connected everything.

industrial systems in the digital age

DOMINOES: aDaptive human-rObot teaMINg fOr rEmote taskS

EPSRC

Engineering and Physical Sciences Research Council

Contents

DOMINOES: aDaptive human-rObot teaMINg fOr rEmote taskS

About DOMINOES

Project Team and Partners

This feasibility study comprises of a team of ten investigators from the University of Nottingham, (including 7 Early Career Researchers at various career stages) working in partnership with our industrial partner UKAEA RACE (Remote Access in Challenging Environments). The project brought together expertise from the areas of Robotics, Computer Science, Human Computer Interaction, Brain Computer Interfaces, Human Factors Engineering, Psychology and Neuroscience. The project was primary based in the Cobot Maker Space a vibrant maker space at the University of Nottingham to explore the future of collaborative robotics. The project began on 1st February 2023 and was completed by 29th of February 2024.

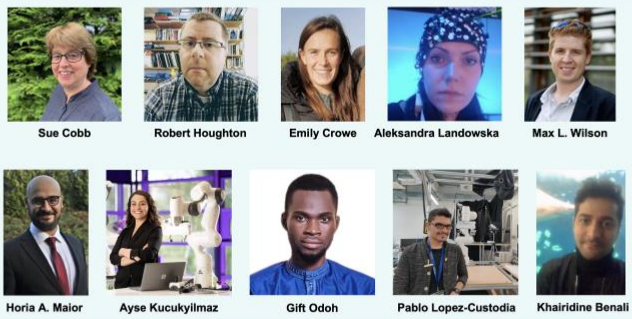

Figure 1 – DOMINOES Project Team

Project Overview

Teleoperation technologies enables humans to control a remote physical system (i.e., a robot) through the mediation of a control interface (see Figure 2). Teleoperated robots are useful to replace manual activities, to reduce the physical load of operators and improve human safety, especially in accessing dangerous, or constrained spaces. The Human-Robot Interactions (HRIs) within teleoperated systems create a setting for "human-robot-teaming" to redefine autonomy, combining human decision-making with robotic power and precision, especially to facilitate the operation of repetitive and dangerous tasks in manufacturing contexts. Indeed this is the vision of future smart manufacturing, where human operators take more of a controlling/supervision role (or human in the loop), replacing both the physically demanding work of humans and the often physically barrier-separated use of dangerous robotics in shared factory spaces. To benefit from human-robot teaming, a cobot (collaborative robot) needs to be proactive to human behaviour and comply to human operation to reduce conflicts, which would reduce the workload of the operator. This is emphasised in remote teleoperations, where the collaboration has a distance barrier for perception and communication.

Figure 2 – This represents the teleoperation context discussed with RACE. It showcases JET Fusion Reactor setup found at RACE where human operators perform maintenance tasks using the Mascot robotic arms. Operator feedback and remote scenes are viewed through multiple screens which display different views of the environment, as well as operational sequence data for the installation of parts. The work is physically and mentally very demanding (due to information coming from many sources as well as the high-risk nature of the tasks).

Aim and Objective

The aim of this work was to investigate suitable measurements of human mental and physical workload in such scenarios, to design effective human-robot teaming for remote teleoperation, where the robotic system may also be equipped with adaptive behaviours (e.g. based on human reactions or intentions).

Figure 3 – This cartoon represents the futuristic goal of this project. The human operator is teleoperating industrial robotic arms on the assembly line. This futuristic scene portrays a blend of high technology and human skill, emphasizing the advanced capabilities in manufacturing through remote operation. In this context, physical demands on the operator are now replaced by mental demands. Using brain and physiological sensors operator's mental workload is being monitored and the robotic systems adapt accordingly.

Outputs and Impact

Description of the conducted work

Part of this feasibility project we conducted a few scientific work packages addressing the two main objectives of this project:

Work Package 1: We have developed a testbed/demonstrator (within laboratory settings) using the robotics arms (2 Panda Franka Emika) available in the Cobot Maker Space to simulate the environment and nature of systems found at our industrial partner RACE and in future manufacturing settings. An image of the setup can be seen in Figure 4. We have additionally integrated brain and physiological sensors from the Mixed Reality Laboratory and the Brain and Physiological Data Research Group at the University of Nottingham, that allow us to collect data and measure operators brain and physiological responses. The robotic system allows us to model a variety of different teleoperation tasks, while the brain and physiological sensors to learn about the operator during these tasks.

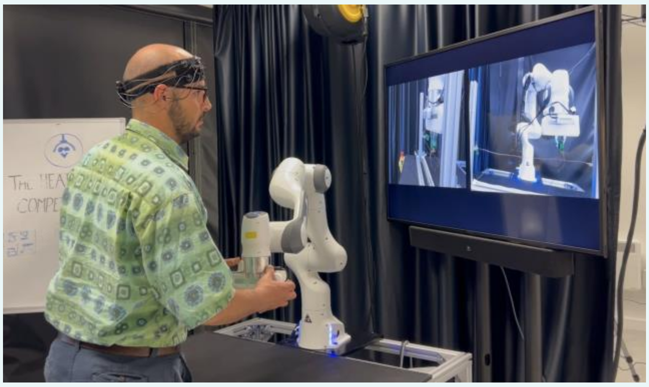

Figure 4 – Study setup developed in this project where participant is interacting with the teleoperation system while wearing the brain sensors. The participant is making use of the screen placed in front of them to gather feedback of the ring on the wire task.

This work package involved mostly technical development of the robot and setup including:

- Programming the robot arms to allow teleoperation.
- Integrating robot data, subjective data, task performance data and brain and physiological data together in Robot Operating System (ROS). This allows different data types to be synchronised, as well as allow the robot to make use of all these data types (based on further developments).
- Develop a ring on a wire structure to allow us to simulate both easy and hard teleoperation conditions (see Figure 5). The operator would have no direct view of the remote robot arm (see Figure 4) performing the ring on the wire task, and like the set up at RACE (presented in Figure 2) operators are using cameras and screens to learn about and get feedback of the task performance. When operators touched the ring to the wire, we have implemented a feedback mechanism that would alert the user using sound and lights, so they can correct their robot moves; we additionally recorded this data as task performance metrics.

Figure 5 – Teleoperation task structure (Ring on a wire); The easy setup (left) has a larger ring, making the teleoperation task easier.

Work Package 2: The second objective of this proposal was to conduct a laboratory experiment focused on evaluating operators' performance (task related performance as well as robot performance), subjective experience (workload and trust), and operators' brain and physiological responses (workload) using physiological data, which involved research grade portable functional Near Infrared Spectroscopy (fNIRS) – an emerging portable brain sensor, and other physiological data (SCR/EMG/Heart Rate sensors) collected from our subjects (see brain sensor in Figure 4). To our knowledge to date, we are the first to build such a dataset of measuring operators brain activity using fNIRS during teleoperation in this context. After pilot iterations, we have designed and conducted an experiment with N=40 participants. Data collected in this experiment was used to learn about what operator states can be detected during teleoperation as compared to standard psychology memory tests, with particular focus to high vs low operator workload. These measurements can then be potentially used as an adaptive mechanism in future iterations of the robotic teleoperation system. Data from this study is currently being written up in the final project publication.

Scientific Outputs and Publications

There are several scientific outputs emerging from this work. This currently includes one peer reviewed workshop publication at the ICRA 2023 Workshop on Multidisciplinary Approaches to Co-Creating Trustworthy Autonomous Systems (see details below), one poster presentation at the International Trustworthy Autonomous Systems (TAS) Symposium in July 2023. A full paper incorporating the full results of this work is under development for submitting to Nature Scientific Reports Special Issue (deadline in April 2024).

Aleksandra Landowska, Pablo Lopez-Custodio, Khairidine Benali, Liangju Min, Sue Cobb, Horia A, Maior, Ayse Kucukyilmaz, Max L. Wilson. Mental Workload Estimation using fNIRS in Robotic Teleoperation, ICRA 2023 Workshop on Multidisciplinary Approaches to Co-Creating Trustworthy Autonomous Systems. https://mactasworkshop.github.io/2023/

Aleksandra Landowska, Gift Odoh, Ayse Kucukyilmaz, Max L. Wilson, Horia A. Maior. Mental Workload Estimation using fNIRS in Robotic Teleoperation. Poster presented at the TAS Symposium in July 2023. https://symposium.tas.ac.uk/programme/posters/

Knowledge Transfer with Industry

This project has helped us consolidate a new research collaboration with our industry partner RACE, which will lead to follow-up proposals and potential future funding. Throughout the project we carried out update meetings with our industrial partners regularly updating them on progress and gathering feedback to make sure both, that our work is relevant and to facilitate knowledge transfer.

The collaboration with our industrial partner RACE will continue through the industry sponsorship for our doctoral Horizon CDT student Gift Odoh, who will also do an industrial placement with them.

Public Engagement and Outreach

There were several public engagement and outreach activities and events where researchers, policy makers and the general public had the chance to see some of this work. Some events are still upcoming. Please see some of these enumerated below:

- TAS Symposium Edinborough, 2023, https://symposium.tas.ac.uk/
- TAS Early Career Researcher Day, Edinborough, 2023
- TAS Skills Day, London, 2023
- ICRA Conference London 2023, https://www.icra2023.org/
- Living with AI podcast - https://lwaip.buzzsprout.com/1447474/13153017-telepresence-the-human-in-the-robot
- Future of work podcast - *https://www.youtube.com/watch?v=gemUuyiHc1E*
- Foundation for Science and Technology Future Leaders Visit in Cobot Maker Space, Nottingham 2024.
- Festival of Science and Curiosity 2024 (outreach event with young people in Nottingham)

We will also be presenting our demonstrator at the TAS Showcase 2024 which will take place in London in March 2024. This work will also be discussed in an outreach activity at the Royal Society Summer Science Exhibition 2024.

Team and Professional Development

Participating in this feasibility project has significantly benefited our project team. We had the fantastic support to fund a small team of amazing researchers to investigate operators' trust and workload in robotic-manual assembling tasks where humans and robots collaborate through teleoperation. We were able to conduct a foundational research study (N=40) based on a few iterations and build a strong dataset to inform on operator performance and workload during tasks. We were enabled to demonstrate this work to other researchers, relevant industries, policy makers, and the general public. Furthermore, this project supported the development and mentorship for 7 ECRs and 3 more established researchers.

This project has enabled new internal collaborations bridging different departments, with researchers across University of Nottingham Psychology (Emily Crowe), Human Factors Research (Robert Houghton and Sue Cobb), and Computer Science and Robotics (Ayse Kucukyilmaz, Horia A. Maior, Max L. Wilson, Aleksandra Landowska, Gift Odoh, Pablo Lopez-Custodia and Khairidine Benali).

connected everything.

industrial systems in the digital age

If you would like to find out more, please do not hesitate to contact us:
Horia.Maior@nottingham.ac.uk