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Collaborative workcell in industrial assembly process with online ergonomics monitoring

Daniel Lanzoni[1,2], Francesca Negrello[2], Alessio Fornaciari[3], Gianluca Lentini[2], Stefano Ierace[4], Andrea Vitali[1], Daniele Regazzoni[1], Arash Ajoudani[2], Caterina Rizzi[1], Antonio Bicchi[2] and Manuel G. Catalano[2]

***Abstract*—With the advent of Industry 4.0, new technologies are introduced to provide welfare beyond jobs and growth, such as collaborative robots. To be effective, the collaboration between human and robot should be safe, intuitive and stable. Safe collaboration does not only means avoiding human-robot contact, the operator must also feel confident during the collaboration with the robot and avoid incorrect postures (physical ergonomics). In this work, we analyzed an industrial use-case related to the automation of manual tasks in production processes. We propose a collaborative workcell design which integrates a solution to real-time remote control of operator's ergonomics in an interactive environment. The platform is tested in a real use case that involves several mechanical tasks in different scenarios, with and without the support of the robot. The results show both improvements in operator's working condition when supported by robots and overall in the efficiency of the process.**

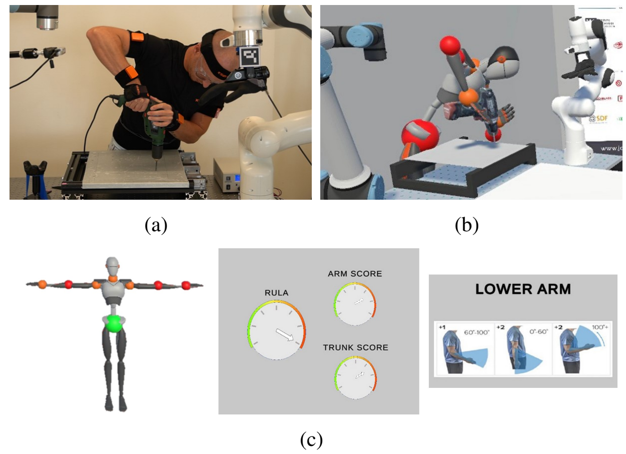
***Index Terms*—Ergonomics, Collaborative Robots, Remote Monitoring, Motion-Capture System**

I. Introduction

Nowadays, the automation of industrial realities is widely different between large, medium and small enterprises (SME). Industry for mass production exploits fully automated production lines, often exploiting industrial robots. On the other side, in SME, given the flexibility of the production processes are often user centered and operator's manual skills cannot be fully replaced.

In this context, innovative technologies such as cyber-physical systems, the Internet of Things and Artificial Intelligence support the development of the smart factory [1]. One of the main technologies are collaborative robots (cobots), which could be used to reduce the physical workload of operators letting them concentrate on the most challenging tasks [2]. An increasing number of industries are considering this, with the goal of improving working conditions for operators. As demonstrated by the International Data Corporation's (IDC), projections that expect during the 2022 an increase of automation by means of 35% of robots and others intelligent systems [3]. In particular, for SME cobots are especially suitable. Productivity may benefits from combining the strength of cobots with the sensitivity and dexterity of human workers. These type of robots allow to interact in a shared workspace with the operator to perform a number of tasks.

[1] Dipartimento di Ingegneria Gestionale, dell'Informazione e della Produzione, Università degli Studi di Bergamo, Viale Marconi 5, 24044 Dalmine (BG), Italy, daniel.lanzoni@unibg.it.
[2] Istituto Italiano di Tecnologia, Via Morego 30, 16163 Genova, Italy.
[3] Elettrocablaggi, Via Nazionale 2, 24060 Pianico (BG), Italy
[4] Consorzio Intellimech, Kilometro Rosso innovation district, Via Stezzano 87, 24126 Bergamo, Italy



(a) (b) (c)

Fig. 1: Workstation and operator, example of drilling. a) Operator drilling the plate using a drill. b) Remote and real-time monitoring of the operations (Digital Twin). c) Interactive human-model, real-time RULA evaluation and example of sub-index thresholds.

In this paper we propose a collaborative workstation for a SME enterprise (Elettrocablaggi) that designs and produces control panels for automation. Given the highly flexible production environment, currently, their processes are fully manual, this implies an high workload on the operators and also impacts the production quality.

In the revised process the cobots assist the operator in performing several tasks (Figure 1). To maintain process flexibility, our solution provides a suitable and intuitive human-robot interface to program and collaborate with the robot. The solution developed provides also an interactive environment that includes a user monitoring interface that allows to remotely assess the operator working conditions by means a digital representation of the physical system (Digital Twin (DT), Figure 1(b)).

We considered three mechanical tasks: drilling, assembly and screwing. We analyzed the human-robot interaction (HRI) and the operator's ergonomics (Fig. 1(c)) during the activity to evaluate the benefits derived from the introduction of the cobot, both for operator well being and process efficiency.

Regarding the evaluation of ergonomics, our solution integrates several aspects, which individually are covered by novel works in the literature. Recently, some research works propose an automated and real-time evaluation of the physical ergonomics of the operator, such as Caputo et al. [4], resulting to be very useful to analyze the manual tasks in contrast with

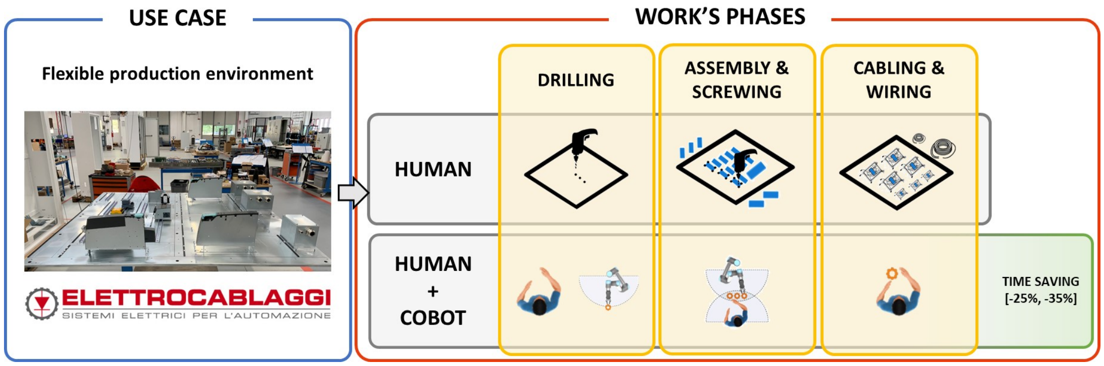


Fig. 2: Analysis of the main phases of the production process. The first line (human) is the current state, where all the tasks are performed manually by the operator, while the second line (Human + cobot) represents the revised layout with the introduction of the cobot.

traditional methods, which are based on standard tables and sets of offline data [5].

This work was carried on within the JOiiNT LAB[1], which is a joint laboratory established between IIT[2] and Consorzio Intellimech[3], dedicated to applied research and technological transfer.

II. Collaborative workcell

A. Use-Case description

We analyzed the assembly process of control panels which is represented in Fig. 2. It consists of three main phases:

- **Drilling**: in this phase the operator draws the holes location on the metal plates that will house the electrical components and drills them. This step is particularly demanding for the operator due to the high loads involved and the size of the plates (2m x 1m) that may lead to uncomfortable positions to reach the target location. While the hole position should be identified by the operator, the cobot could assist the machining part.
- **Assembly**: in this phase the operator places the components on the metal plate and screws them to the plate. This activity does not require particular operator skills, while it could introduce some moderate effort due to the component weight and location on the plate. This activity is suitable for cooperation between human and cobot.
- **Cabling and wiring**, this step does not involve specific loads, but requires high precision to insert the connectors and advanced skills to manipulate deformable objects, e.g. wires. Therefore, it is more efficient to delegate it entirely to the human operator.

B. Control System Design

According to the previous analysis, it is crucial to preserve the central role of the human assembler in the process. Therefore, we designed the collaborative workstation as shown in Fig. 1. It consists of two cobots UR10 and Panda, equipped respectively for assisting the drilling and the assembly tasks and a 'trackable pen' that allows the operator to program the robots in an intuitive fashion, leveraging also on learning in one shot techniques [6]. The framework used interconnect the different parts of the workstation is based on ROS (Robot Operating System)[4];

In the redesigned workflow (Fig. 2 Human + Cobot), the operator needs to program the location of the holes and to teach how to grasp and manipulate the components over the plate by means of the digital pen. Then the drilling is performed automatically, while human and robot cooperate during the assembly phases.

C. User Monitoring System Design

To analyze the operator condition in the workstation we need a motion capture system that satisfies several requirement:

- **Non-invasive**: the operator must be able to carry out operations with complete freedom, without being restricted by the system used;
- **Accurate**: the final evaluation of the ergonomics must be accurate in order to take the optimal decision;
- Allow to **send data** to perform online ergonomics evaluation;
- Allow to **track objects**: tracking of any heavy objects used during operations have a significant influence on ergonomic evaluation;
- Easy to **integrate** with software, graphical engine for DT, and the workstation framework.

According to this criteria, the choice went on a wearable system composed of inertial sensors (Xsens) because the depth-based sensors (i.e. Kinect) are affected by problems with the accuracy of final data when occlusion occurs [7]. The same problems affects marker-based motion capture systems. In addition, these are composed by a set of cameras that are complex to bring into the company to analize the workstations.

Our systems is composed by 17 IMUs (Fig. 1(a)) containing accelerometer, gyroscope and magnetometer. In this way, it is possible to avoid occlusion problems and track the body

[1]https://www.joiintlab.com/
[2]https://www.iit.it/
[3]https://www.intellimech.it/
[4]https://www.ros.org/

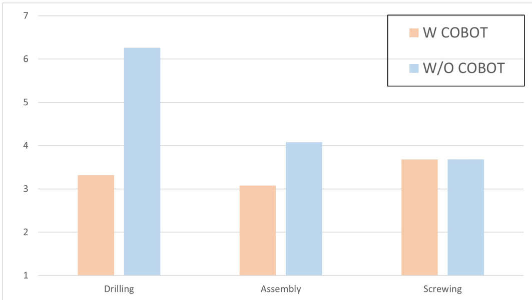


Fig. 3: RULA average during the different phase of the work.

continuously during the performance. The graphical engine Unity[5] has been chosen to develop the DT. This software easily communicate both of the Xsens system and the ROS framework.

In this work, the standard index Rapid Upper Limb Assessment (RULA) [8] has been exploited to evaluate the physical ergonomic of the operator. This score take into account the postural risk associated to each joint (e.g., shoulder, elbow, wrist, etc.) and eventually the force, such as related to the use of external loads. The ergonomics evaluation is performed online by three indicators (Fig. 1(c)), that refer to the final RULA evaluation and to the two main sub-indexes (arm and trunk) while the operator performs the tasks. The digital twin (Figure 1(b)) shows the virtual avatar and the cobots that replicates faithfully and in real-time the motion of the real one. An interactive human model is shown at the center of the display (virtual skeleton represented in Fig. 1(c)) in order to better emphasize the condition of each joints based on the respective RULA sub-index: each joint's sphere becomes green, orange or red according to the value of the RULA sub-index. Each of these spheres, when clicked with the mouse button, shows on the right column the associated RULA index calculation with an indication on the expected threshold.

III. Preliminary Results

Preliminary tests was carried out by one participant who performed all the phases of the work, both with and without the cobot. The Xsens sensors allow the operator to perform any kind of tasks without interfering in the execution of the actions.

We estimate that this automated procedure saves operations time by about 25% - 35%. Also, as shown in the Fig. 3, drastically improves the physical ergonomics of the operator. In particular, the analysis shows that the most ergonomically onerous task for the operator is drilling. Making this automatic we obtain a twofold advantages: it drastically improve the ergonomics of the operator and reduces the number of times I have to perform this operation. In the automated procedure, the only step that requires attention is screwing. For about 20% of the time, in fact, the RULA is in the range of 5 to 6, which means that further investigation may be needed.

Finally, the online monitoring allows to identify in real-time any eventually incorrect action/task associated to an high RULA's score. Also, it can be useful to analyse remotely the interaction between the human and the robot and evaluate the correctness of the collaboration.

IV. Conclusion

In this paper, we presented the design of collaborative work-cell with online ergonomic monitoring based on a real use case provided by Elettrocablaggi. The solution developed allows a remote and online monitoring of the RULA index during the different phase of a general operator's work; moreover provides a DT that faithfully replicates the movement of the operator and the cobots. We analyzed the considered tasks in two conditions, with and without collaborative robots. Preliminary results show that the most onerous manual operation is the drilling phase, for both the postures assumed and the forces involved during the process. The introduction of the cobots in the process allows an improvement of the operator's working conditions.

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