Work-in-Progress: Fog Computing for Adaptive Human-Robot Collaboration

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***Abstract*—Fog computing is an emerging technology that enables the design of novel time sensitive industrial applications. This new computing paradigm also opens several new research challenges in different scientific domains, ranging from computer architectures to networks, from robotics to real-time systems. In this paper, we present a use case in the human-robot collaboration domain, and we identify some of the most relevant research challenges.**

I. INTRODUCTION

The paradigm of fog computing appeared in the last years with the idea of complementing cloud architectures with a computing architecture that is closer to the end-devices [2]. This allows for more predictable and reliable behavior, while extending the functionalities that can be implemented on the single devices.

One of the relevant industrial applications that could benefit the most of the fog computing paradigm is the collaborative robotics [3], [7]. In particular, the design of an improved human-robot interaction (HRI) is critical for advances in industrial applications. A robot can assist a human with a repetitive, highly defined set of actions, whereas the human operator can focus on more cognitive-oriented activities. This cooperation mitigates the need for manpower, increase the rapidity of the manufacturing process and thus decrease the operational cost of the factory.

On the other hand, this calls for novel computing architectures able to handle a large amount of data in real-time, both coming from the sensors, and sending commands to the robots to adjust its behavior. In this paper, we present a use case scenario where sensors measure the stress level of the human operators collaborating with the robots [5], while the robots adapt their behavior(e.g. speed movement) to decrease the stress level of the human operators. In particular, we highlight what are the main research challenges and questions emerging from the use case.

II. USE CASE DESCRIPTION

Consider the cooperation between different human operators with a set of dual arm industrial robots, such as the ABB YuMi robot[1]. Zanchettin et al. [9] showed that the stress level of the human operator working with such robots decreases when the robot is designed to exhibit a human-like behavior. The intuition behind this finding is that the human operator feels more comfortable when he/she is able to predict what to expect from the robot behavior [1]. On the other hand, human-like design typically comes at the cost of a decreased efficiency in the robot operation [6].

This use case considers a real-time monitoring system of the stress level of multiple operators collaborating in a production line with multiple dual arm robots (see Figure 1). Based

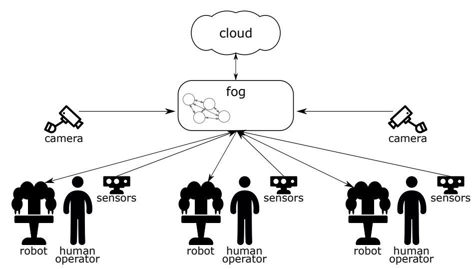

Fig. 1. Architecture of the system.

on the measured values, the behavior of the robots will be adapted to decrease the stress level while maximizing the efficiency of the robots' tasks. The operators and the robots are monitored by cameras and stereo-cameras, while biometric sensors measure physiological signals, such as temperature, skin conductance, and pulsewave [8]. Such signals must be transmitted and processed in real-time, to (i) provide safety guarantees on the collaboration between the robots and the operators, (ii) estimate the stress level of the operators, and (iii) compute suitable strategies to both maximize the efficiency of the robots operation, while minimizing the impact on the stress level of the operators. For example, when the operator is not within the workspace of the robot, the latter can work at full speed maximizing the efficiency of its production. On the other hand, when the operator is within the workspace of the robot, the robot should reduce its speed, and it should behave in a human-like way.

The computation cannot be computed completely on the robot, since it requires to collect and elaborate information of the overall status of the production line. The need to offload some of the computation, while providing real-time guarantees

This work was partially supported by the European Commission under the project FORA with grant number 764785.

[1]http://new.abb.com/products/robotics/industrial-robots/yumi

978-1-5386-5560-3/18/$31.00 ©2018 IEEE

on the system operation calls for fog computing solutions. In fact, the adoption of a fog architecture can limit the latency of data processing (the computation is performed closer to the end-devices), and makes the latency more predictable.

From an architectural perspective, the system is divided into the following three layers (see Figure 1). **Layer 1 (Sensors, actuation and local control of the Robot)**: Sensors are collecting data, which is sent to the upper layers for further elaboration, actuators are receiving commands from the upper layers, and local controllers control the basic functionalities onboard of the robots.

Layer 2 (Fog Network): The data collected in the first layer are elaborated and sent to the actuators. The behavior of the set of robots is controlled to preserve a safe interaction with the operators, while maximizing their productivity, and minimizing the impact on the stress level of the operators. Additional and aggregate data is forwarded to the upper layers.

Layer 3 (Cloud): The data sent from the fog layer is elaborated for business analytics, predictive maintenance, and other long-term purposes.

III. Fog computing challenges

The described scenario poses a number of challenges related to the design, implementation and management of the fog layer. Due to its central role, it is of key importance to identify and address such challenges to optimize the overall behavior of the system. We therefore highlight five main research challenges (RCs) related to the presented use case.

RC1: Fog architecture design. The fog network is a distributed environment consisting of fog nodes offering resources for hosting virtualized services. An orchestration node can be included in the architecture to provide virtualized resources, to monitor and to controls the rest of the nodes within the same fog network, with the main responsibilities of (i) managing the virtualized resources within the fog network, (ii) schedule and dispatch requests to the fog nodes, and (iii) monitor the fog colony. Types of connection and protocols for the data transmission of the sensors and actuators to and from the fog devices must be properly designed according to safety requirements.

RC2: Mixed-criticality management. The fog infrastructure has a limited amount of resources, that needs to process different types of information with different levels of criticalities. High criticality operations need to be prioritized, and suitable scheduling approaches must be designed.

RC3: Resource management and optimization. The number of operators and active robots, and therefore of the sensor data can increase and vary significantly within the regular operation of the production line. This affects the processing capacity and bandwidth needed required from the fog perspective. Suitable elastic approaches needs to be designed in order to adapt and optimize the resources allocated for the elaboration of the incoming data. Scalability of the provided solutions is therefore the major challenge in this respect.

RC4: Deployment and dynamic placement. The initial deployment of the different application components for the real-time monitoring, data elaboration, and behavior adaptation of the robot requires a careful analysis of how to decompose the application in components – e.g., microservices – and how to deploy such components in the designed architecture. Moreover, the placement of such component can be re-evaluated at run-time based on the actual utilization and availability of resources, locality of data, fault tolerance mechanisms, or real-time requirements.

RC5: Provide real-time guarantees. The presented use case has a mix of both hard and soft real-time requirements. The adaptation of the robot speed, when the operator enters the robot's workspace is of primary importance for a safe co-existence, imposing hard real-time requirements on the reaction time of the robot. On the other hand, the evaluation of the stress level of the operator and the consecutive human-like adaptation of the robot behavior is a secondary goal and it is associated with soft real-time requirements.

IV. Related Work

Several cloud-based approaches for the design of novel HRI usage scenarios have been proposed [4]. Whereas the potential of adopting cloud computing solutions may significantly improve the capabilities of the multi-robot system, three main factors limit the usage of such approaches in practice: the need for connectivity to the internet, the high data rates due to the high number of sensors involved, and the need for predictable and timely responses from the cloud service. Other relevant use cases for fog computing architectures are presented in [2].

V. Conclusion and Future Work

This paper presented an HRI use case where the use of fog computing is necessary for the correct operation of the multi-robot system. RCs were identified, with focus on the fog computing aspect of the use case. Other challenges related to signal processing, robot control, HRI can be also identified within the use case but they are beyond the scope of this work.

As a future work, we plan to better analyze and refine the identified RCs and prototype the presented use case in order to evaluate different solutions for the corresponding RCs.

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