Multimodal Execution Monitoring for Robot-Assisted Feeding

Project Team: Daehyung Park
Principal Investigator(s): Charles C. Kemp
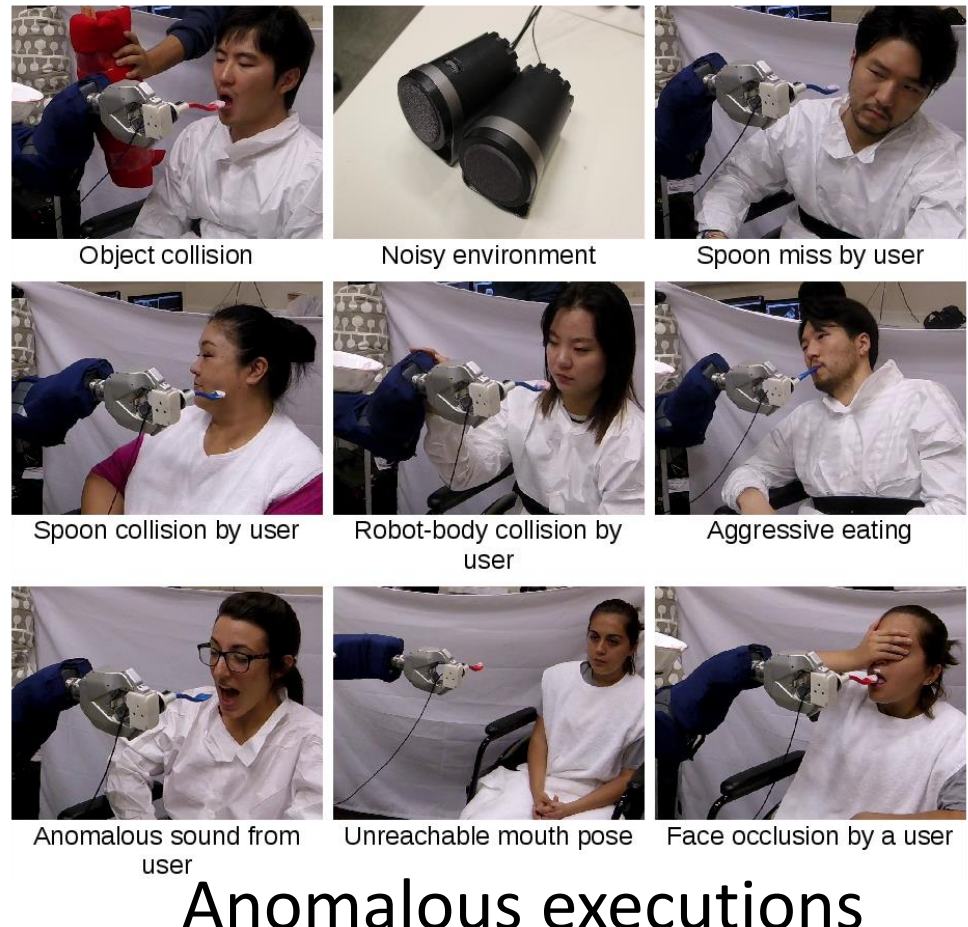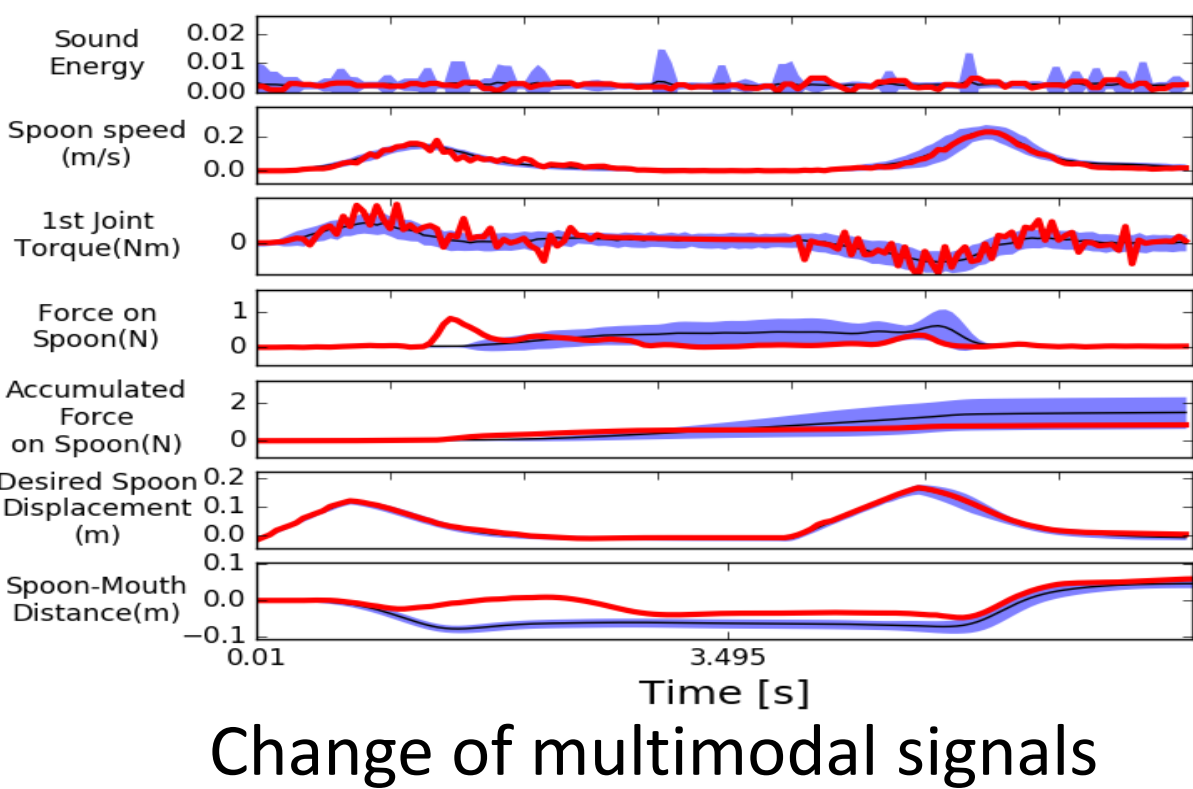
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Introduction

- When a robot provides real-world assistance, anomalies may occur.

- The detection of anomalies is valuable to provide safer assistance.

- We introduce a multimodal execution monitor in the context of robot-assisted feeding.
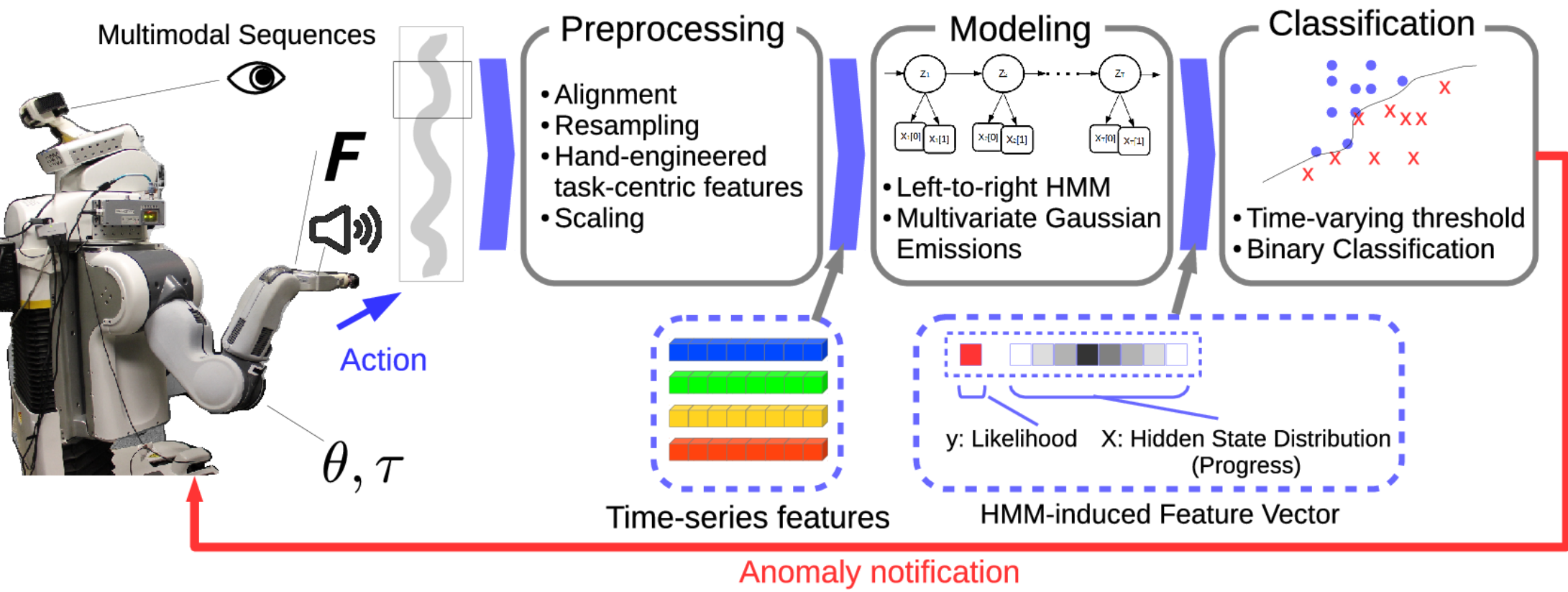

Feeding

Shaving

Multimodal Sensory Signals

- Non-anomalous (successful) executions (blue)
- anomalous executions (red)

Change of multimodal signals

Object collision · Noisy environment · Spoon miss by user
Spoon collision by user · Robot-body collision by user · Aggressive eating
Anomalous sound from user · Unreachable mouth pose · Face occlusion by a user

Anomalous executions

A Multimodal Execution Monitor

Multimodal Sequences

Preprocessing
- Alignment
- Resampling
- Hand-engineered task-centric features
- Scaling

Modeling
- Left-to-right HMM
- Multivariate Gaussian Emissions

Classification
- Time-varying threshold
- Binary Classification

Action

θ, τ

Time-series features

HMM-induced Feature Vector

y: Likelihood   X: Hidden State Distribution (Progress)
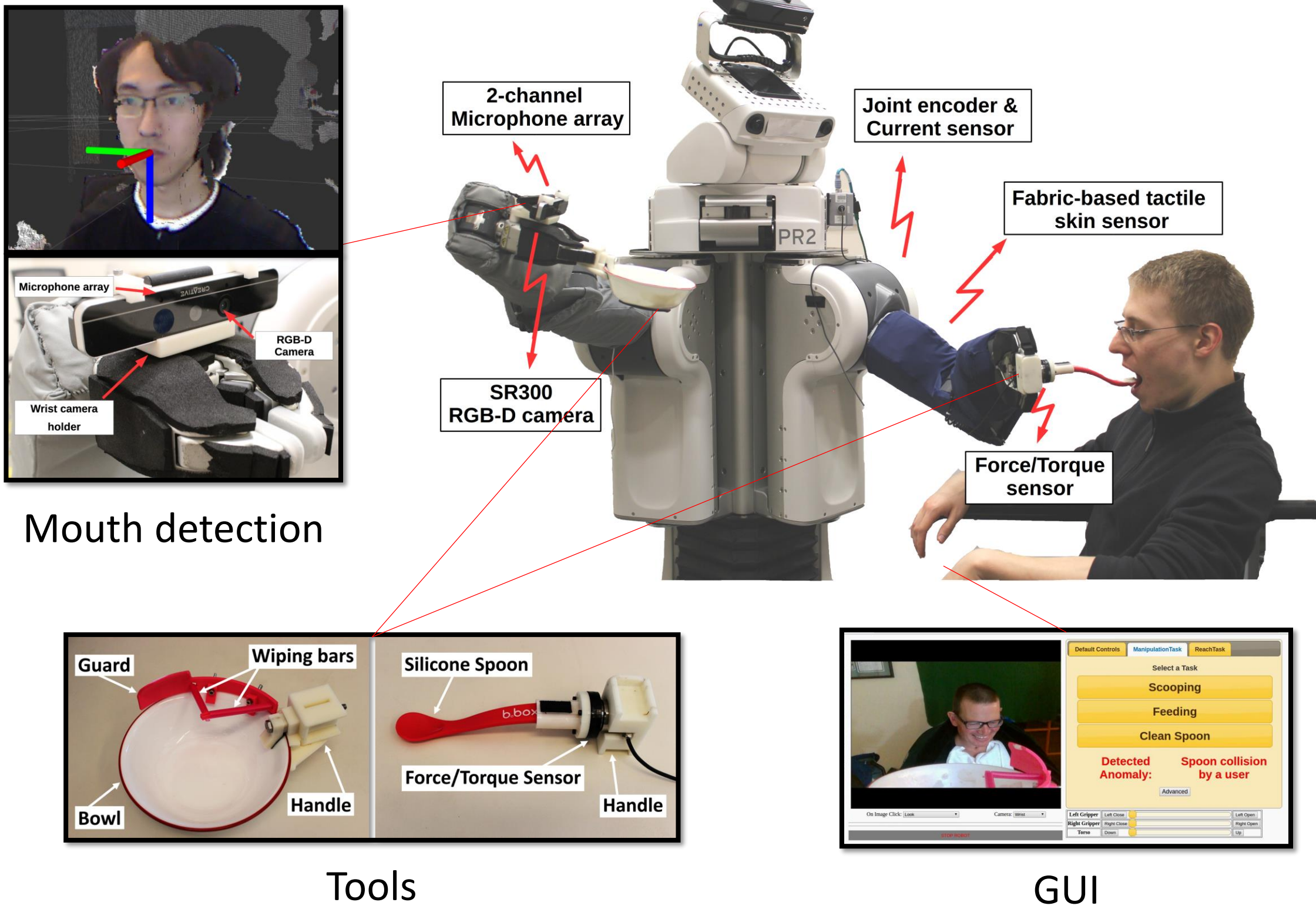
Anomaly notification

Overview of multimodal execution monitoring system

- Modeling multimodal sensory signals using an HMM

- Detecting an anomaly using a time-varying likelihood threshold based on execution progress

[1] **D. Park**, H. Kim, and C. Kemp. "Multimodal Anomaly Detection for Assistive Robots", *Autonomous Robots* [submitted]

A Robot-Assisted Feeding System

2-channel Microphone array

Joint encoder & Current sensor

Fabric-based tactile skin sensor

Microphone array

RGB-D Camera

Wrist camera holder

SR300 RGB-D camera

Force/Torque sensor

PR2

Mouth detection

Guard · Wiping bars · Silicone Spoon

Bowl · Handle · Force/Torque Sensor · Handle

Tools

GUI

Detected Anomaly: Spoon collision by a user

An image sequence of robot-assisted feeding task with Henry Evans who has severe quadriplegia

Spoon · Camera · Bowl · Mouse

Evaluation Result

Lab tests with 8 able-bodied participants
- 81.21% detection performance (AUC) over all 352 executions
- Outperformed to 5 baseline methods in the literature

Field tests with a quadriplegic in his house
- 100% successful feeding rate for all 20 consecutive executions
- 86.36% detection accuracy for all 110 executions over 4 days

Question	Response
The system successfully accomplished tasks.	Strongly Agree
I felt safe while using the system.	Strongly Agree
The system was simple and easy to use.	Strongly Agree
The anomaly detection helped me feel more safe.	Agree

Five-point Likert scale survey result from Henry Evans

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