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CREATION OF A FRAMEWORK FOR AN EMPATHY-BASED IMPROVEMENT OF A HYBRID WORKING SYSTEM

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Abstract

Collaborative robotics is changing the way we work, making it safer, more efficient, and more productive, by merging human and robot strengths. The increasing utilization of hybrid working systems has led to a need for improved methods of operator stress detection and mitigation. This thesis proposes a framework for an empathy-based improvement of hybrid working systems. The framework uses galvanic skin response (GSR) measurements, captured with the physiological data sensor "Empatica E4", to detect moments of stress (MOS) in the operator. Subsequently, a stress-level, based on the number of MOS within a predefined duration, is estimated. Therefore, the framework's reactive mechanism adapts the collaborative robot's (cobot) manipulation speed and task allocation by sending the corresponding signals to the robot control. The aim of this adaptation is to reduce the operator's stress-level while maintaining or increasing productivity. The framework was evaluated with a platform for assembling a miniature robot. Results showed that the framework was able to effectively detect moments of stress and adapt the cobot's manipulation speed accordingly. The framework could be used to reduce operator stress and improve productivity in a variety of industrial applications.

Keywords: Collaborative robotics; Empathy; Stress detection and reduction; Reactive mechanism.

1. Introduction

Cobots enhance the classical approach of industrial robots by making it possible for humans and robots to work on a task simultaneously. The growing importance of concurrent utilization of humans and robots is leading to the development of dynamic interfaces to accommodate individual workers' capabilities [1]. Understanding the human's state, particularly stress, is crucial, and this work aims to design an interface that collects physiological data to assess stress-levels and establish a reactive interaction, referred to as empathy, between the robot and the human.

Human-robot collaboration poses challenges such as safety risks, data privacy and security, and limitations in payload and reach. However, one of the biggest challenges is to keep the productivity level consistent, as human behavior is unpredictable and can be affected by factors such as stress and mood. Thereby, the interpretation of the mental state of the operator and a corresponding reaction becomes a key factor. Recent developments are emphasizing the demand for a corresponding non-invasive reactive mechanism that is affected by human manipulation to a minimal extent [2].

That is why authors have dealt with the problem of finding a suitable solution for interpreting the operator's mental state. The paper [3] classifies five existing State of the Art approaches for the operator's emotional state assessment. It concludes that each existing approach is based on "facial recognition", "speech recognition", "body language", "electrocardiography (ECG)" or electroencephalography (EEG).

In the paper [4] the authors investigate the effectiveness of a human sensor-based emergency stop interface designed to respond promptly when a human operator detects or anticipates a potential emergency in the context of Human-Robot Collaboration. The proposed approach utilizes a mobile EEG to detect potential emergencies.

With the BAZAR Cherubini et al. merge the vision and sensing-based approach with a reactive system for power and force limiting with torque sensors within the robot's structure [6]. It is deployed in smart logistics use cases like carrying specific car parts to autonomous ground vehicles for assembling. Since the examined literature shows that the challenge of creating a secure and tamper-free interpretation of the mental state of the human remains, this work suggests a novel approach using GSR/electrodermal activity (EDA). To provide a comprehensive overview of the work's proceedings, the paper is organized as follows. Before depicting the context of the work, the problem and the starting point is outlined. To examine the effectiveness of the framework, a subset is applied in a laboratory setup. Section 3 displays used materials and methods. In section 4, the concept of the framework is shown. The analysis of the results is presented in section 5. In section 6, a concluding reflection of the implementation is presented and recommendations for further research are given.

2. Problem statement

Since 2015, the University of Applied Sciences Technikum in Vienna has been developing low-cost robots made of polyamide for educational purposes [7]. This robot series bears the name of the developer, Mo-Robot or Morobot. In the meantime, however, they have been further modified and optimised for automated production (Design for Automation). One task in this production line is assembly. As can be seen in Figure 1. a), this task consists of several steps. Although all parts have been optimised for automated assembly, hybrid applications (robot and human - Figure 1, b and c) are also being tested as part of the research. These hybrid working systems are designed to combine the high performance of robotic systems with the energy efficiency of humans. In addition, humans are able to check the functionality of the products with little effort (Figure 1, d and e).

The evaluation of concept variants (robot-robot, human-human and robot-human) according to the methodical system in [8] and based on customer requirements has shown that this variant is the optimal one for a given batch size. In addition, threatening circumstances such as climate change and the scarcity of the earth's fossil resources are leading to greater energy awareness in society. Energy efficiency has therefore become an integral part of this work.

However, the interaction between the technical part of the system (the robot) and the biological part (the human) is a major challenge in maintaining a constant level of productivity. In addition, the unpredictability of human behaviour (stress, mood swings, etc.) has an immense impact on the overall efficiency of the hybrid work system. It is therefore necessary to design a reactive system between the robot and the human.

This reaction is called "empathy" and must be decomposed into well-defined correlations between the participants of the system. Each correlation should be defined as an input variable (e.g. stress moment level) for the reactive part of the

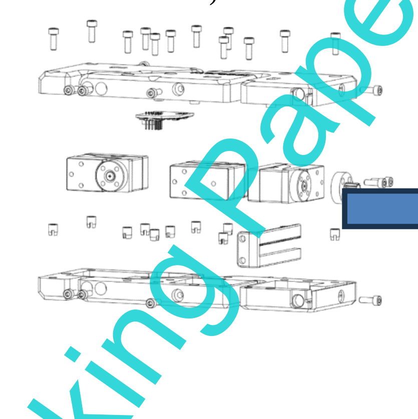
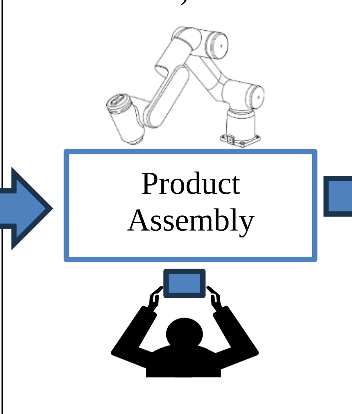
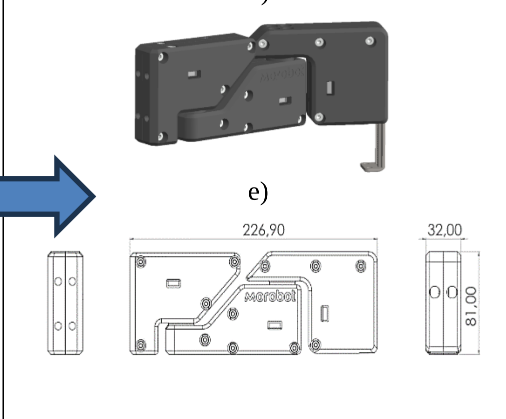
Input : Assembly Task to be performed	**Processing: Human-Cobot Station**	**Output: Product**
a) 	b)  c)	d) 

Fig. 1. Human-Cobot Station- Assembly Task.

system (robot system). This means that the rate of work is set by the human, e.g. in case of fatigue the manipulator's speed should be reduced resp. the manipulator should react with emphatic behaviour.

3. Material and Methods: Processing Station

The proposed structure of the subset, which is shown in figure 2, encapsulates a specific use case scenario where a miniature robot (morobot) is assembled by the human operator and the cobot. The reactive mechanism is the controlling parameter of the PLC program so that the speed of the cobot can be adapted based on the stress level of the operator. An experiment with ten participants was conducted in order to validate the framework.

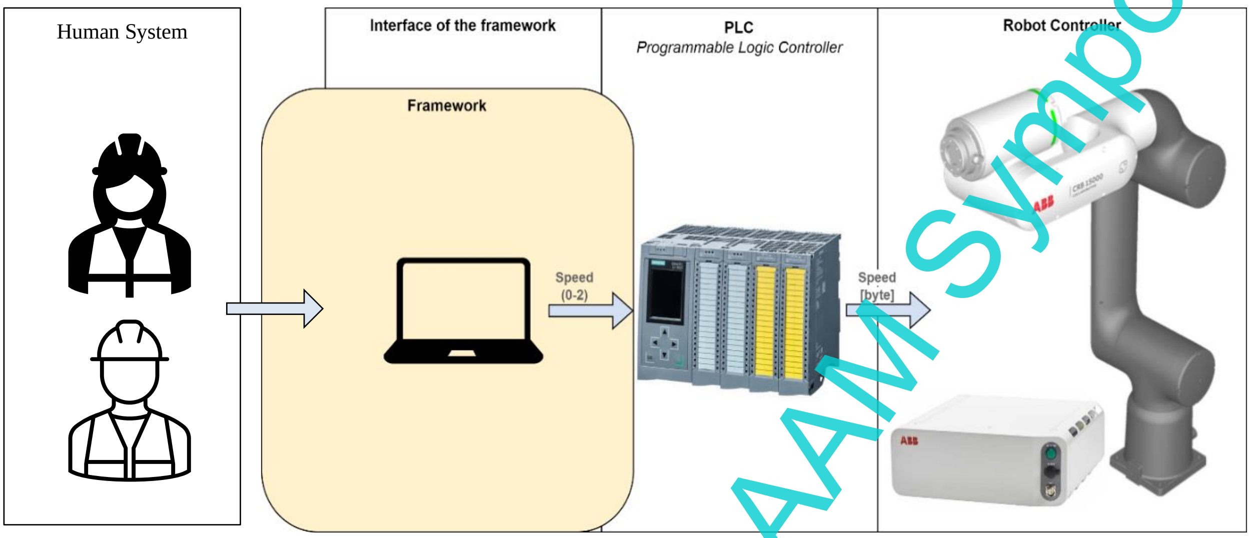


Fig. 2. Structure of the application of the framework's subset

To allow validation of the framework, each operator's stress-level and the corresponding timestamp were captured during the morobot assembly. Due to the window size and the fact that a maximum number of one MOS can be captured per window, stress-level values from 0-2 are provided every 10 seconds.

4. Conception of Collaboration-Framework

As there is currently no available approach for a reaction toward the emotional state of the operator without using vision-based or hardware-expensive equipment, research on possible empathetic approaches was conducted. As a consequence of that, a rule-based algorithm for the detection of MOS suggested in [5] was called into play. With the help of that algorithm a framework, which is composed of three sequential phases that are repeated cyclically (see figure 1), was constructed.

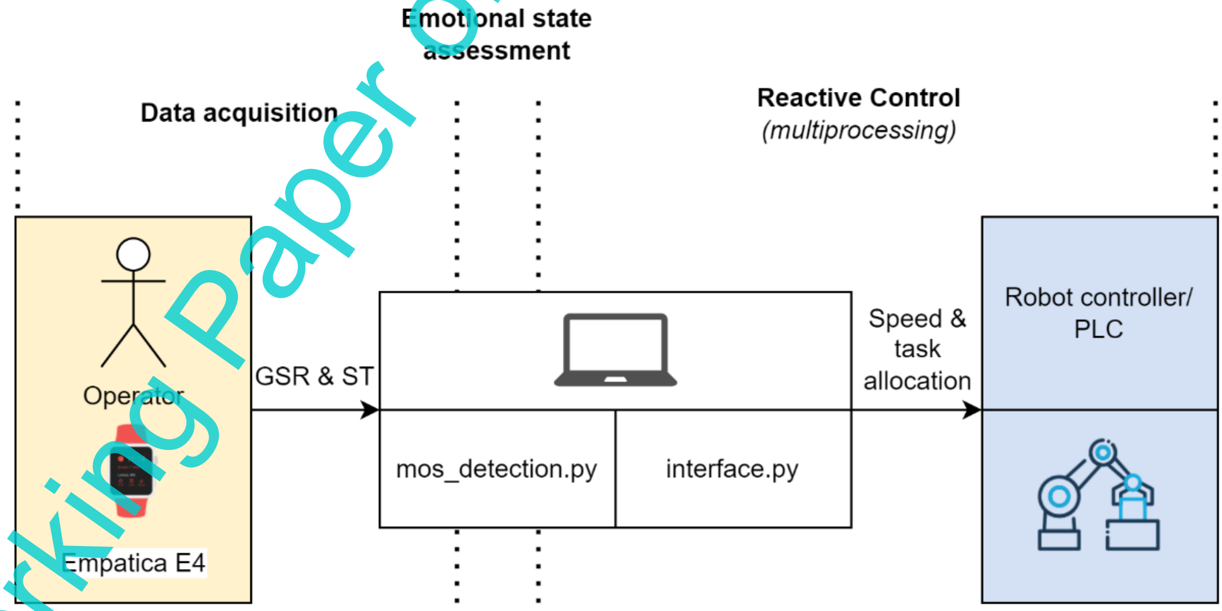


Fig. 3. Structure of the framework and its phases

In the first phase, the physiological data of the operator is captured utilizing the "Empatica E4" sensory module and setting up a Bluetooth-based stream with the USB dongle "BLED112". Subsequently, a PC, serving as an interface, pre-processing the data and estimates a stress-level, based on the changes in the GSR data. This is done with the help of the rule-based MOS detection algorithm suggested in research of Kyriakou, Moser et al. [6]. The proceedings of both works make use of the GSR-value propagation over time and investigate the magnitude and the corresponding derivative. Since the interface is continuously collecting data, a moving window approach was chosen in order to be able to pre-process and make use of the data during runtime. Establishing a window size of 10s ensures that the defined rules of the MOS detection can be applied, and the reactive control's latency is kept to an acceptable extent. By counting the MOS within the last and its previous window, a stress-level from 0 to 2 is estimated.

- ***Case 1*** - The number of MOS in the present and past window is 0; **The operator is not stressed**.
- ***Case 2*** - The number of MOS in the present and past window is 1; **The operator is extremely stressed**.
- ***Case 3*** - The number of MOS in the present window is 1, and the number of MOS in the past window is 0; **The operator is moderately stressed.**
- ***Case 4*** - The number of MOS in the present window is 0, and the number of MOS in the past window is 1; **The operator is moderately stressed.**

According to the estimated level of stress, being an interpretation of the mental state of the operator, the interface sends signals for adapting the speed and task allocation of the collaborative robot. For the purpose of establishing parallel communication between sensor-PC and PC-cobot, multiprocessing for the PC's Python modules was implemented. Thereby, the communication for data acquisition and reactive control can be maintained simultaneously. The following figure gives a comprehensive overview of the implemented processes and the required organization of units and connections for establishing the functionality of the framework.

Furthermore, this reactive mechanism was validated with a subset located in the facilities of "UAS Technikum Wien". In the experiment each of the ten participants had to assemble a miniature robot (morobot) with a predefined task allocation between the human and the cobot "CRB 1500". To apprehend the effect of the presence or absence of the reactive control, each participant assembled the morobot with and without it being active in an arbitrary order.

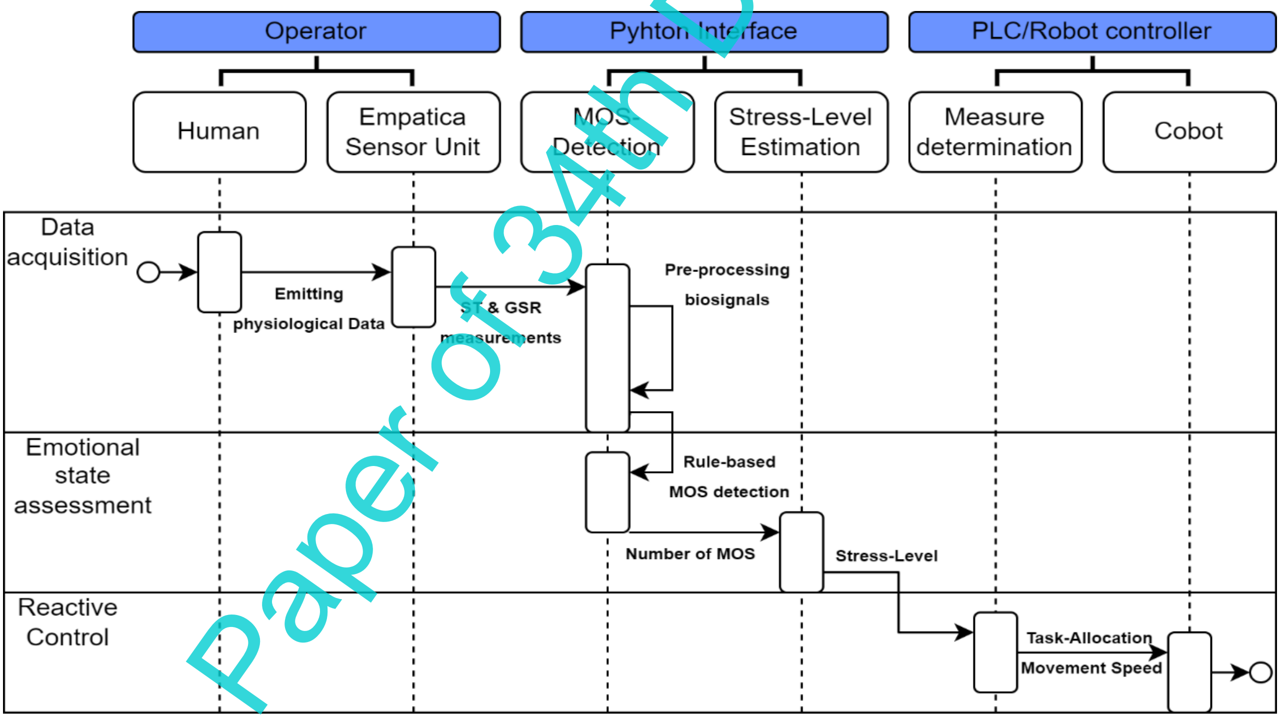


Fig. 4. Units and connections of the framework

5. Results

The results showed that the framework was able to adapt to the speed of the cobot and thereby change the Duty Cycle of the assembly process. Furthermore, a change in the workload of both the cobot (WLC) and the human (WLH) with the reactive mechanism enabled or disabled can be observed. However, the effect of the presence of the reactive mechanism on the well-being of the operator was difficult to examine. As table 1 also shows, due to the sequential process order of the subset, a validation of the positive impact of the framework's presence on the operator's mean stress level (OPML) was strenuous to accomplish.

Parameter	Enabled	Disabled	Difference[%]
OMSL	0.5	0.38	24.23
WLC	7.27min	7.52min	10.32
WLH	7.42min	7.7min	4.64
Duty Cycles	18.67min	16.83min	9.86

Table 1. Parameter of the validation process and relative comparison

6. Conclusion and Future Work

The proposed framework introduces a novel approach to reacting to the operator's mental state by capturing MOS, estimating stress levels, and implementing empathy-based improvements in a hybrid working system. Unlike existing solutions, this framework offers a non-invasive, difficult-to-manipulate algorithm for assessing operator well-being. It suggests actions to enhance the emotional state of human operators during collaborative tasks, potentially increasing productivity and reducing Duty Cycle. By fostering empathy between cobots and human workers in the manufacturing environment, this framework aims to improve job satisfaction and overall well-being, marking a crucial step toward a more harmonious and productive future in manufacturing. However, the performed research's validation is limited to the utilized subset consisting of equipment present in the facilities of the "UAS Technikum Wien". Therefore, the validation proceedings leave gaps for improvements.

In terms of future work, several opportunities for improvement and research gaps have emerged. Validation of the framework with a customized or substantially modified subset within the "Digitale Fabrik" of the UAS "FH Technikum Wien" could enhance result significance. Exploring suitable cutoff frequencies for MOS detection and adjusting statistical power calculation parameters, such as effect size and sample size, could lead to more accurate evaluations. Additionally, leveraging geo-data from "Empatica's" E4 sensory module could establish a novel safety mechanism for collaborative setups. Addressing challenges posed by metal implants in data capture and investigating such scenarios further would provide valuable insights. In an evolving work landscape, this framework not only envisions empathy-based hybrid workstations but also sets the stage for a transformative paradigm where technology and human connection seamlessly shape the future of collaboration and productivity.

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