Demo: TINGLE: Pushing Edge Intelligence in Synchronization and Useful Data Transfer for Human-Robotic Arm Interactions

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***Abstract*—This demo presents a lightweight framework for the remote operation of human-robot interactions. As always, proper synchronization between the human (master) and the robot (controlled) is a critical issue during manipulation. In this experiment, we present an end-to-end synchronous system to establish near real-time maneuvering. Moreover, by leveraging the devices' limited yet available computational capabilities in master and controlled domains, we aim to apply edge intelligence to determine the amount of data required for mimicking the human's hand movement before wireless transmission to the controlled domain. We observe from extensive experiment results that our proposed TINGLE demonstrates a noticeable performance with fewer missing movements in the controlled domain than baselines.**

I. Introduction

Due to the flexibility and facilitating close collaboration with humans, equipment handling with remotely operated robots [1] has been widely applied in several applications, ranging from car manufacturing, heavy machinery, constructions, mines, and particularly hard-to-reach and hazardous environment [2]–[4]. Many of these human-robot interactions demand *synchronization between master and controlled domains*. Moreover, it becomes indispensable to *reduce network overhead* in terms of data transmission when we take wireless connectivity in master-controlled manipulation [5], [6].

Contributions. In the following, we summarize main contributions of this demonstration as

- We design an end-to-end master-controlled domain wireless data transmission system while pushing Edge In**T**ell**IG**ence in Synchro**N**ization and Usefu**L** Data Transf**E**r, acronym as TINGLE, with acknowledgment enabled in human-robot interaction.
- We demonstrate how the computing resources of the participating devices can be leveraged as a part of *edge computing* to determine the amount of data required for the almost immediate reaction of the robotic hands to the movement of the human fingers. Moreover, we show that synchronization of the action/reaction between the master and controlled domains plays a critical role in these closed-loop interactions.

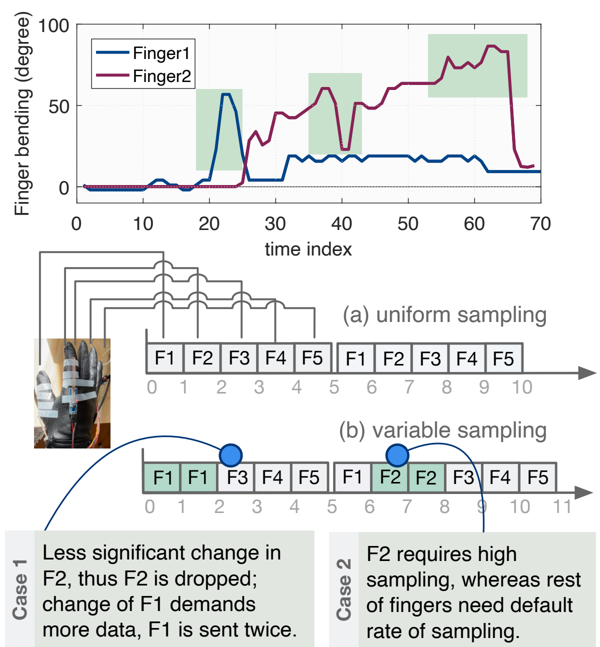

Fig. 1. To establish a proper synchronization between master and controlled domain, we collect more data (i.e., sampling at a higher rate) than default values. It also becomes necessary to drop less significant changes.

II. System Design

We broadly consider the following two stages.

Data transmission stage. Fig. 1 illustrates the data collection and sampling stage. We initialize the position of each flex sensor attached with the finger to 0 degrees. Afterward, we measure the absolute change in degree as $\Delta\phi_i(t) = \phi_i(t) - \phi_i(t-1)$, where $\phi_i(t)$ is the position of the ith finger at time t, and arrange the value of all fingers, $\Delta\phi_i(t)$ in ascending order. Afterward, we set the transmission number in a single slot based on the highest order, leveraging the concept of edge intelligence.

Data Receiving stage. The receiver side obtains the required amount of data for mimicking the human's finger movement, and the expansion board drives the steering motor of the robotic arm.

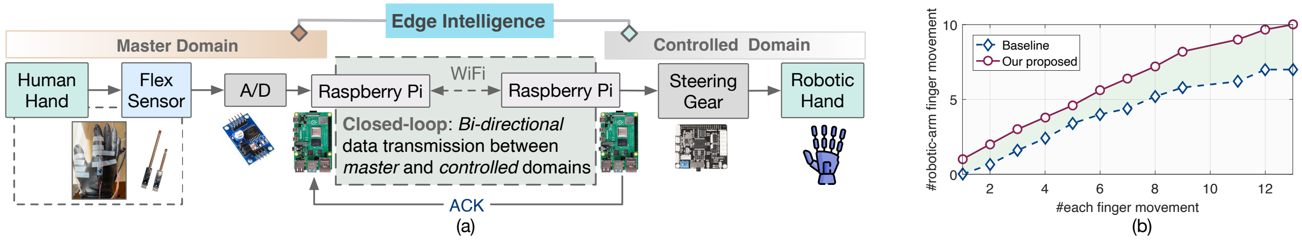

Fig. 2. (a) Block diagram of the proposed TINGLE (b) preliminary results.

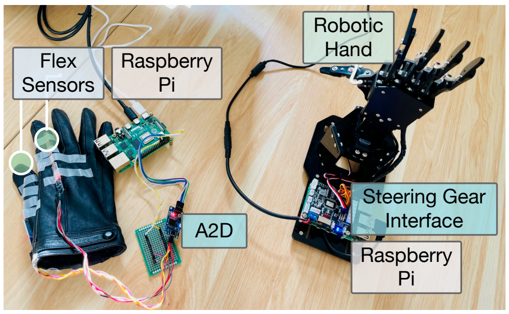

Fig. 3. Demonstration of TINGLE.

III. Demo Setup and Conclusions

Experimental setup. In this experiment[1], we take five flex sensors to measure finger movement/bending, one 8-bit analog-to-digital converter, two Raspberry Pi 4B+, one servo interface to drive the robotic hand, and one robotic hand. We use WiFi to establish wireless connectivity between two Raspberry Pis. We show the setup in Fig. 2(a) and demonstration in Fig. 3.

Finger movement data collection. We attach a flex sensor with each finger. The bending angle of each finger has been measured using a variable resistor in the flex sensors. In brief, the change in resistance results in the bending degree.

Analog-to-digital conversion. We use a PCF8591 analog chip with multiple inputs as an 8-bit A/D converter. The three address pins, denoted as A0, A1, and A2 used for hardware address programming, allow multiple flex sensors to be connected with the integrated circuit bus without any additional hardware. This converter takes the analog voltage data from the flex sensors, converts them into digital form, and sends them to Raspberry Pi.

WiFi. We use WiFi (mobile hotspot assigns private IP address) as a wireless connectivity between two Raspberry Pis. We establish a local area network and use TCP/IP as a part of the communication protocol. With the help of a socket interface, a bi-directional channel has been initiated through client request, server listening, and ACK.

Steering gear interface and robotic hand. The manipulator for the robotic arm is equipped with anti-blocking multi-engines. Moreover, the steering gear has a built-in blocking protection algorithm to ensure that the steering gear will operate smoothly. The robotic arm itself has two-degree-of-freedom (2 DoF). The movement of the fingers is controlled by a servo expansion with onboard 8-channel pulse width modulation (PWM) steering gear interface. The steering gear rotation range is 0–$180°$ using PWM control, and the pulse width range of 500–2500us. The servo interface on the expansion board controls the rotation of the robotic arm.

Discussion and Conclusions. We compare our proposed demo with a baseline that uniformly collects and sends data from the flex sensors. (a) From the observation (see, Fig. 2(b)), we see that when the average finger movement is low (i.e., changing the position by around two times over 5-sec duration), then with both default sampling and the proposed scheme, the robotic arm can follow the movements. However, as the number of position changes of the finger increased (for example, 5-7 times per 5 sec), the occurrence of missing is higher in baseline than the proposed TINGLE. (b) In addition, we consider the case when the transmitter drops the packets when it finds less significant change than the fingers' previous position. This results in useful data transmission. The future work includes studying a lightweight near-to-real-time operation while exploiting the available computing, storage, and communications resources of the master, network, and controlled domains in human-robotic-arm interactions.

[1]Source code and video are available in https://github.com/MithunHub/TINGLE

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