Trustworthy Autonomous Systems (and the TAS Hub)

Outline

- **My work on Human Autonomy Teaming**
- **Understandable Autonomous Systems Theme at UofG**
- **UKRI Trustworthy Autonomous Systems (TAS) Hub**

University of Glasgow

Human Autonomy Teaming

Emma Liying Li, PhD

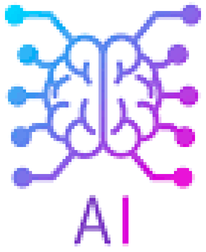
Lecturer in Responsible & Interactive Artificial Intelligence

School of Computing Science, University of Glasgow

Email: Liying.Li@glasgow.ac.uk

Behaviour Functioning for Human-Centred Robotic System

Autonomous Robots



Human partners

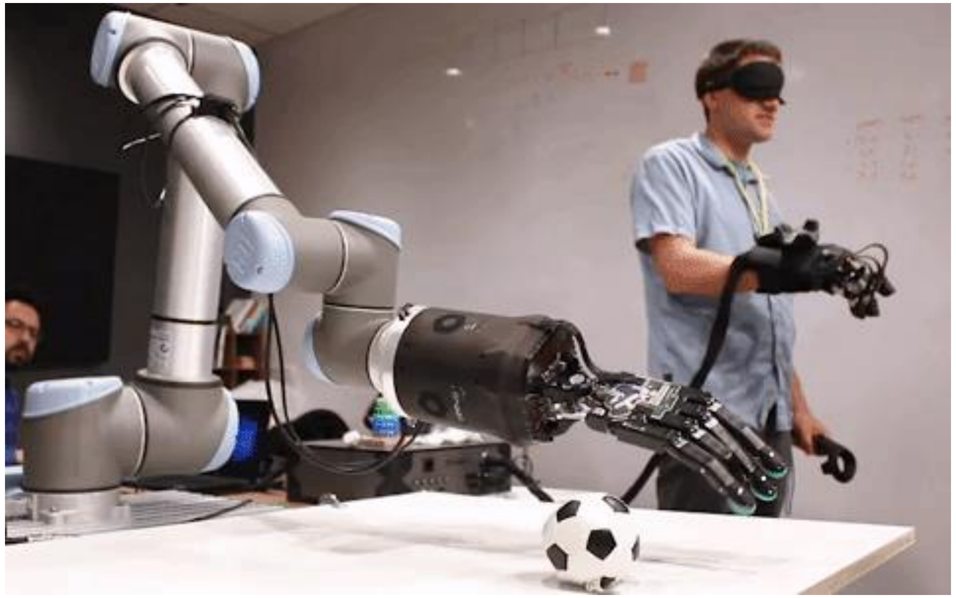
Autonomous system

- Collaboration performance
- Individual Motion behaviours
- Long-term companionship behavior in the robot

A robot can carry human behaviour

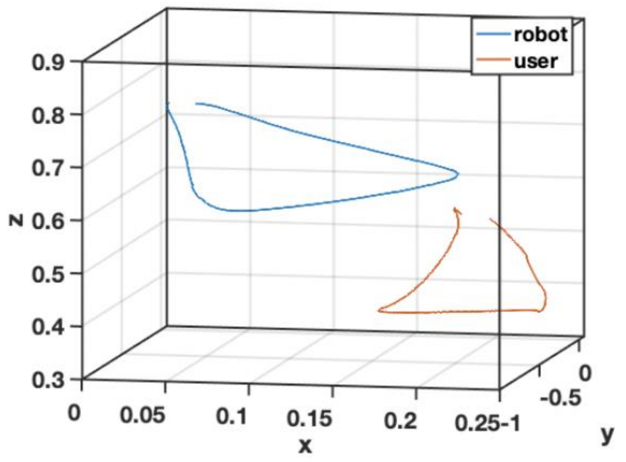
- Our experiment

The Shadow Robot Tele-Operation Experiment



* This video is from Internet

• Feasibility study



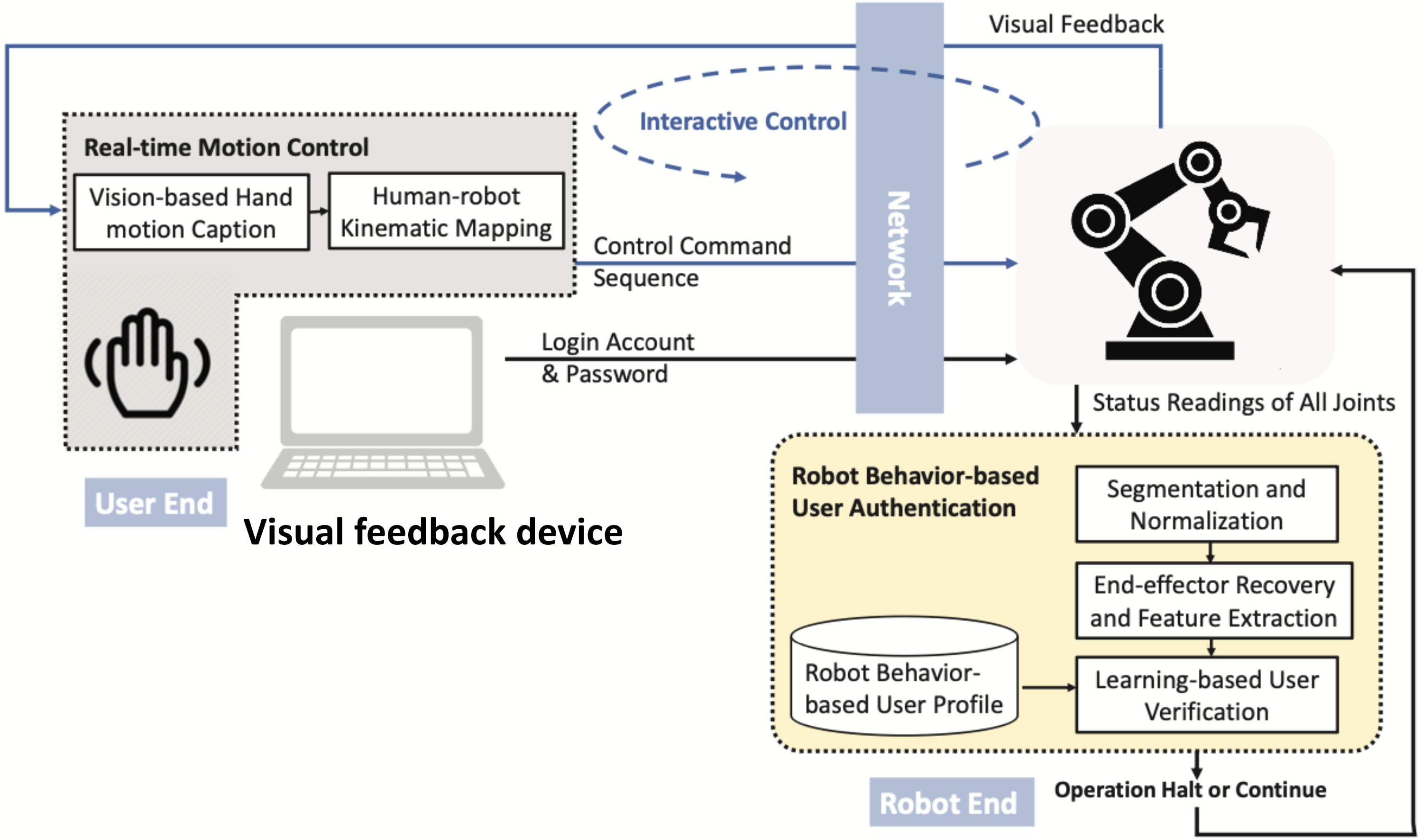
Comparison of the user's hand and the robotic arm end-effector raw trajectories of drawing a "triangle". Both are obtained by OptiTrack cameras.

Comparison of human hand and the robotic arm end effector

- ➢The movement trajectory of the robotic arm doesn't completely replicate that of the user's hand
- ➢The sampling errors and the network traffic delays cause the robotic arm to show much more additional movements
- ➢The robotic arm's trajectory still exhibits a certain similarity to that of the user's hand

User identification

- System Framework



Reconstructing the Robotic Arm's End-effector Trajectory

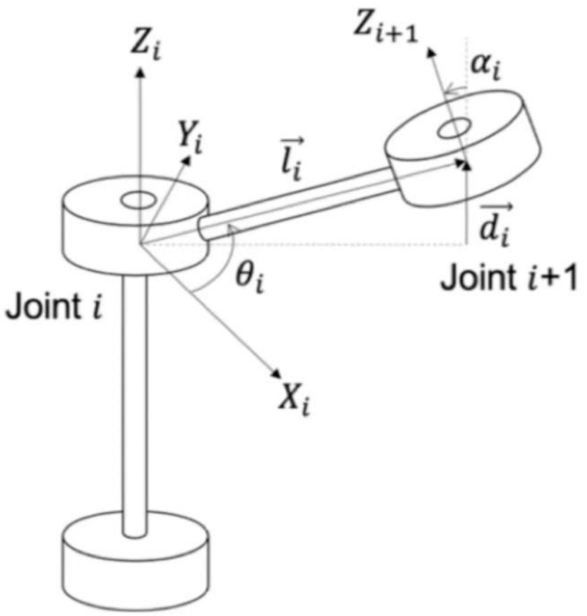
- Forward kinematics

$$^{i}T_{i+1} = R_X(\alpha_i)D_X(|\vec{l}_i|)R_Z(\theta_i)Q_i(\vec{d}_i)$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha_i & -\sin\alpha_i & 0 \\ 0 & \sin\alpha_i & \cos\alpha_i & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & |\vec{l}_i| \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & 0 \\ \sin\theta_i & \cos\theta_i & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & \vec{d}_i \\ 0 & 0 & 0 & 1 \end{bmatrix} =$$

$$\begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & |\vec{l}_i| \\ \sin\theta_i\cos\alpha_i & \cos\theta_i\cos\alpha_i & -\sin\alpha_i & -\vec{d}_i\sin\alpha_i \\ \sin\theta_i\sin\alpha_i & \cos\theta_i\sin\alpha_i & \cos\alpha_i & \vec{d}_i\cos\alpha_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



$$^{n}pos = \begin{bmatrix} x_n \\ y_n \\ z_n \\ 1 \end{bmatrix} = {}^{0}T_n \begin{bmatrix} x_0 \\ y_0 \\ z_0 \\ 1 \end{bmatrix} = {}^{0}T_n \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

User Identification

- Feature Extraction
  - ➢Six types of feature sequences are derived:

    3D coordinates, coordinate differences, velocities, accelerations, slope angles and curvatures
- Robotic Arm Task Recognition
  - ➢Given a robotic arm end-effector trajectory in the testing phase, we compute its weighted DTW distance to each of the task templates as

$$\sum_{k=1}^{11} DTW(f_{k,test}, f_{k,task}) \times w_{k,task}$$

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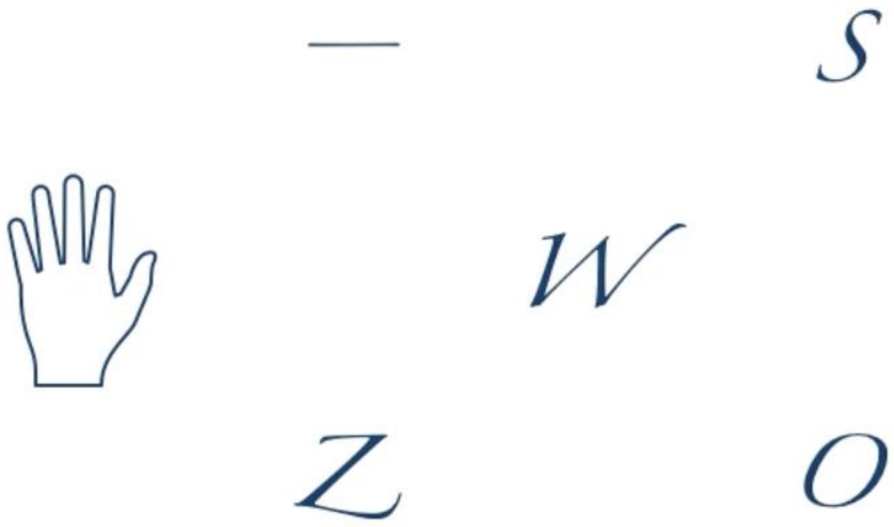
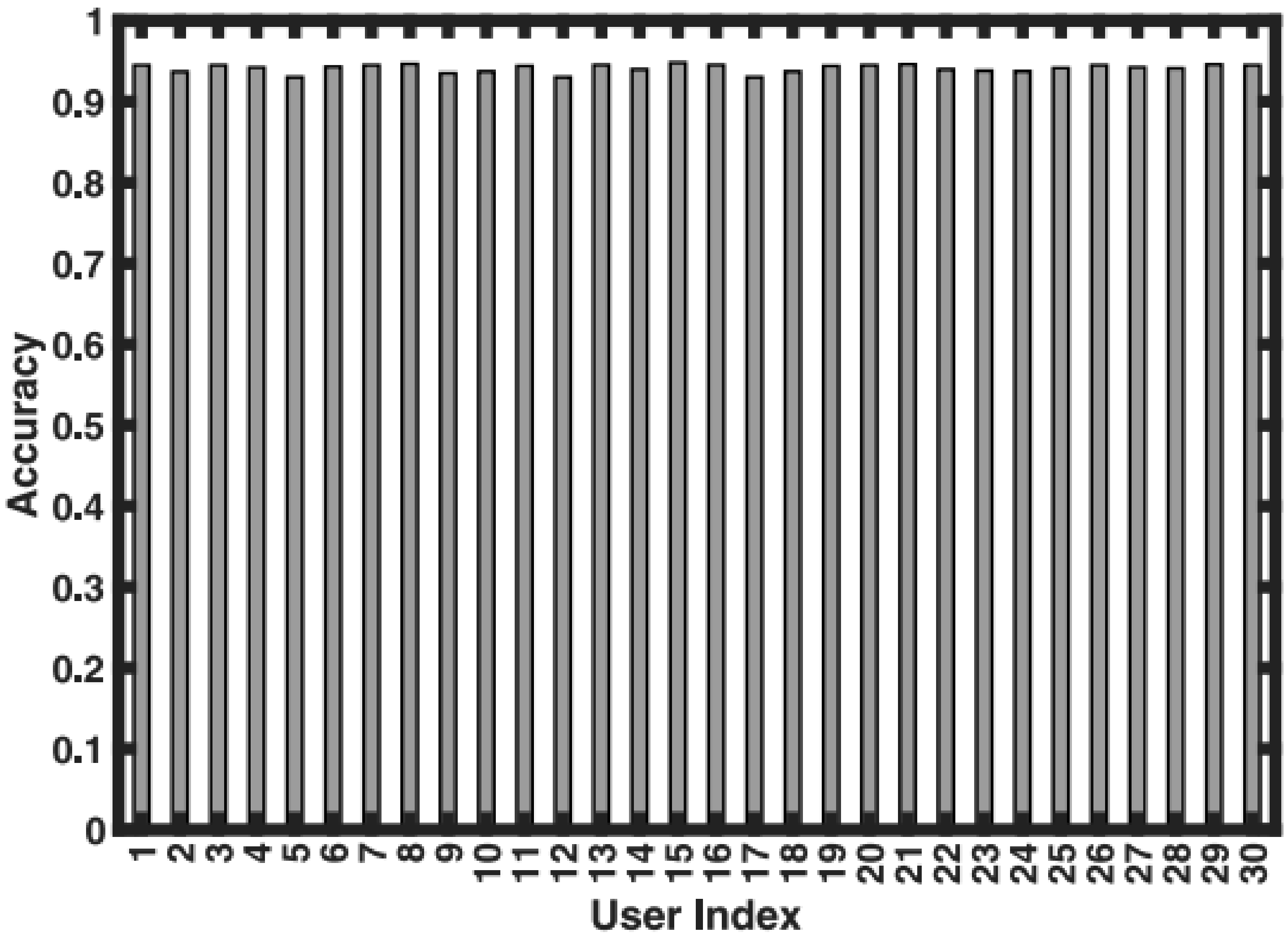
Experimental Setup

- Participants
  - ➢30 first-time users
- Device
  - ➢Our designed platform
- Tasks
  - ➢ “–”, “S”, “W”, “Z” and “O”
  - ➢ABC, star, triangle, stirring, pointing



Performance of User Authentication



- High accuracy for all participants, i.e., over 93% accuracy.
- Some could achieve 95%

Related Publications

- "Extracting human behavioral biometrics from robot motions," in Proc. MobiCom 2022, 2022
- "Towards verifying the user of motion-controlled robotic arm systems via the robot behaviour," IEEE IoT Journal Special Issue on Security, Privacy, and Trustworthiness in Intelligent Cyber-Physical Systems and Internet-of-Things, vol. 9, no. 22, Nov. 2022
- "Robot behavior-based user authentication for motion- controlled robotic systems," in Proc. IEEE INFOCOM 2021 Workshops, May 2021. (Best Paper Award)

On-going work

- Identify behaviours that will lead to building human and robots companionship relations

- Implement the behaviour features into the robots, e.g., the quadruped robot and robot arm

Understandable Autonomous Systems Theme - School of Computing Science

- Overarching research theme
- I currently lead the theme (Previous lead- Prof. Alice Miller)
- Webapge: https://www.gla.ac.uk/schools/computing/research/researchthemes/understandableautonomoussystems/

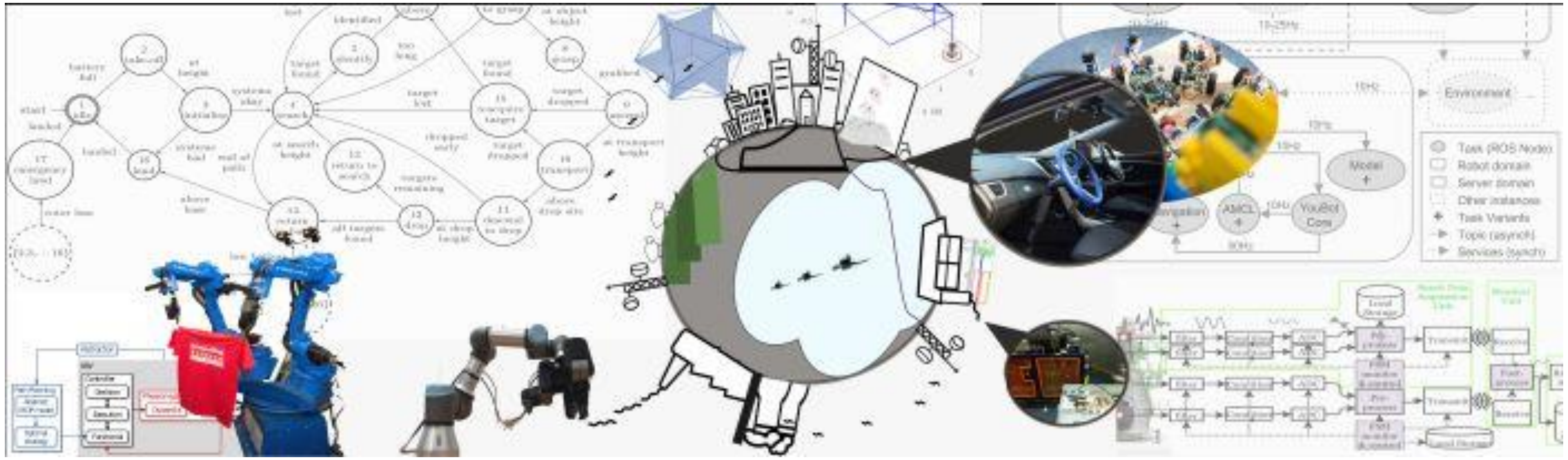


Image courtesy of Lito Michala

•People of the Theme

- **Formal Analysis, Theory and Algorithms Section (FATA) (Miller, Norman, Calder, Andrei, Gay, Dardha, Enright and McCreesh)**
  - Modeling and reasoning, verifiability of constraint based tools
  - Programming language approaches
- **Information, Data and Analysis Section (IDA) (Aragon Camarasa, Siebert, Anagnostopoulos, Adel)**
  - Robot manipulation and grasping
  - Computing vision and sensng
  - Machine learning algorithm and models
- **Glasgow Interactive SysTems Section (GIST) (aka HCI) (Brewster, Foster, Chalmers, Guha, Ding)**
  - User interface design
  - Human-autonomous system interaction
- **GLAsgow SyStems Section(GLASS) (Trinder, Cano Reyes, Pezaros, Singer, Michala, Perkins, Storer, Thamsen, Elkhatib, Li)**
  - Reliable software systems
  - Reliable network for autonomous system
  - Privacy protection and security design
  - Resource allocation

UKRI Trustworthy Autonomous Systems (TAS) Hub + Nodes - https://www.tas.ac.uk/

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The UKRI TAS Hub

- Universities of Southampton, Nottingham and King’s College London
- £33M Trustworthy Autonomous Systems Programme
- Six nodes