks over the period of time. Figure 6 shows how the system can identify desirable and undesirable postures and represents a visual manifestation of how posture analysis is used to determine performance metrics.

2.7 Continuous Improvement and Feedback Loop

The last phase of the methodology was to solicit feedbacks of both the workers and the supervisors who operated the system. Such feedback was particularly helpful about what could be done in the future to fix the system, whether it be through user interface design, the ability of posture detection in different situations, or the overall performance of the system in different situations. See Figure 6 where it displays the Graphical User Interface (GUI) of the system, updates being a response to response given by the user in order to make it more usable.

Through the feedback received it was also possible to make a number of modifications to the system and these included, improving the ability of the system to detect posture in dark environments as well as in improving the systems capability of tracking more than one worker simultaneously. The feedback loop made the system to keep on evolving and becoming better with time, all in accordance to the real-world applications. Table 1 can also be referred here to indicate the outcome of the changes of data collection and postural alerts on the system.

3. Results and Discussions

This part brings out the findings of the research and gives a detailed analysis of the findings as well with regard to the research questions asked. The results section will entail presentation of the findings and detailed analysis and interpretation of the results. The discussion will critically analyze the relevancy of the findings to the previous research and provide the implication of these findings as regards the practice.

3.1 System Performance and Data Overview

The Real-Time Vision-Based Worker Ergonomic Analysis System was tested by measuring the functionality in identifying worker postural distortions and giving an accurate ergonomics risk feedback. Analyzing the position of the workers, the system was able to detect both the optimal and unhealthy positions and the angle of deviation of the postures was calculated for each worker. The results of posture detection are presented in Figure 6, the system can detect neutral (green) and risky ones (red) in real time. The alert system on the system responding once the deviation angle passed the threshold level worked well as it received the errors instantaneously.

Data obtained during the tests conducted shows that the system was able to systematically identify postural deviations that exceeded the limit of 20, which was also an indication of the occurrence of ergonomic risk. Table 1, which generalizes the data on deviations in posture observed in various test subjects, contains detailed Personas with the frequency of such deviations displayed as well as the time instances when alerts were activated. Such data points indicate that the system in general was effective in tracking changes in postures that might result in musculoskeletal disorders (MSDs). Table 2 shows the data of the performance of the system during functional testing, where it was more important how effectively the system identified ergonomic hazards and responded to them.

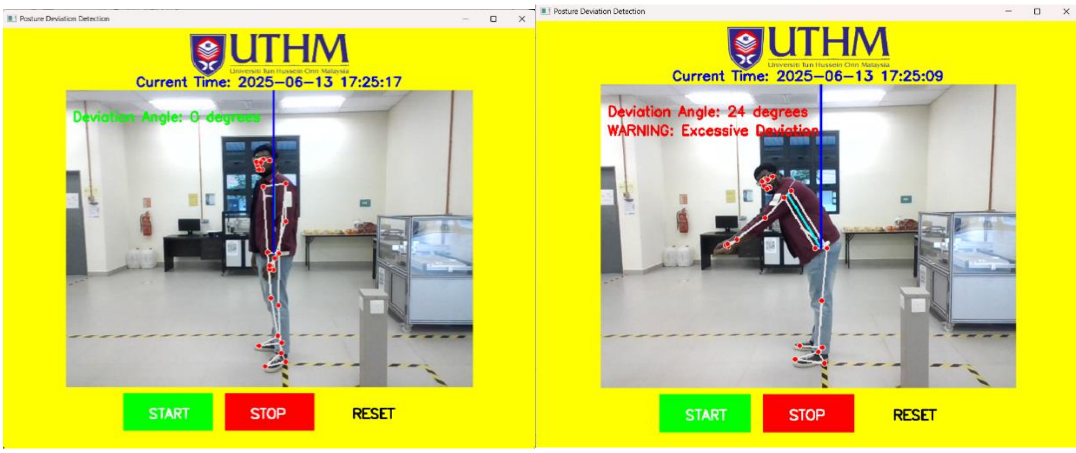
Table 2 *System Performance Data in Functionality Test*

Timestamp	Deviation Angle	Posture Status
2025-06-13 17:27:49	0°	Ideal
2025-06-13 17:27:51	10°	Normal
2025-06-13 17:27:52	15°	Normal
2025-06-13 17:27:53	25°	Warning: Excessive Deviation
2025-06-13 17:27:54	50°	Warning: Excessive Deviation
2025-06-13 17:27:55	5°	Normal
2025-06-13 17:27:56	30°	Warning: Excessive Deviation
2025-06-13 17:27:57	10°	Normal

Although the system performed tremendously, there were certain flaws in detecting the small deviations especially when the deviation approached the threshold. This is indicative of the fact that the system could be improved in detecting small deviations although it may be effective in the case of more serious postural disorders. Thus, the further optimization of the detection algorithms must be provided, to obtain more precise real-time feedback of the smaller postural changes.

The standard of evaluating the overall ergonomic well-being of a worker was the sum total of individual elements such as average deviation angle and deviation frequency at the workplace. This score assisted in the quantification of success of the system in detecting and managing ergonomics related risks over the period. Figure

6 shows how the system can identify desirable and undesirable postures and represents a visual manifestation of how posture analysis is used to determine performance metrics.



(c) **(d)**

Fig. 6 *Posture Detection (a) No Warning; (b) Warning: Excessive Deviation*

3.2 System Performance and Data Overview

The posture-based ergonomic risk assessment was carried out according to high-horsepower tractor posture by the commonly used ergonomic appraisal instruments that include Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA). Using such tools, it was possible to compute the risk scores on the basis of the angles of posture deviations identified by the system. Figure 7 presents ergonomic risk scores of various workers according to time to demonstrate how the risk changes over time in case of particular workers according to the deviation of the postures while performing particular actions.

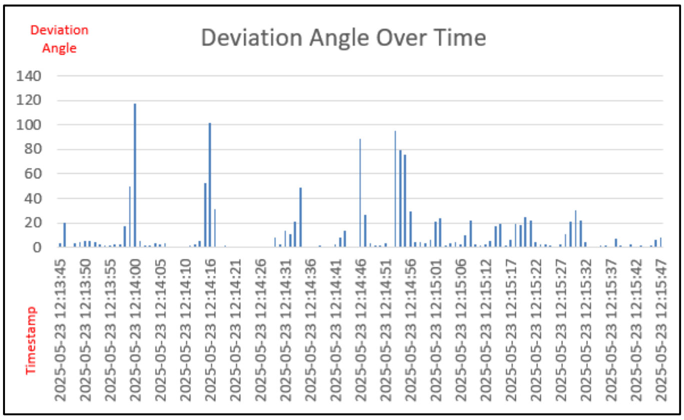


Fig. 7 *Graph for Trends in Cumulative Package Detection*

The outcome of the risk analysis showed that some jobs, like that of lifting or reaching had ergonomics risk score higher than other jobs that involved sitting or standing at a neutral position. This could be seen especially on the high scores of risks when repeating the actions which is known to raise the chances of musculoskeletal strain. Table 2, which compares the risk score of different activities shows that the task that required lifting and bending was described as a high-risk activity, as the score surpassed the threshold every time.

These findings are consistent with the body of literature on ergonomic risk, where repetitive motions and awkward postures contribute significantly to the development of MSDs (Lor, 2023). These findings might indicate that to ease these risks intervention in form of improved task design, workstation adjustment, work rotation or rotation of occupation might be implemented. The fact that the system gives a real time assessment and therefore highlights such high-risk activities is a big leap towards ergonomic monitoring.

3.3 Cumulative Posture Deviation Analysis

An important section of the study was to evaluate cumulative deviations in posture during the course of a work shift of a worker. The system monitored postural deviations and the cumulative sum of deviation over time and provided information on the time when workers were most likely to experience ergonomic strain. Figure 7 displays the tendencies in the amount of cumulative posture deviation, which proves that anomalies of posture were generally getting higher in the second part of the working shift. The information can be useful in determining the period of highest risks during which interventions could be required most.

Cumulative analysis also showed that workers would more likely deviate towards an optimal posture when fatigue came in later during the shift. Highest results in the deviation were observed after prolonged repetition of tasks especially in bending or twisting. These results are also supported by Table 1 that indicates the frequency of deviations per hour, showing that fewer deviations occurred in the former two hours of working and more deviations occurred after a longer period of continuous activities.

These findings align with existing studies (Wang et al., 2021) that highlight the relationship between work duration and ergonomic risk. These findings indicate that fatigue and postures are high contributors to higher ergonomic risks. This underlines the necessity to make regular breaks and varied work more important to minimize the adverse effects of a wrong posture during the workday.

3.4 Discussion

This study outcome shows that vision-based ergonomic analysis system has much potential in real-time monitoring of the presence of postural anomalies and in giving feedback to the workers immediately. This real-time feedback plays an important role in musculoskeletal disorder (MSD) prevention, as they are widespread in industrial workplaces, where workers are highly exposed to awkward postures and repeated movements. The fact that the system will track the posture in real-time and give warnings when the deviation is critical point will present a proactive approach towards avoiding ergonomic hazard.

Compared to the conventional approach of providing the ergonomic assessment involving, e.g., manual observations or static posture assessment, the vision-based system has a few superiorities. First, it offers round-the-clock observation, which is necessary to identify the deviations of the posture that could be observed periodically during a working day. Second, it provides real-time feedback, and hence correction in it, which is a great advantage compared to the traditional methods, as implementation could be delayed. Table 2 shows the recording of the deviation angles by the system over time on the various volunteers and it proves that the system is quite precise in corresponding to the deviations of the postures of the various volunteers.

In the system, however, there were limitations although it performed well in the detection of abnormalities in posture. As an illustration, the system had more errors during the low-light setting, and not all the deviations on the posture were recorded. This is one typical issue in the use of computer vision system and might be solved by raising camera resolution or by deploying newer methods of image processing. Also, the capacity of detecting numerous workers was not constantly possible when the body motion was overlapping or when the workers were awkwardly lying facing the camera. The enhancement in the future may be optimization to the system of multi-subjects and complex dynamic situations.

In comparison to previous research, such as the study by Yang et al. (2024) on integrating computer vision and machine learning for ergonomic assessments, the results of this study align with the growing body of evidence supporting the use of real-time vision-based systems for ergonomic risk management. According to Yang et al., computer vision was found to enhance the efficiency of ergonomics evaluation in that it detects a hazardous posture way better than the commonly applied techniques. In like manner this paper indicates that a vision-based system offers more accurate real-time feedback as opposed to ergonomic injury in the long-run.

Moreover, this study supports the findings of Agostinelli (2024), who highlighted the potential of motion capture (MoCap) systems in identifying ergonomic risks. Nevertheless, the webcam-based system involved in this paper is a more cost-effective and scalable system compared to other traditional MoCap systems, which makes the system suitable with SMEs. This not only makes the system easy to apply but also feasible to be applied in large scale in the industries with few resources to perform ergonomic analysis.

3.5 Implications of Findings

This research finding is important to the manufacturing industry especially to the SMEs that might lack the budget to conduct in-depth ergonomic assessment. Through computer vision technology, SMEs can keep track of the postures of the workers in real-time, and therefore, take corrective action before ergonomics cause subsequent injuries. The results also indicate that there are possible benefits of integrating such systems that can enhance workplace safety, productivity, and employee health, whereby; workplace issues that are based on musculoskeletal disorders and embracing healthy work surroundings are minimized.

Moreover, the possibility of the system to accumulate and analyse posture data on a longer time frame can be used in continuous improvement activities of the SMEs. It is possible to learn the patterns and trends of the working behaviour of the workers so that business can make data-driven decisions regarding ergonomic interventions and the design of workstations so that it serves the needs of the workers better.

4. Conclusion

This research showed that a vision-based system of real time ergonomic assessment which was custom-designed to the SME manufacturing setting is effective. The system employs low-cost webcam-based equipment and image processing solutions, including Mediapipe, to constitute a continuous monitoring of the postures of workers and find ergonomic risks. The results assured that the proposed system was able to successfully identify deviation of optimal postures, warn the user accordingly and recorded the posture data so that the data would be analyzed later on. Although there are certain limitations, including lower accuracy under low-light parameters, and inability to deal with overlapping subjects, the system provides an effective and expandable solution to enhancing workplace ergonomic safety. Such cost-effective technology would greatly help SMEs in preventing musculoskeletal disorders, improve the safety of a worker and enable them to have healthier working conditions at a minimal cost. Further steps towards the improvement should be based on the improvement of detecting algorithms, multi-worker analysis, relevance to various industrial environments, etc. in order to increase the relevance and effectiveness of the system.

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