Industrial Wearable Robots: A HUMANufacturing Approach

Gaia Salvadore, Edoardo Rota, Elena Corsi, and Giuseppe Colombina(✉)

COMAU S.p.A, 10095 Grugliasco, TO, Italy
giuseppe.colombina@comau.com

Abstract. In the last decades, exoskeletons have mostly been developed and studied for applications in the medical field, as rehabilitation or assistive devices for patients with movement disabilities. Recently, given the high performance of emerging wearable technologies, new applications have been proposed including the every-day support of able-bodied subjects such as workers. The execution of repetitive operations or actions that require excessive effort are the main causes of musculoskeletal injuries in people working in production lines or construction sites. The Industry 4.0 program is bringing companies to re-think their processes by considering human factors, ergonomics and sustainability issues. This is leading to a new trend in automation, which place the workers at the center of a modern smart factory, allowing them to take advantages of new interconnected tools. This new tendency fully embodied Comau's vision. The company, in fact, has coined a term for better picturing its vision: HUMANufacturing.

In this framework exoskeletons have the potential to become more and more adopted by industries as tools to provide support to the workers, preventing the rising of musculoskeletal diseases. This paper provides an overview of the main drivers of this nascent technology. Specifically, it aims to define the requirements that led to the development of an industrial exoskeleton, considering both the end-users and the manufacturers perspective, and showing how the HUMANufactuing approach has a role during the development of a new product.

Keywords: Industry 4.0 · Upper limbs exoskeleton · Ergonomics · HUMANufacturing

1 Exoskeletons: From Medicine to Industry

Exoskeletons are wearable external structure that enhance the wearers physical strength. Exoskeletons work in conjunction with the wearers, reproducing his/hers biomechanical movements. Exoskeletons has their origin, in the late 60ies, both in the medical and in the military field. In the first case they were born as assistive technologies for handicapped patients, in the second cases they had the aim to augment the ability of military users [1]. In the past five years exoskeleton technology has been transposed to the industrial market. Since it is a new technology and the application for

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industry are still under investigation, data regarding exoskeleton market in industry are few and tend to be different.

The reasons why this technology is now being under use for industrial application are plenty. They go from the possibility of minimizing absenteeism from work, to providing factory accessibility to employee of all ages, and/or assist in reducing strain and stress on joints, and finally, and equally important, they started to be adopted with the aim of improving the operators work quality [2]. Several long-term studies are necessary to further investigate the previously mentioned benefits, which are not the target of this work. On the contrary, this paper focus on the main drivers that brought this kind of technology to the industrial field, providing an overview of the requirements necessary to build an industrial exoskeleton.

2 Market Drivers

2.1 Work-Related Musculoskeletal Disease

Musculoskeletal diseases (MSDs) are injuries and disorders that affect the musculoskeletal system; the apparatus that provide support, movement and stability to the human body. Some of these disease, include, for example, problems such tendonitis, ligament sprain, digital neuritis, carpal tunnel, rotator cuff syndrome and others that may concern bones, cartilage, tendinous ligaments and joints.

Despite in the past year, the health and well-being of the operator has always been an employer priority, the rate of work-related disease in general is still high, one every 5 workers in Europe. Of these disease, almost 50% can be classified as MSD, as shown in Fig. 1, meaning that almost half of European workers (75–80 million) suffer from Work Related Muskoskeletal Diseases (WMSDs) [3].

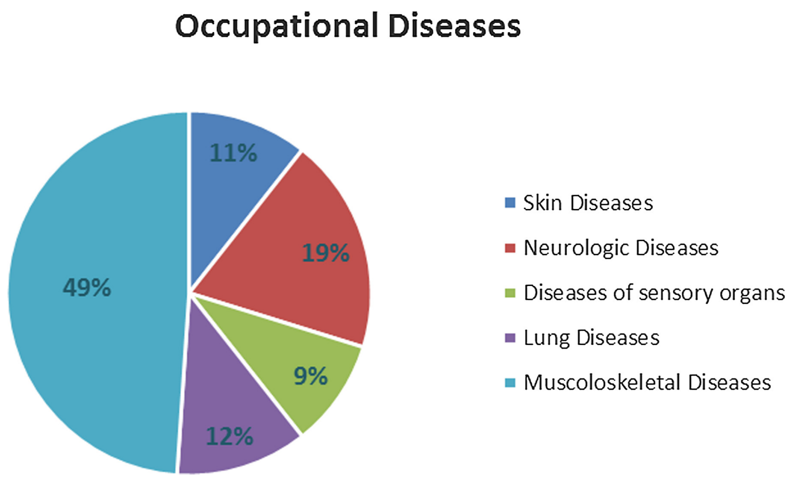

Fig. 1. Distribution of occupational diseases in Europe

In general, work related MSD can be divided depending on the body part they are acting on: lower limbs, backs or upper limbs. According to the UK department of labor, 45% of MSD concern the upper limbs. The most common ULMSD include: rotator cuff syndrome, shoulder bursitis, carpal tunnel syndrome, myofascial 7 pain of upper neck [4]. Those that concern the shoulder are the most critical since they may require a long recuperation period. A risk factor that may cause shoulder disease is any kind of job that required to work with elevated arms, in particular any work performed at or above the acromion level, this is motivated by the fact that this kind of movement imposes high intramuscular pressure and biomechanical demand, loading the soft tissue on the shoulder complex [5].

In US, the direct cost associated to MSD from the companies have been about 50 billion dollars, while the indirect cost can be up to five times the direct cost. It has been documented that shoulder injuries, may results in about 23 lost work days comparing to other kind of injuries that requires from 7 to 9 days off [6].

In UK, an estimated of 3 million working days were lost due to UL-WRMSD, an average of 13 days per case. The total costs to the companies were about 500 million pounds per years. These costs are the sum of work-reorganization, sickness payment, insurance, administration and legal costs.

The economic and human costs of MSDs are unnecessary since Musculoskeletal disorders are “preventable”.

2.2 Ageing of the Population

Another key driver is the ageing of the population that need to be active and independent for longer time. According to Bureau of Labor Statics people are not retiring in their 50 anymore. In US the number of workers aged 45 and older increased from 34% to 44%. Those employees may start to experience physical and mental changes with vision, hearing, mental health and stress level. The ageing it may be also related with the lead of sprains and strains and injuries in the different job sector [7].

3 Development Requirements

Most of industrial exoskeleton currently available on the market, have the aim of providing support to the upper limb. When talking about passive exoskeleton, the intention is most of the time to provide a re-distribution of the load, trying to preserve the shoulder joint, being one of the most exposed joint to high biomechanical risk. Below the main design requirements for the development of a passive upper-limb exoskeleton are recapped.

3.1 End-Users Perspective

We will consider as end-users all those operators that work in manufacturer scenarios and that are subject to overhead and repetitive movements. Ideally, they will use the device every day for their entire work-shift. Therefore, they would need a device to be light, or, at least, with almost no perceived additional weight to his current equipment.

As well, they would like the device to be breathable, comfortable, and at the same time it should not to impede any kind of movements he/she usually performs during the working hours. Since the job considered, most of the time, may be an exhausting job for the operators, the final aim of the exoskeletons should the one of bringing relief to the users by alleviating their daily fatigue [8]. If the benefit of using the device overcome the possible negative residual drawbacks (e.g. dressing and undressing time) the operator may be willing to accept a compromise in wearing it.

It is necessary, though, to consider the following two points: first of all, since for most of the end-users, an industrial exoskeleton is something far from their imaginary and everyday life it is fundamental to create awareness and educate them on the actual features and benefits exoskeletons may bring. In order to let them gain confidence with this kind of devices and collect more specific input, it is suggested to involve the end users since the very beginning of the development, and keep the same level of involvement during pilot test with each versions of the device. This is, in fact, reflecting the 'Humanufacturing' approach in the developing phase of a new product made for workers.

Second, it is necessary to consider that, since, at the moment, the technology is not yet mature, the operators are the key figures who will have the final word on the adoption of this new technology.

3.2 Manufacturer Perspective

From the manufacturers perspective, different factors are coming into play. First of all the necessity to guarantee and provide the well-being of the operator. In a sense, exoskeleton, may be seen as a way to make the factory more attractive to work, since they are a tangible symbol of the fact that the employer is taking care of his/her employee. Second the device should respect the plant safety requirements. E.g. if there are aerial line or dynamic line, it is important that the risk of getting stuck with the surrounding environment is minimized. This may be translated in avoiding any kind of cables or tubes protruding from the device itself. Third, it is necessary to satisfy the technical specification of the material of the clothes and uniform usually used in the plant considered. Of course this may change from industry to industry. Food and Medical Industry are the more restricted in terms of uniform and clothes requirement, while industry such as foundry industry may require a fire-resistant device.

Fourth, the manufacturers would also require a minimum time of dressing and undressing. This time, in fact, is considered time of 'non-added value' for the production.

Finally, and equally important, the manufacturer would require a cost-benefit analysis in the long term. This analysis would be depended on the specific industry and company that decide to adopt the technology. Since, among other factors, it is also correlated with the potential number of operators that perform an application where this technology may be used.

3.3 Clinical Perspective

Even if we are talking about industrial devices, exoskeletons, for its nature, have a strong potential clinical impact. During the development phase it is important to ensure that the requirements from a clinical and physiological perspective are met.

The functional target of the device is to reduce the operator fatigue during his/her daily activity. This is possible when there is a reduction of the muscular activation when the operator is wearing the exoskeleton compare to when he/she is not wearing it. The target of a passive upper limb exoskeleton are the muscles of the shoulder chain. Therefore, it need to be verified, through clinical studies, that this hypothesis is valid. Another important point is the avoidance of overloading other muscles of the human body. This, may ensure as well, the avoidance of other kind of discomfort to the users.

Finally it is necessary to verify that the use of exoskeleton do not provide change in the subject posture and/or in the kinematic of the persons.

Both acute studies and long term clinical studies are necessary to investigate these points. At the moment, in the literature, no long-term studies are currently present given the recent years of the adoption of this technology in the industrial field.

4 Discussion and Conclusion

The aim of the work was to first explain the reasons that are leading a technology such an exoskeleton to be exploited in industrial fields, secondly to show the challenges in the definition of the requirements for the development of an exoskeleton for industrial purposes. Answering the new emerging need and exploiting the benefits coming from its background, Comau is the first industrial company adopting the Humanufacturing approach, both for its vision and for its development of new technologies.

As result, using the rationale and the requirements described in this paper, Comau lunched on the market a revolutionary upper limb exoskeleton called “MATE”, which stands for muscular aiding tech exoskeleton.

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