CURAMI: Human-Robot Collaboration for Intelligent Assembly Tasks

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***Abstract*—Within the context of Industry 4.0, human-robot collaboration plays a crucial role: it potentially increases the process efficiency while improving human operator working conditions from both an ergonomic and a self-satisfaction point of view. To face this challenge, this paper presents CURAMI: an intelligent robotic framework able to manage the warehouse and feed the assembly workstations in a semi-autonomous way. CURAMI also assists workers during the assembly and assesses their postures in real-time through an ergonomic tool able to detect potentially dangerous movements and give adequate feedback. The benefits are manifold: the framework reduces human operators' fatigue, improves their comfort, and minimizes injuries risk.**

***Index Terms*—Computer Vision, Task Scheduling and Decision Making, Robot Motion Planning, Assembly, Human-Robot Collaboration, Ergonomics, Knowledge Base**

I. Introduction

In an industrial scenario where product customization is increasingly essential, making the warehouse management efficient and automated becomes crucial for being competitive. Most warehouses are still manually managed: operators check the stocks, receive the materials, store them, and supply the workstations. With the increase of product customization and their consequent similarity, however, these operations are becoming more and more error-prone, leading operators to confuse similar - but not identical - assembly sequences and causing delays and additional costs. The smaller the production batches are, the more crucial this aspect becomes due to the increase in the number of production switches. Another crucial challenge in the current industrial scenario is the improvement of human working conditions. The aim is to relieve workers from repetitive and potentially harmful activities to reduce task-related physical and mental stress, injuries risk, as well as increase their self-satisfaction.

Within this context, this paper proposes CURAMI (*Collaborazione Uomo-Robot per Assemblaggi Manuali Intelligenti*): an intelligent robotic framework for semi-autonomous warehouse management and just-in-time supply of ergonomic robot-assisted assembly workstations. CURAMI also assists human operators during the critical phases of the assembly (e.g., by holding or changing the pose of heavy components to facilitate human actions). Finally, it real-time monitors operators' working postures, detects potentially hazardous non-ergonomic human poses and suggests operators corrections and improvements for safer and healthier working habits.

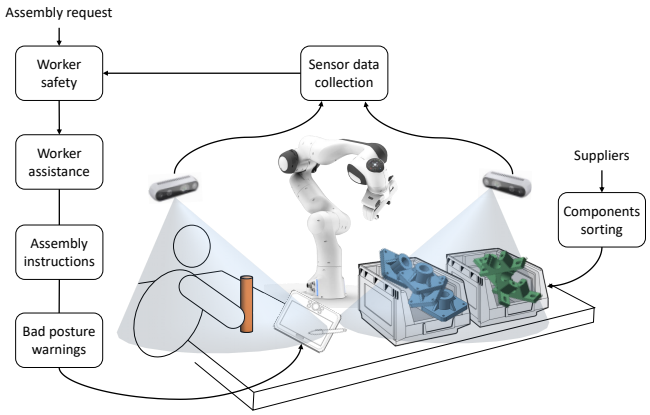

Fig. 1. The CURAMI framework.

The rest of the paper is organized as follows. Sect. II reviews existing works on human-robot collaboration for warehouse management and assembly execution. Sect. III describes CURAMI and overviews its five pillars: vision, task and motion planning, ergonomics, digital assistance, and the existence of a knowledge base. Finally, Sect. IV concludes the paper.

II. Related Work

Multiple studies have been performed on how to improve work quality in assembly workstations. [1], for example, analyses time consuming and fatigue causing factors. [2], instead, investigates the effects of assembly of a product on operator performance using a fully adjustable ergonomically designed assembly workstation.

With the advent of collaborative robots, Human-Robot Collaboration (HRC) emerged as a branch of human-machine interaction that, together with the adoption of ergonomic workstations, can further improve work quality. However, efficiently subdividing tasks between humans and robots is still challenging. A valuable approach is by task analysis: [3] evaluates HRC based on productivity, quality, and human fatigue implications. [4] takes into consideration also human

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safety and part feeding: it distributes the tasks in HRC by identifying task-features as decision factors for dynamic workload distribution in HRC. Task features used are weight of the assembled part, the displacement, accuracy requirements and dexterity requirements. However physical features of components, are not described that can influence a robotic task performance. [5] discussed various robotic skills required to perform tasks in automotive assembly lines. Robotics skills (pick, place, move along path, navigate, wait, handle/apply tool, and trigger) were identified and further extended with six additional skills (position, hold, align, apply force, and apply force along path).

Our approach combines ergonomic studies with HRC ones, proposing a system able to guarantee workers correct posture while assisting them based on physical features of components, human fatigue, and safety.

III. The CURAMI framework

CURAMI is an intelligent robotic framework for semi-autonomous warehouse management and just-in-time supply of ergonomically efficient assembly workstations (see Fig. 1). In detail, a manipulator robot divides and places in assigned areas the components coming from the suppliers. When a product should be assembled, the robot feeds the assembly workstation with the right pieces in the correct order. If required, it also assists the human operator by holding or turning around heavy components and adapting their pose according to human's preferences (e.g., working height and dexterity). To further improve the operators work conditions, a motion-tracking system is mounted on the workstation together with digital display support. The former monitors human movements and fine-tunes the workstation configuration (e.g., table height and lighting). Such a system warns operators about "bad" postures, potentially reducing work-related diseases. The latter provides the visual instructions to assembly the products.

A. The Five Pillars

The framework is based on five pillars, each willing to face one of the CURAMI challenges. Their description follows.

- **Vision**. The multi-camera system proposed in [6] tracks human motions and provides this information to the subsequent modules. At the same time, it recognizes the components according to a complete CAD-models library.
- **Task and Motion Planning**. Starting from the studies we performed in [7], [8], a Task Scheduling routine efficiently supplies assembly workstations while assisting human operators. A collision-free robot Motion Planning is also fulfilled to ensure worker safety.
- **Ergonomics**. The worker is provided with a fully adjustable ergonomically designed assembly workstation. Moreover, from perceived data, a real-time estimation of the operator upper-body kinematics is performed. Principal ergonomic indicators, selected among available scientific literature and industrial practice, are then computed and exploited to give feedback on posture correction.
- **Digital assistance**. A digital assistance module is integrated in the framework to support operators in following the correct assembly sequence while providing them with improvement tips on their posture.
- **Knowledge Base**. To increase framework efficiency and reduce the overall computational cost, a Knowledge Base based on [9] is employed to store gained experience and environmental data. Such information includes components' features, processing and assembly sequences, robot capabilities, human operators' capabilities, and preferences.

IV. Conclusions

This paper proposed CURAMI: an industrial framework targeting assembly scenarios and endorsing, through the introduction of cooperative robotic manipulators, semi-autonomous warehouse management, just-in-time workstation feed, and robot-assisted continuous monitoring of the ergonomic risks. Focusing on ergonomics, CURAMI could potentially reduce the risks associated with non-optimal operators' movements and poses, thus limiting both their fatigue and the occurrence of work-related diseases. Focusing on warehouse management, the framework could significantly reduce inefficiencies due to components misplacement like wrong stock management and incorrect workstation feed. Moreover, it could benefit workers' self-satisfaction, relieving them from repetitive and tedious activities in favor of more challenging and satisfactory tasks. Finally, by automating and synchronizing the workstation feeding process, CURAMI could reduce the cost of coping with errors in the assembly.

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