CNS-2204785: CCRI: Medium: Collaborative Research: Hardware-in-the-Loop and Remotely-Accessible/Configurable/Programmable Internet of Things (IoT) Testbeds

PIs: **James Xiaojiang Du**, Stevens Institute of Technology; **Jia Di**, University of Arkansas; **Qiang Zeng**, George Mason University

Introduction:

- Internet of Things (IoT) devices and systems have a lot of applications, such as smart home, smart office, healthcare, elderly care, and industrial control and monitoring systems.

- However, most existing IoT research uses small-scale, ad hoc and non-realistic testbeds or simulation tools to generate data and/or evaluate their work.

- This project addresses the critical issue by developing remotely accessible IoT testbeds at three universities, including smart-home testbeds, smart-office IoT testbeds, and an IoT hardware testbed.

IoT devices, servers, robots, drones

Various IoT devices. The photo shows 21 of them.

(1) Centralite: Pearl Smart Thermostat
(2) Sengled Bulb: E11-N1EAW light
(3) Innr: FL 120C Smart light
(4) Philip: Bloom Smart light
(5) Sengled Strip: Smart light
(6) Third Reality: Smart Blind
(7) Lumi: Smart plug
(8) Schlage: Smart Lock
(9) Kwikset: Smart Lock
(10) Tuya: Sensor
(11) Tuya: Smart Switch
(12) Third Reality: Switch
(13) Sengled: Dimmer Switch
(14) Minoston: Smart plug
(15) Aeotec: Smart Wall Switch
(16) Aeotec: Sensor
(17) Aeotec: Smart Switch
(18) Fiboro: Motion Sensor
(19) Honeywell: Smart Thermostat
(20) Kwikset: Smart Lock
(21) Minoston: Dimmer Plug

Lambda Server   NAO robot   LoCoBot robot

Smart-home IoT Testbeds

| Label	Name	Attributes	Deployment
AM	Aeotec Multisensor 6	motion temperature humidity illuminance	On wall
DL3	Dimmable light	switch switch level	On ceiling
HB	Hue bulb	switch	On ceiling
HM	Hue motion sensor	motion temperature illuminance	On wall On the table
HS	Hue dimmer switch	button	On doors On windows
LB	LIFX bulb	switch	On wall
MO	SmartThings motion sensor	motion	On wall
MU	SmartThings multipurpose sensor	contact temperature	On door On windows
OL	SmartThings power outlet	switch power	Attach to appliance
PR	Smartphone as presence sensor	presence	In wallet
SL	Sylvania light bulb	switch	On ceiling
SW	ThirdReality smart switch	switch	On wall
WL	Honeywell water leakage	water temperature	On floor
WS	SmartThings water sensor	water	On wall

Table 1. Notation and explanation of IoT devices in the testbeds.
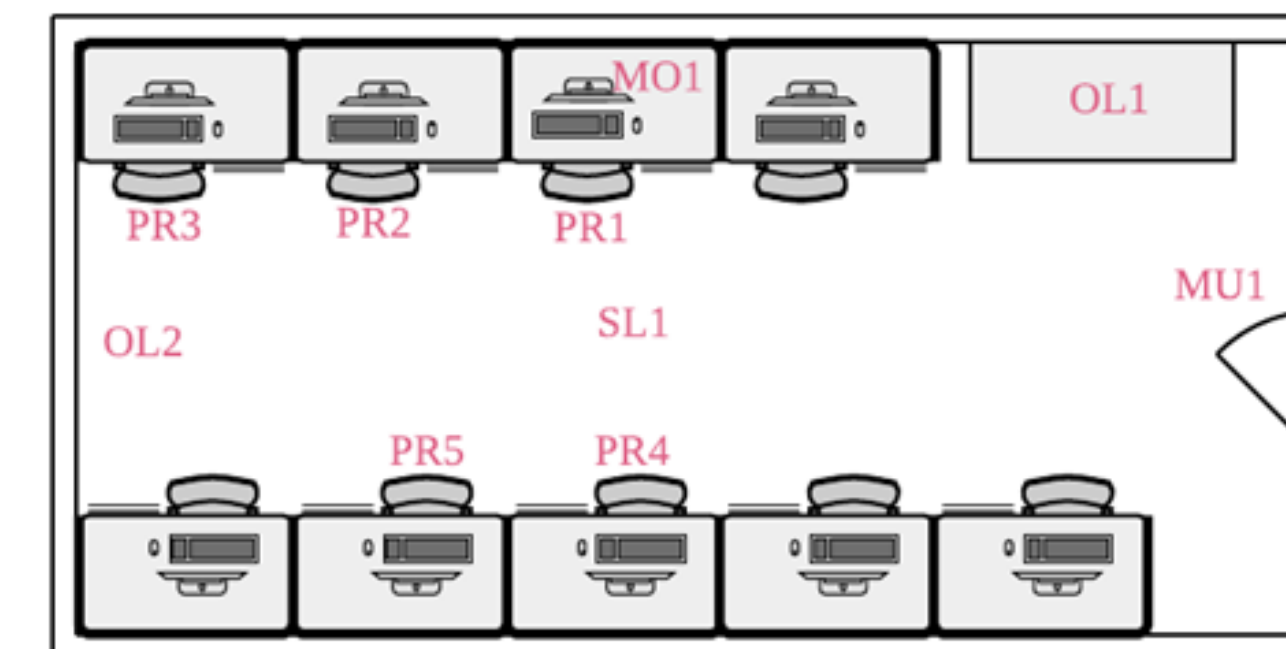

Smart home testbed
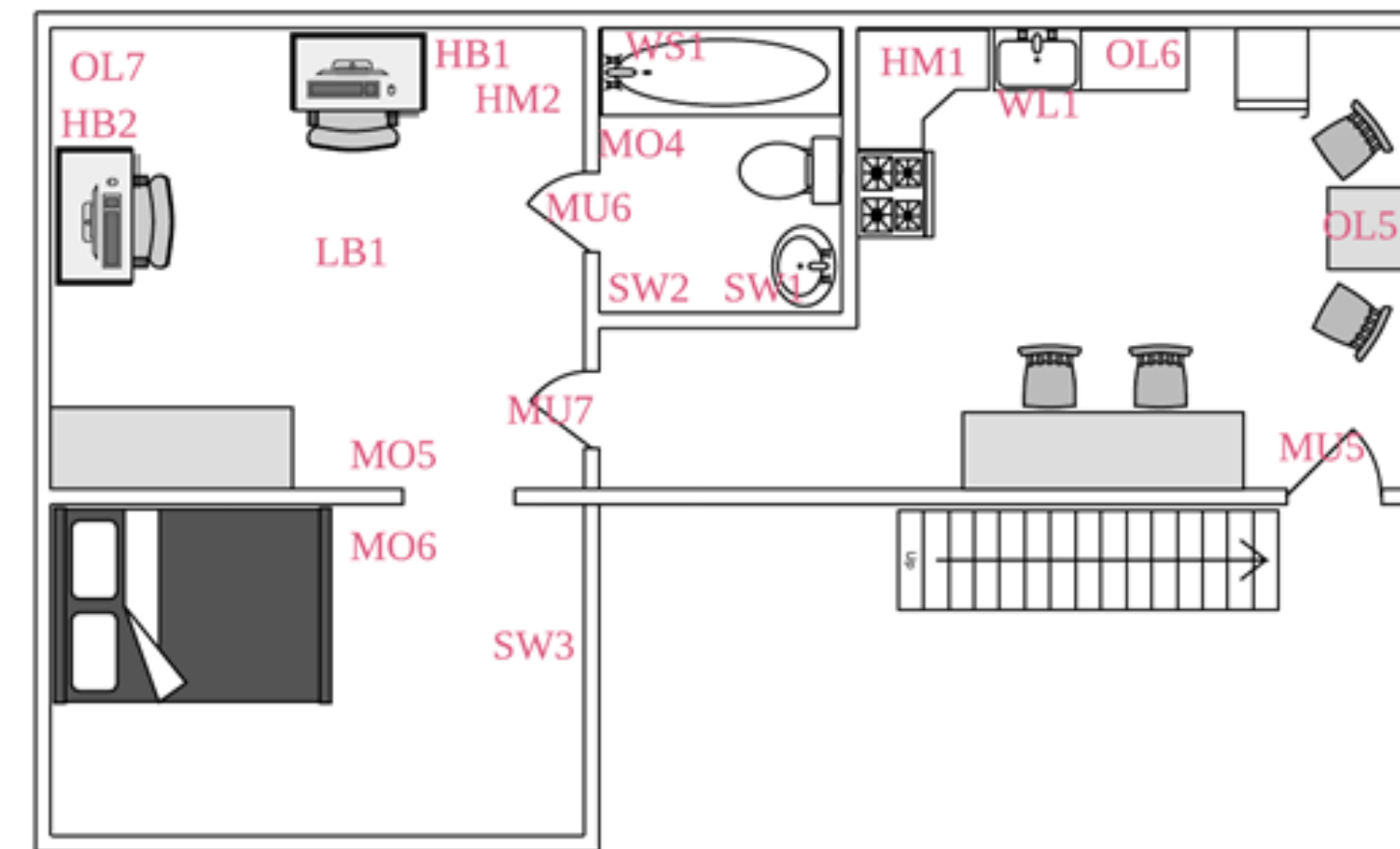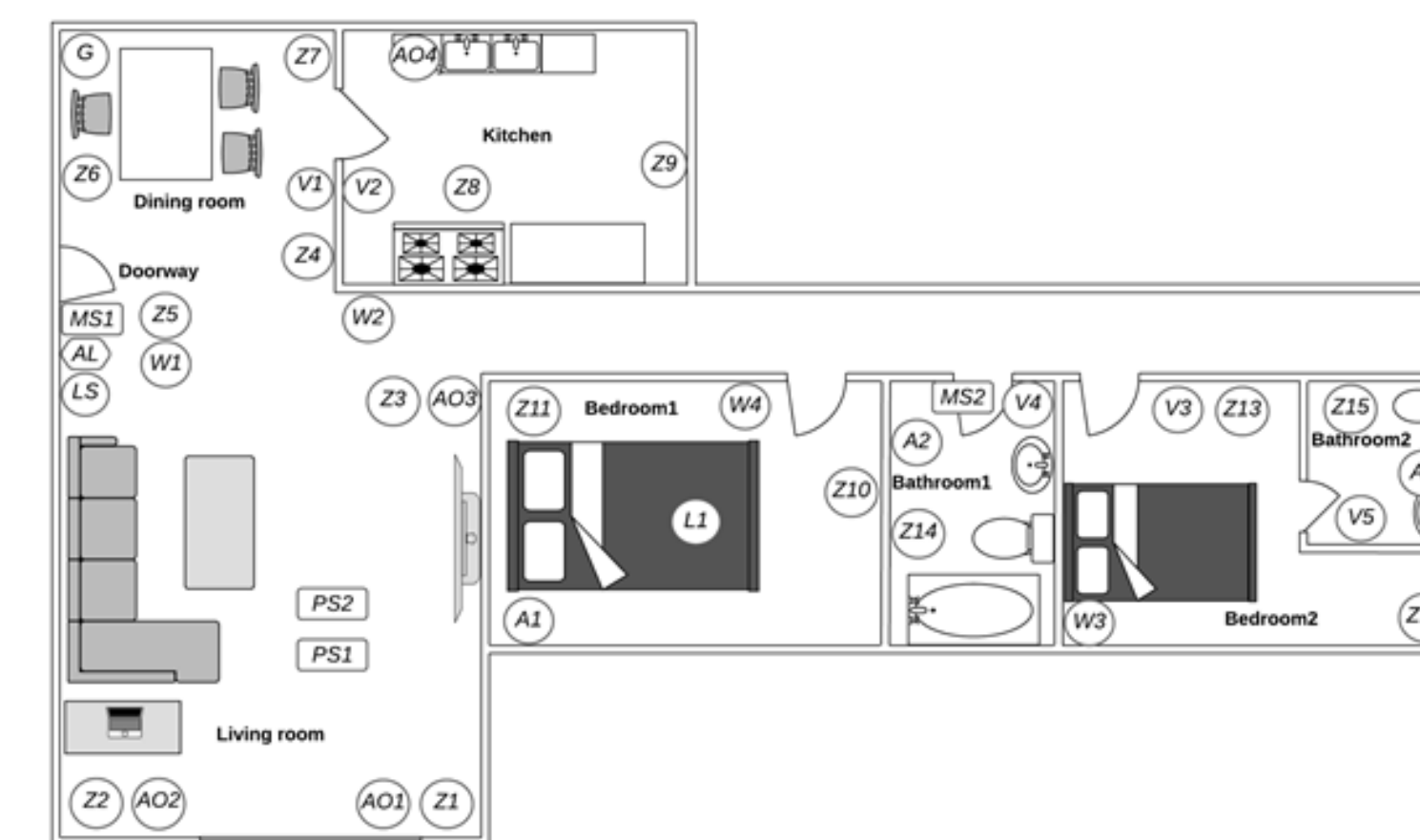
Smart home testbed

Smart home testbed

Smart-office IoT Testbed

IoT hardware Testbed.

- The testbed is centered around an access point server. This access point server serves as the primary point of control, enabling users to monitor and configure all aspects of the testbed, including device configuration, data collection, and analysis.

- The server offers remote accessibility, which allows users to connect to the server from outside of the testbed.

- The smart home testbed incorporates commercially available devices, modified devices, and self-built devices.

- We have full control of the self-built devices, such as changing the source code to implement customized functions.

- The self-built video doorbell and climate sensor were created using off-the-shelf parts. The Raspberry Pi video doorbell is based on a Raspberry Pi4 computer. A wide field-of-view camera is mounted on the front of the 3D-printed case.

- The self-built smart climate sensor is based on a Raspberry Pi Zero. Two sensors are soldered to a printed circuit board which is mounted to the Pi Zero's GPIO pins. One measures temperature and humidity, and the other measures brightness and UV index.
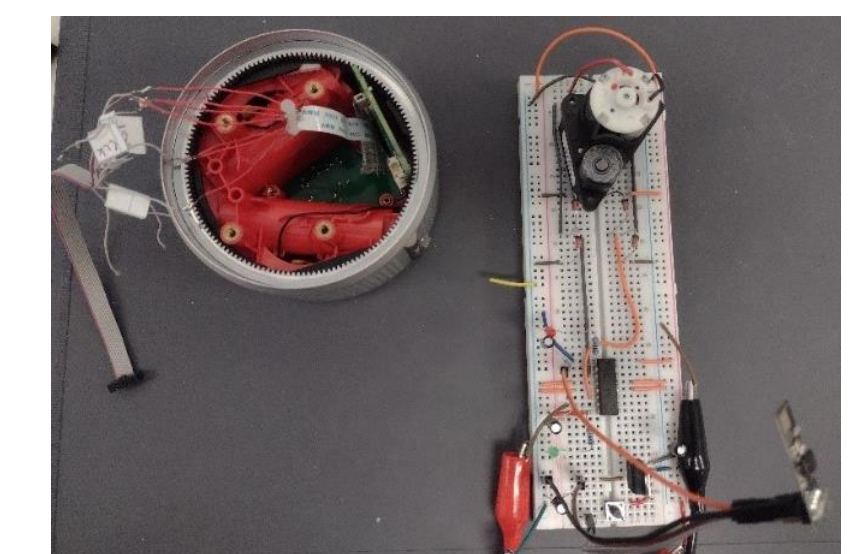
August smart lock housing (left). Lock motor control (right)

Raspberry Pi based climate sensor

Self-built Raspberry Pi based video doorbell

Support Research – Some of the Joint Publications

- C. Workman, G. Tomlinson, J. Di, X. Du, and Q. Zeng, "A Framework of an IoT Testbed," IEEE SoutheastCon, Mobile, AL, April 2022.

- C. Wu, X. Li, F. Zuo, L. Luo, X. Du, J. Di, and Q. Zeng. "Use It—No Need to Shake It!" Accurate Implicit Authentication for Everyday Objects with Smart Sensing. UbiComp 2022, in Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies) (IMWUT), Issue 3, Vol. 5, 2022. (Acceptance rate = 21%).

- H. Chi, Q. Zeng, X. Du, "Detecting and Handling IoT Interaction Threats in Multi-Platform Multi-Control-Channel Smart Homes", USENIX Security (a big four security conference), August. 2023.

- J. Swaim, C. Workman, J. Di and X. Du, "An Internet of Things Testbed for Education and Community Research", IEEE International Conference on Artificial Intelligence, Blockchain, and Internet of Things (AIBThings), Sept., 2023.

- C. Fu, Z. Zhao, F. Zuo, X. Du, Q. Zeng, J. Di, "Seeing Is Believing: Extracting Semantic Information from Video for Verifying IoT Events", under submission.