G Ital Med Lav Erg 2018; 40:3, 176-178
ISSN 1592-7830

ATTI 81° CONGRESSO NAZIONALE SIML

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Monitoring human activities that might cause work-related musculoskeletal disorders by means of inertial and magnetic sensors

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**RIASSUNTO. L'utilizzo in ambito lavorativo di nuove tecnologie indossabili è considerato una sfida chiave di ricerca nel campo dell'ergonomia applicata. Il deterioramento della salute fisica dei lavoratori e la perdita di giorni lavorativi non influiscono solo sul loro benessere e sulla qualità della vita, ma anche sull'economia dei Paesi Europei.
I disturbi muscoloscheletrici lavoro correlati interessano muscoli, articolazioni e tendini. Se essi sono conseguenza dell'attività lavorativa si parla di Disturbi Muscoloscheletrici Lavoro-Correlati (WMSD). I sensori inerziali e magnetici (IMU) potrebbero aprire nuove prospettive nel rilevamento e nella misurazione obiettiva dei WMSD in quanto consentono di raccogliere dati senza interferire sulle attività lavorative svolte per periodi di tempo prolungati. L'evoluzione delle tecnologie ha permesso, infatti, non solo il miglioramento della precisione nelle misurazioni, ma anche la riduzione dell'intrusività e la maggiore vestibilità degli strumenti di rilevazione.**

Parole chiave: disturbi muscolo-scheletrici lavoro-correlati, sensori inerziali, sensori magnetici.

ABSTRACT. Activity recognition based on new wearable technologies is considered a key research challenge in the field of applied ergonomics. Deterioration of workers' physical health and loss of workdays impact not only on their wellbeing and quality of life, but also on European countries economy. Musculoskeletal disorders are injuries or pain affecting muscles, joints and tendons. If these disorders are work related are described as Work related Muscoloskeletal Disorders (WMSDs). Inertial and magnetic sensor units (IMUs) might open new perspectives in detection and objective measure of WMSDs because they allow to collect data on work activities under free conditions and over extended periods of time. The evolution of technologies has observed not only improvement in measurement accuracy and precision, but also a reduction in intrusiveness and an enhanced fit of the measure technologies.

Key words: *work-related Musculoskeletal Disorders, Inertial and magnetic sensor units.*

Activity recognition based on new wearable technologies is considered a key research challenge in the field of applied ergonomics. Deterioration of workers' physical health and loss of workdays not only impact their well-being and quality of life, but also European countries economy (1).

Musculoskeletal Disorders (MSDs) are injuries or pain affecting muscles, joints and tendons. MSDs result from daily awkward postures and handling tasks, such as: prolonged adoption of impairing postures, forceful exertions in lifting or carrying loads, bending and twisting the back or limbs, exposure to vibration or repetitive movements. If these activities are work-related, then the resulting injuries and disorders are referred to as Work-related Musculoskeletal Disorders (WMSDs). Recognizing and monitoring human activities that might cause WMSDs are of great importance in the assessment of workplace safety and in the prevention of occupational diseases (2). In turn, WMSDs can result in a reduction in the quality or quantity of work produced.

Several procedures are available for analyzing the execution of work tasks designed to assess the risk of biomechanical overload caused by the loads handling, the execution of repeated movements with high joint excursions and the prolonged assumption of trunk and limbs non-physiological postures. These procedures, however, are essentially observational and therefore burdened by a lack of objectivity. The practical application of observational procedures for the assessment of biomechanical risk is a complex process that requires considerable experience and that takes company resources out from other missions. Information such as the frequency of movements, their articular excursion, postural attitudes, the movement of loads and the consequent load on joints, etc., are nowadays assessed in a subjective way, through observation of the various phases of work with the sole aid of video footage (3). In terms of accuracy, a difference of ten degrees in a posture is not easily noticeable while observing a worker in real time or by means of two-dimensional video images. Besides, visual observations tend to be imprecise and result in excessively subjective evaluations including when conducted by expert observers (e.g. ergonomists) (4).

Inertial and magnetic sensor units (IMUs) might open new perspectives in detection and objective measure of

WMSDs. They are commercially available, low-cost, portable motion analysis systems, and consist of light-weight sensing units that typically comprise a 3D accelerometer, gyroscope, and magnetometer. IMUs have been used mainly for navigation of aircraft, ships, land vehicles and robots, and also for shock and vibration analysis in several industries. Rapid development of micro-electromechanical systems (MEMS) technology has contributed during the last decade to the development of small-size and fully wireless IMUs. Currently, many manufacturers propose inertial sensors that are easy to attach, wear and handle. These sensors allow one to collect data on work activities under free conditions and over extended periods of time. IMUs typically include a micro-controller, a set of a 3D accelerometer, gyroscope and magnetometer MEMS sensors, a module for external communication and real-time data streaming (e.g. Bluetooth or wi-fi), a memory for local data storage and a Li-ion battery. IMUs might also include a thermometer, as aiding sensor to compensate for temperature dependencies of other sensing elements, and a barometer, a sensing element that measures atmospheric pressure used as an aiding sensor to get height information. The sensor nodes are usually recharged by standard micro-USB ports, by induction or by a docking station provided by the manufacturer. Normally an on-board processing allows to pre-process data in order to obtain orientation estimation. The orientation of the IMU is computed typically by a Madgwick's complementary filter or by a Kalman filter, with in input angular velocity and accelerations increments and magnetometer samples. The filter optimally fuse inertial and magnetic data to obtain orientation estimates for both static and dynamic movements. The 3D orientation of the IMU is provided with respect to a global, earth-based coordinate system. This means that an IMU can measure the orientation of the body segment to which it is attached without the need of any camera or external infrastructure. Given this 3D orientation, IMUs have the potential to estimate body postures and joints kinematics by means of the definition of a biomechanical model based on anatomical reference systems (5). In particular, segment positions and orientations are typically estimated by applying the result of a sensor-to-segment calibration procedure to the corresponding sensor orientation estimates, and applying it to a (scaled) biomechanical model of the human body. Under the technical point of view, there is already a body of evidence suggesting a strong consistency between measuring posture and kinematics with IMUs and gold standard systems such as the optoelectronic systems (5).

In the healthcare domain, IMUs are the most widely used type of wearable systems for gait and balance analysis and have been extensively validated in healthy volunteers and in groups of persons with motor impairment. Additionally, technology is being developed for inertial sensor data collection, storage and/or transmission with smart devices such as phones and watches (6).

In the occupational domain, maintenance or assembly tasks have mainly been considered. Despite IMUSs are increasingly being promoted in various studies (7), yet, a literature review also shows that, while some initial works have been reported on the use of IMUs for tracking the motion of construction workers in the fields of productivity, just very few works have been conducted to assess body posture or motion more completely to evaluate WMSDs (8).

Despite this huge advantage over alternative motion capture systems, inherent drift of orientation (and position) in current solutions has prevented inertial motion capture systems to become a commodity. Specifically the direct use of the magnetometer readings to obtain heading is a major source of error, since magnetic distortions, for instance from common materials in buildings (steel constructions, reinforced concrete, etc.), furniture, and electronic equipment, or magnetometer calibration errors significantly affect the overall accuracy (8). No longer than few months ago Xsens, the global leading manufacturer of inertial sensors (Xsens Technologies BV, NL) has announced to have released a new motion capture engine immune to magnetic distortions but evidences have still to be produced by the scientific community (9).

MEMS-based accelerometers alone have the pros of being extremely limited in energy consumption and dimension, allowing to increase furthermore the user-friendliness and simplicity of use in working contexts. Furthermore, by avoiding the use of magnetometers, the aforementioned magnetic distortions do not affect accuracy and robustness of measures. These systems appear to have a good potential in applications where the WMSDs are due to the prolonged adoption of static impairing postures of limbs or back more than to the performance of uncorrected movements. In fact, the accelerometers used as inclinometers are able to assess workers' exposures in terms of degree and intensity of inclinations of body parts.

The great advantage of wearable sensors is the ability to measure human movement in any working environment for extended periods of time without hindering or interfering with workers' tasks. The evolution of technologies has observed not only improvement in measurement accuracy and precision, but also reduction in intrusiveness and enhanced wearability. IMUs allow to have body posture and movement measurement systems that are non-intrusive to enable their use over long periods of time, ubiquitously and without external infrastructures. Their ability to be free from magnetic field distortion is still to be proved especially in working automotive environments.

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