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A framework for evaluating muscle activity during repetitive manual material handling in construction manufacturing

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A B S T R A C T

Workers in construction sites are exposed to highly labor-intensive tasks. Ergonomic principles, in addition to engineering considerations, should thus be included in the design of workstations in order to minimize the risk of injury. The objective of this paper is to propose a framework to assess muscle force and muscle fatigue development due to manual lifting tasks using surface electromyography (sEMG) and human body modelling. Muscle forces are calculated using the human body model and compared qualitatively to sEMG muscle activities. The results show that sEMG is capable of visualizing muscle activity. However, sEMG application in identifying muscle fatigue development is limited to bulkier and superficial muscle bundles in low fat areas. The proposed human body model, which is driven by kinematic motion capture data, predicts muscle forces during the entire task maneuver. The predicted muscle forces from the human body model are compared with sEMG data from corresponding muscles as well as data available in the literature. In future research, the developed model will be used to determine optimal task maneuvers that minimize muscle forces with the ultimate goal of preventing muscle injuries in workstations.

1. Introduction

Manufacturers seek to automate construction processes in order to reduce over-exertion and awkward body postures of workers. However, manual work in construction is inevitable. Repetition of task maneuvers in particular is a major issue and causes musculoskeletal disorders [1]. Hsie et al. [2] investigate working time and break schedule in order to optimize the operation process by minimizing job duration and workload. A repetitive task during a certain period requires involvement of a specific group of muscles repeatedly, a condition which results in the development of muscle fatigue. Alternatively, working with adequately timed breaks may reduce the risk of injury [3]. In conventional retrospective risk assessment of workstations, workers' compensation claims are evaluated to identify ergonomic problems, so exposure to the causes of injury usually occurs prior to unsafe tasks being identified. However, a prospective ergonomics study of human body interaction with workstation elements could reduce future injury incidents. Therefore, observing the way workers perform their repetitive tasks in a construction company, for instance, is of high importance for health and safety programs as it supports preventive measures to prevent or reduce instances of injury to workers.

Muscle activity is an important metric that provides insight into the load and function of muscle control. Surface electromyograms (sEMG) have been used in past studies to collect the electrical potential when muscles are electrically or neurologically activated. The sEMG signal is altered based on the extent of muscle involvement during the occupational work [4]. Analysis of sEMG can thus serve as a non-invasive method to predict muscle activity and development of fatigue [5,6]. To study muscle fatigue development using sEMG, some parameters, such as Root-Mean Square (RMS), Average Rectified Value (ARV), Mean Frequency (MNF), and Median Frequency (MDF), are suggested in the literature [7–10]. Although sEMG technique provides valuable information about muscle activity, its application is limited to superficial muscles. Hence, the state of load distribution throughout the entire human body cannot be assessed using the sEMG technique.

Knowledge of internal loads and moments acting on body segments is important in describing interactions of skeleton components in a wide range of human body-related studies, such as prosthesis design, preclinical testing, and numerical models of the musculoskeletal system. Despite the advancement of technology, *in-vivo* measurements are limited to a relatively small set of applications, as they are invasive methods and are inhibited by technical limitations [11–13]. It is thus vital to develop musculoskeletal models in order to estimate internal loads. These models consider bones to be rigid segments, the degrees of freedom of which are constrained by joints and the motions of which are actuated with contractions of attached muscles. The success

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of human models in the estimation of muscle forces and joint moments, meanwhile, is widely reported in the literature [14,15]. Musculoskeletal modelling, in contrast with *in-vivo* muscle force measurement, is a non-invasive and a more feasible technique in most muscle activity analysis. Musculoskeletal models calculate the muscle/joint forces/moments level required to complete a task, and help with assessing the tissue-level loading condition. Human body models have been used in a variety of applications spanning from clinical assessments to job safety evaluation and task visualization [16]. Recognizing their success in estimation of the internal loads, researchers prepare sophisticated and highly accurate human body models and further implement them in industry applications with minimum manipulation. Inverse-dynamics analysis of human body muscles and joints has been undertaken in recent studies to measure real-time muscle forces while performing a task maneuver [14–17]. The AnyBody Modeling System [18], a software for development and analysis of the musculoskeletal system, is used in this study to dynamically assess the human body interaction with workstation elements. The AnyBody Modeling system is able to calculate individual muscle forces and joint moments using advanced optimization techniques in order to solve the muscle redundancy problem [16].

Low back pain (LBP) is extremely prevalent and widespread among construction workers [19]. Back-related complaints are more costly than those from any other body part for work-related claims. Hence, in this study, repetitive heavy material lifting maneuvers are simulated and fatigue development is studied in some of the superficial low back muscles using sEMG experiment and human body modelling. A human body model, including musculoskeletal bones and muscles, is constructed to predict muscle forces and joint moments. The human body model is driven using motion capture data from the experiment in order to replicate the lifting maneuver. The objective of this study is to propose a framework to (1) investigate muscle fatigue resulting from repetitive tasks in construction manufacturing operations by analyzing four sEMG parameters, RMS, ARV, MNF and MDF; and (2) investigate muscle forces and joint contact forces and moments by creating a human body model which interacts with workstation elements. The sEMG parameters, calculated from experimental data, and muscle activity, calculated in the human body model, are compared and cross-validated. The long-term objective is to create a proactive ergonomic analysis method to reduce the risk of work-related injuries by identifying overloaded bones and muscles in the musculoskeletal system, and to seek alternatives by modifying and simulating the interactions between the worker and workstation. The methodology of this framework is described in the next section, followed by the results of a case study. The results of fatigue analysis, muscle forces, joint moments and corresponding methodology limitations are discussed.

2. Methods

The research framework illustrated in Fig. 1 is implemented and tested in a Canada-based window and door manufacturer, All Weather Windows, and consists of three steps. The first step is plant observation and physical demand analysis, which identifies high-risk tasks such as heavy material lifting [20]. The next step is to simulate high-risk construction tasks identified from observation both experimentally and numerically. Reflective markers are used to capture the kinematics of the task maneuvers; the obtained motion-captured data from experimentation is used as input to the human body model in order to drive the human body model and confine the degrees of freedom. sEMG sensors are attached to the low back area to experimentally measure the electrical activity of muscles. The sEMG data are used for two purposes: (1) to study the fatigue development in corresponding muscles, and (2) to validate the human body model. The human body model has been extensively used in sport injury prevention and pre/post-operation implant analysis. However, the use of human body models in the ergonomic design of workstations remains a science under development. Through these kinematic analysis, interactions between worker and workstation can be analyzed. Grounded in experimental and simulation modelling results, proactive analysis can be accomplished in order to reduce

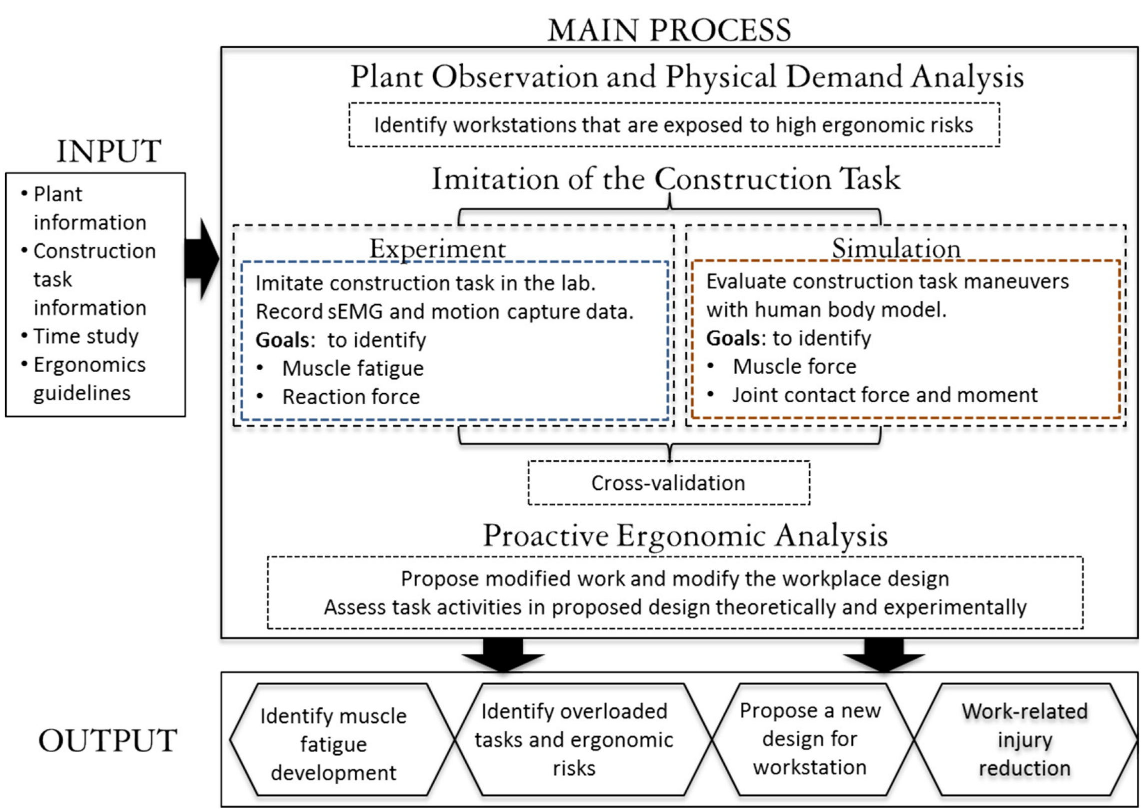

Fig. 1. Description of the proposed research framework.

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