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RTSIMU: Real-Time Simulation tool for IMU sensors

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ABSTRACT

A software system, called RTSIMU, was developed for analyzing worker movements in the textile industry using Inertial Measurement Units (IMUs). RTSIMU software converts raw positioning data from IMUs into quaternions, which represent orientation relative to the Earth, and further translates them into angular values of movement. To assess relevant angular values and simulate various working movements (such as abduction, flexion, rotation, and elevation of both shoulders), a biomechanical model of the upper body was created using OpenSim to visualize and evaluate these movements in real-time and offers a unique approach for analyzing worker movements, potentially enhancing work safety and productivity.

Code metadata

Current code version	V1
Permanent link to code/repository used for this code version	https://github.com/SoftwareImpacts/SIMPAC-2023-222
Permanent link to Reproducible Capsule	https://codeocean.com/capsule/0968525/tree/v1
Legal Code License	MIT
Code versioning system used	None
Software code languages, tools, and services used	Python 3.8; Opensim 4.4
Compilation requirements, operating environments & dependencies	RTSIMU requires hydra-colorlog; hydra-core; imufusion; numpy; and pandas
If available Link to developer documentation/manual	https://github.com/pauladiasss/RTSIMU/README.md
Support email for questions	paulacdias2000@gmail.com

1. Software for real-time worker motion analysis

In this paper, we present the Real-Time Simulation tool for IMU sensors (RTSIMU) software that allows a real-time monitoring of industrial worker movements. The goal is to prevent Work-related Musculoskeletal Disorders (WMsD), often associated to repetitive manual tasks. The software uses Inertial Measurement Units (IMUs) to capture raw body part positioning data. Then, the raw data is preprocessed, generating quaternions and angular data. Next, the obtained preprocessed data is visualized by using a biomechanical model. Finally, standard WMsD rules applied over historical angular movements are computed, allowing to detect if a risk as occurred. The RTSIMU software was implemented using the Python language and it makes use of several of its modules, namely `numpy`, `hydra-core`, `imufusion`, `hydra-colorlog` and `pandas`.

With the advent of technologies, it has become possible to develop new, increasingly precise and efficient data collection methods, allowing for greater reliability of real-time information [1]. This has been particularly relevant in industrial sectors that require physical labor, such as the textile industry [2]. Indeed, in textile environments, it is common for sewing workers to perform repetitive and monotonous movements at a fast pace, which can result in incorrect ergonomic postures and lead to Work-related Musculoskeletal Disorders (WMsD). These WMsDs can be highly detrimental to the health and comfort of workers, which could lead to fatigue and injuries. Therefore, to minimize these risks, it is essential to adopt measures aimed at ensuring the health and well-being of workers [3,4].

Nowadays, Inertial Measurement Units (IMUs) are the most commonly used devices for capturing WMsD risky movements, as they

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[1] https://docs.sensry.net/Datasheets/SY020-PCB/

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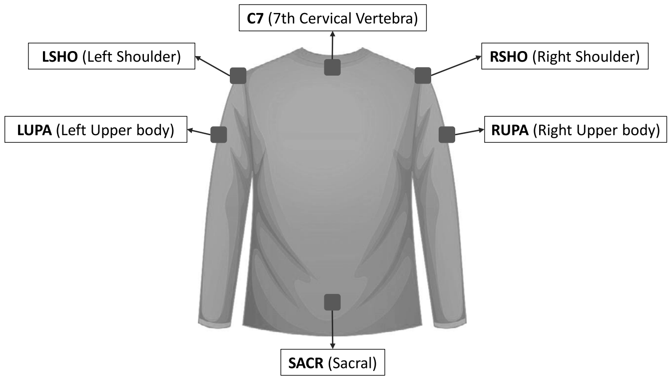

Fig. 1. IMUs position within the ergonomic vest.

offer higher precision, reliability, and efficiency [5]. The IMUs are composed of three sensors that measure the orientation and movement of an object or individual, namely an accelerometer (acceleration); a gyroscope (angular velocity); and a magnetometer (magnetic field). Our real-time worker motion software is developed on an exoskeleton equipped with six IMUs named Kallisto.[1] These IMUs are positioned in six areas of the upper body, namely: the right arm, left arm, right shoulder, left shoulder, cervical and sacral, as shown in Fig. 1. The data from these sensors are collected at a frequency of 100 Hz, with the accelerometer unit of measurement being G, the gyroscope being in θ_s, and the magnetometer in μT.

The collected raw data requires a preprocessing (e.g., filters), in order to transform it into valuable and WMsD reliable information. To filter the collected data, the Fusion library from XioTechnologies[2] is used, which allows the fusion of IMU sensors through the Attitude And Heading Reference System (AHRS) algorithm. This software allows the conversion of raw data from the three sensors into quaternions, a unique measure of orientation relative to the Earth, contributing to a better understanding of movement data. To obtain more efficient data, some algorithm parameters are fixed, including the gain (0.5), the acceleration rejection (10), the magnetic rejection (20), and the rejection time limit (5). These values were assigned such that the preprocessing works for most motion analysis applications. The result obtained after applying this filter is a quaternion (e.g., an orientation of the movement performed) for each IMU.

For real-time visualization and evaluation of movements, the open-source tool OpenSim is used, which allows the development of musculoskeletal biomechanical models and dynamic motion simulations. Although pre-existing biomechanical models are available on SimTk, such as the scapulothoracic model,[3] and the full-body lumbar model[4] these are not suitable for the textile worker context since the former has only the right side of the upper body and the latter does not allow for the calculation of shoulder elevation movement.

Therefore, creating a biomechanical model adapted to the entire upper body was necessary, which converts quaternions into motion angles. The model includes six components, shown in Fig. 2 in orange, located in the cervical, sacral, shoulder, and arm regions. These components represent each IMU and are oriented by the corresponding quaternion, simulating the movement and computing the relevant Euler angles for studying textile workers. The measured angles correspond to abduction, flexion, rotation, and elevation of the shoulders on both sides of the body concerning the individual's trunk[5].

Based on the computed movement angles, the RTSIMU software applies a set of predefined rules to assess the risk of musculoskeletal injuries in textile workers. This assessment follows the ISO 11226_2013 and EN 1005-4_2005+A1_2008 standards [6], as well as the Rapid Upper Limb Assessment (RULA) method [7] for ergonomic evaluation during task performance. If the movement angles exceed a certain value for a given movement, the software identifies it as a potential risk to the worker's health. It also provides information on which specific shoulder movement (abduction, flexion, rotation and/or elevation) are causing the risk.

2. Software impact on ergonomic position monitoring

The RTSIMU software has a potential impact on the health and well-being of workers, as it allows for real-time monitoring of their posture and movements, providing immediate feedback on the correct ergonomic position to adopt, thus ensuring workers to maintain a healthy posture and reducing the risk of injury.

One of the key features of our software is the filter that combines the accelerometer, gyroscope, and magnetometer data, included an analytically derived and optimized gradient-descent algorithm that calculates the direction of the gyroscope measurement error, thus outperforming other algorithms. This contributes significantly to the effectiveness of the motion data, allowing for more accurate monitoring and feedback. In [8], the orientation filter used by our software was employed to represent the motion angle. However, the process was not automated, since the data was obtained from a dataset containing the values of the three sensors rather than being collected directly from the IMUs. Subsequently, the sensor data was fused, resulting in a single time series with the angular values of the movement. This study then utilized machine learning algorithms to train the system to anticipate future angles and send alert signals when they were considered of high risk to the worker.

The scientific studies described in [9,10] used the RTSIMU worker motion analysis software, which contributes to the real-time detection of sewing workers' movements and the classification of their associated risks. After calculating the angle of a movement, our software evaluates whether the movement is considered risky based on a set of predefined standard rules. If it is deemed risky, the system immediately sends a warning message in string format to an actuation system. In Fig. 3, it is possible to observe the abduction movement on the right side and identify the moments that present risk to the worker. According to the abduction rule, a movement greater than 40° for 4 or more seconds is considered harmful to the worker's health. In this sense, the graphical representation shows the red line indicating the instant in which risk was identified for the user. Clearly, this system promotes workers' health and safety, increasing productivity in tasks performed, and reducing the number of work-related injuries and the costs associated.

3. Future work

RTSIMU is a recently developed software that aims to monitor industrial worker movements, in order to detect the risk of WMsDs, once they occur. In the future, we aim to incorporate an intelligent system component into RTSIMU, by using machine learning algorithms to model the angular observations as a time series. This would allow the RTSIMU software to perform an Ahead of Time (AoT) WMsD risk prediction. To achieve this objective, a vast dataset of worker motion data must be carefully collected, processed, and then integrated into machine learning algorithms. Once these algorithms have been trained, they can be seamlessly incorporated into a real-time monitoring system that can provide workers with valuable feedback on their posture and movement techniques. In particular, once a WMsD risk is predicted, we wish to study the effect of triggering a safety mechanism, such as an alarm bell, in order to prevent worker injuries.

[2] https://github.com/xioTechnologies/Fusion
[3] https://simtk.org/projects/scapulothoracic
[4] https://simtk.org/projects/fullbodylumbar
[5] An Illustrative example is also present in https://github.com/pauladiasss/RTSIMU

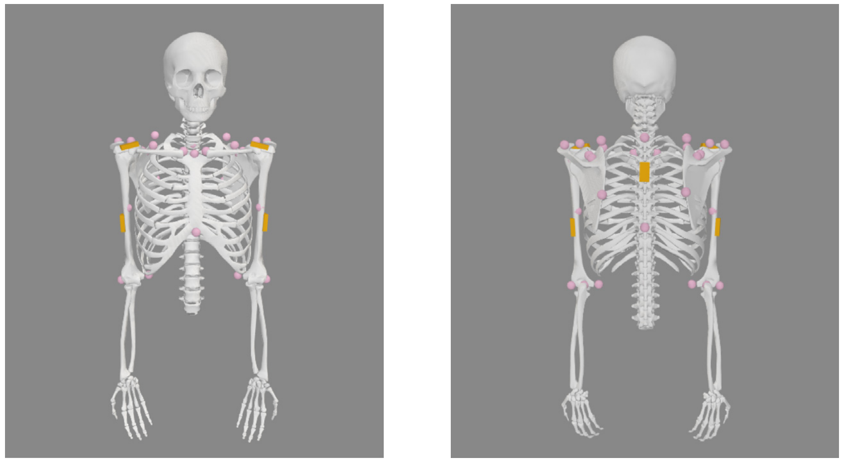

Fig. 2. Biomechanical model with frontal and back view.

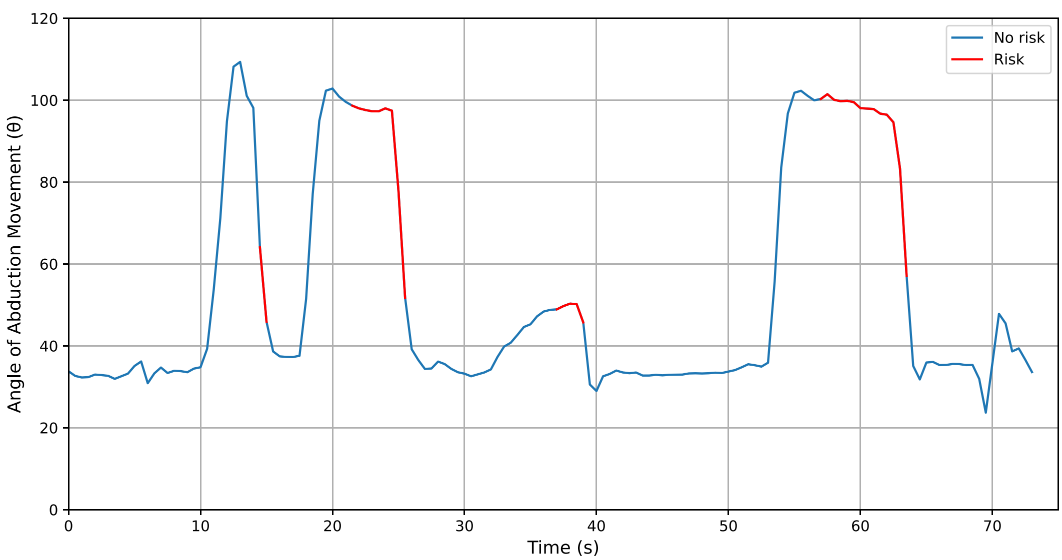

Fig. 3. Shoulder abduction movement. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.simpa.2023.100522.

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