



A Supernumerary Soft Robotic Hand-Arm System for Improving Worker Ergonomics

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Abstract. Long exposure to overload and vibration transmission on the upper limb are among the high risk injury factors in industrial environments. They contribute to the development of musculoskeletal disorders, which can lead to economic and social setbacks. To address this issue, robotic systems have been developed that act either as an autonomous system or in collaboration with the workers. In this direction, and with the aim to develop a system that contributes to a simultaneous reduction of the overloading and vibration transmission, we present a novel wearable soft robotic hand-arm system. Preliminary experimental results in a vibrational tool use are reported to shown the potential of the system in improving worker ergonomics.

1 Introduction

Several industrial job duties require physical demands that may result in excessive internal forces and vibration transmission, increasing the risk for work-related musculoskeletal disorders (WMSD). In the last decades, numerous safety policies were defined and applied to reduce the workers' exposure to such risks. A parallel line of work deals with the use of robotic solutions for improving both the safety and the comfort of the industrial workers. Such systems can act either autonomously, to perform the tasks that are potentially risky for human workers, or in collaboration with them (e.g. collaborative robots or exoskeletons), so that a certain level of dexterity can be added to the industrial processes [1].

More recently, a new robotic paradigm has taken place in this field: the Supernumerary Robotic Limbs (SRL). Differently from an exoskeleton, a SRL does not constraint the human joint to follow a specific trajectory. During the task execution, the SRL can augment the worker's ability, e.g. by providing additional robotic arms and/or legs. This can help the workers to carry objects

Funded, in part, by the European Project H2020 SoftPro, Grant Agreement No. 688857.

while using a tool with their own hand [2], or to augment the body stability in uncomfortable working positions (e.g. crawling-like) [3].

Noteworthy, most of these devices only reduce the payload on the arm joints, leaving the fingers still overloaded for grasping. In addition, this could be painful especially using vibrational tool (e.g. drill or polisher). In fact, vibration transmission on the hand/arm have been correlated with chronic nerve and tendon disorders [4]. Some industrial solutions (e.g. www.deltaregis.com/Tool_Supports) already deal with this problem, but they are usually grounded, limiting the natural workspace. To address these challenges, we present a new wearable and under-actuated soft robotic platform. The system is composed of the Pisa/IIT SoftHand [5] mounted on a commercial steady-cam (Armor Man 2.0, Tilta), with four passive dampers in between. The whole system reduces the load on both the arm and finger joints during tasks. In addition, since the user does not hold the tool directly with his/her own hand, most of the vibration are dissipated by the system, highly reducing the injury risk on the nerves and tendons. A detailed description of the system, and its potential to improve human ergonomics is provided below.



Fig. 1. The proposed supernumerary soft robotic hand-arm system.

2 System Description

Developed with the aim at improving the ergonomics of workers in industrial environments, it is a wearable system, composed of two passive gravity compensator arms (the Armor Man 2.0 suite), integrated with two robotic hands. The suite can be worn as a backpack, while the robotic hands are integrated thanks to a custom mechanical wrist interface (see Fig. 1). This interface allows passively the prono-supination rotation of the robotic hand.

In this first prototype, a handle attached to the wrist interface was used to proportionally control the opening/closure of the SoftHand (see Fig. 1).

3 Improving Worker Ergonomics

To improve worker ergonomics in industrial environments, the system is meant to reduce two of the main injury factors: vibration transmission and overloading.

Vibration Suppression: Several studies showed a direct correlation between the exposure of hand-transmitted-vibration (HTV) and symptoms and signs of disorders in the vascular, neurological and osteoarticular systems of the upper limb [4]. Thanks to this system, an important suppression of these vibrations on the worker's upper limb is carried out. This suppression is due to mainly to the four dumper by which the robotic hand is attached on the mechanical interface and to the padding of both the robotic hand palm and the suite. A simplified mass-spring-damper schema of a user wearing the system is shown in Fig. 2. The overall impedance, composed by the four dampers, with intrinsic damping that can be chosen based on the vibration suppression cutoff frequency, and the Pisa/IIT SoftHand, is shown under SOFTHAND block. This block will isolate the vibration from a tool to the human hand. The residual vibration is also reduced by the Armor Man's intrinsic mass-spring-damper system. The effect of such design parameters in reducing the level of vibration from the tool to the person's hand can be calculated from:

$$\begin{aligned}
 X_b(s) &= \frac{F_e(s)}{(s^2 m_{SH} + s b_{SH} + k_{SH})} \\
 &\quad \times \left[1 - \frac{(s b_{SH} + k_{SH})^2}{(s^2 M + s B + K)(s^2 m_{SH} + s b_{SH} + k_{SH})} \right]^{-1} \\
 X_a(s) &= \frac{X_b(s)(s b_{SH} + k_{SH})}{(s^2 m_{SH} + s b_{SH} + k_{SH})} \left[1 - \frac{(s b_{SH} + k_{SH})^2}{[s^2 M + s B + K]} \right]
 \end{aligned}$$

where $X_a(s)$ and $X_b(s)$ are the Laplace transform of the motion equations of the point a and b . K_{SH} , b_{SH} and m_{SH} are the spring coefficient, the viscous damping coefficient and the mass of SoftHand. While, M is the sum of the mass of the human arm/hand and the Armor Man (m_{HAH} and m_{AM}), and B and K are the sum of all the viscous damping coefficient and the spring coefficient respectively.

Load Reduction: The system helps the worker to reduce the load not only on the arm joints (mainly elbow and shoulder), but also on the finger ones. In fact, the user does not need to carry the tool directly with his/her own hand. In this way, during the working phase the fingers are not over-loaded. In addition, thanks to this system, the worker can hold an object while using other tools (e.g. screw driver, see Fig. 3).

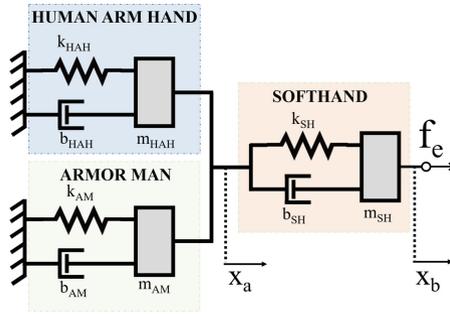


Fig. 2. Mass Spring Damper model of a user wearing the system, where K_i , b_i and m_i are the spring, and viscous damping coefficients and mass respectively. f_e is the external force applied to the whole system.



Fig. 3. The system can hold a part for the worker while using two hands to manipulate it.

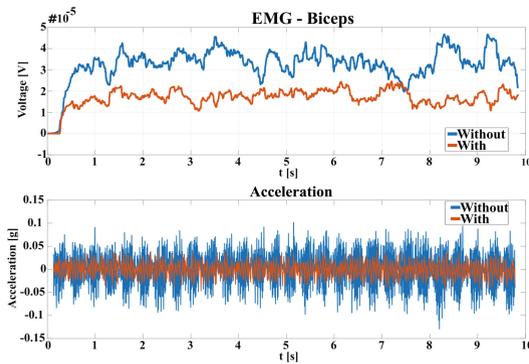


Fig. 4. Top: The envelope (RMS window of 150 samples) of the EMG activity signal of the biceps muscle. Bottom: Acceleration on the hand (removed mean value). In both: orange with the system, blue without.

4 Preliminary Results

To evaluate both the vibration and the load reduction on human arm, an experimental task was designed, simulating the usage of a vibrating tool (mass: 1 kg). The EMG activity and the acceleration on the user's arm, while holding a rotating polisher for 10 s (no contact with any surface), were acquired using eight wireless EMG electrodes the Trigno EMG system (Delsys Inc.). Sensors were attached to the right arm as shown in Fig. 1: two on the dorsal side of the hand; two on the forearm (one on the extensor muscle and one on the flexor muscle of the wrist); two on the arm (one on biceps and one on the triceps); two on the shoulder deltoids anterior, and posterior (EMG rate: 2.0 kHz; acc. rate: 150 Hz). Figure 4 illustrates the preliminary results of this experiment. On the top plot, the activation of the biceps muscle, as the major muscle in holding the object, with (orange line) and without (blue line) the use of the system demonstrates a significant reduction of the loading on the right arm. While, in bottom plot, the vibration suppression is shown by the different amplitude of the two signal.

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