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Intelligent cobot systems: human-cobot collaboration in manufacturing

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Introduction

During the last decade large part of research and development in human-machine relationships has evolved in the arena of collaboration between human operators and their digital workplace including machines and robots. Cobots (collaborative robots) that safely share the workspace with the operator, came to the front stage of this arena. This is not surprizing since collaborative applications of cobots are more complex than traditional industrial robot applications and provide new challenges to both research and development. To safely share the same space with the worker, avoid collisions, and still be efficient, the cobot must possess some moving and manipulating intelligence. Large part of cobot literature deals with collision avoidance and smart manipulation movements and precision, along with safety measures. However, real collaboration requires much more than collision avoidance. It requires the cobot to be able to track and understand situations in an intelligent way and manage communications in a manner closer to a human-to human communications. Trying to understand human behavior and perception contribute a whole new level of complexity to collaborative robotics. Moreover, human factors and cobot capabilities must be linked to all the modern production systems features that characterize the Industry 4.0 and 5.0 paradigms.

Considering all the above, the special issue combines aspects of human factors (HF) and human in the loop (HIL) with cobots and the integration of advanced technologies, such as: digital twins (DT), augmented reality (AR), machine vision (MV), artificial intelligence (AI), advanced mechatronics, and advanced operator interaction and monitoring. It also provides reports on industrial case studies, new ICT technologies, mathematical models and methods, automatic solutions, and management techniques and approaches.

The future of collaborative applications research is promising as they gather popularity. The intelligence requirements of human-machine collaboration are expected to provide new challenges in the forseeable future. In that regard, cobots are expected to continue to play a major role in this vivid arena.

Summary of the special issue articles

This Special Issue collects 10 papers that cover different aspects of Cobots systems design and management with emphasis on the human perspective.

The special issue contains a literature review of cobots in manufacturing and assembly that gives the big picture of this evolving field. The literature review title is **Collaborative robots in manufacturing and assembly systems: literature review and future research agenda.** The review declares that recent research has already shown that Cobots bring many advantages to manufacturing systems, especially by improving their flexibility. The Systematic Literature Review (SLR) investigates such impacts in the context of assembly and disassembly lines is performed.

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Accordingly, insights are formulated, and research perspectives are highlighted.

The very basic requirement of cobots is to safely share the workspace with humans. Thus, it is natural to first present work on adaptive safety constraint by predicting trajectories of closest points between human and co-robot. The paper's title is **Development of adaptive safety constraint by predicting trajectories of closest points between human and co-robot.** The paper declares that safety is a critical component for human-robot cohabitation. The human trajectories are not known in prior, which may cause the above safety constraint to fail. In this paper, safe constraints based on discrete control barrier function are proposed. The results show that the robot can maintain a safe distance from the human when the method is used.

The human movements during manual assembly tasks are reflecting the opposite side of the cobot movements. Augmented Reality (AR) is providing many advantages for the human assembly operator, but also frequently cause a cognitive overload. The following paper deals with these pros and cons. **HAR2bot: A Human-centered Augmented Reality Robot A Programming Method with the Awareness of Cognitive Load.** Augmented Reality (AR) applied to Cobot Systems Programming. About the Cobot programming AR can be a valid element to support novice users to complete complex tasks effectively, efficiently, and intuitively. To answer this question, a human-centered augmented reality programming interface is proposed with the awareness of cognitive load.

Assigning tasks to humans and cobots determines the movements and requirements of the collaborative work in Cobot systems. The following paper deals with multicriteria classification of tasks to support the task allocation and assignment to humans and cobots. **Multicriteria Task Classification in Human-Robot Collaborative Assembly through Fuzzy Inference.** Cobot excels in strength, endurance, accuracy and is expendable for risky activities. Therefore, task assignment problem in a production line with coexisting humans and cobots should make the most of everyone respective abilities. The outcomes should be both an increased productivity, improved production quality, human safety and well-being.

Task allocation to humans and cobots aims at maximizing the advantages of both humans and robots. The following paper shows a case that illustrates this assertion. **Adaptive Planning of Human-Robot Collaboration Disassembly for End-of-Life Lithium-ion Batteries based on Digital Twin.** In this paper it is shown that Human-Robot Collaboration Disassembly mode maximizes the advantages of both humans and robots, progressively replacing single-person disassembly and single-machine disassembly to become the standard method for disassembling. The results demonstrated that the proposed method could plan an effective action sequence, effectively reduce the design time of the target domain disassembly strategy and enhance the flexibility of Human-Robot Collaboration Disassembly.

Another paper that deals with task allocation between humans and cobots. **The effects of role transitions and adaptation in human-cobot collaboration.** This study proposes a human study in which 16 participants executed a collaborative human-robot sawing task where the Cobot altered between three different control strategies. The results suggest that subjects prefer to abandon modes that require more effort, and they adapt faster to energy demanding modes and subjects prefer collaborative mode.

An interesting point related to the effects of cobots on motivation is investigated in the paper titled **Investigating the effect of intelligent assistance systems on motivational work characteristics in assembly.** In this paper, digital assistance systems are designed to counteract rising cognitive demands caused by increasingly individualized manufacturing processes in assembly. The results indicate that the digital assistance systems improve some motivational work characteristics of the assembly workplace, although it misses the primary goal of cognitive relief.

Fault detection and diagnostics of collaborative robots' operations is crucial feedback for assessing the quality of cobot's operations and tasks. The following paper discusses this issue thoroughly. **A framework for fault detection and diagnostics of articulated collaborative robots based on hybrid series modelling of Artificial Intelligence algorithms.** Cobots are subjected to degradation and functional failures may influence their operation, leading to anomalous trajectories. This work proposes an approach that leverages on a framework for fault detection and diagnostics of Cobots. The framework demonstrates the capability to accommodate and handle different trajectories while notifying the unhealthy state of Cobots.

Active Learning and Novel Model Calibration Measurements for Automated Visual Inspection in Manufacturing. Model calibration measurements for automated visual inspection in manufacturing. Quality control is a crucial activity performed by manufacturing enterprises to ensure that their products meet quality standards. Artificial intelligence enables higher degrees of automation, reducing overall costs and time required for defect inspection. This paper proposes a novel approach to probabilities calibration of classification models and two new metrics to assess the performance of the calibration.

Finally, a paper that presents an intelligent digital twin shows that it can improve situational awareness. **Self-improving situation awareness for human-robot-collaboration using intelligent Digital Twin.** The situation-awareness, particularly of the collaborative robot, plays

a crucial role when human and machine work together in a human-centered, dynamic environment. In this paper, the authors propose a metric for measuring the state of situation awareness. The scheme of situation awareness is adapted to the collaborative robots' domain to improve the situation consistency systematically. The quality metrics show reasonable behaviour and consistency due to the improvement process.

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Declarations

Competing interests No competing interest to declare.