An open challenge in current telecommunication systems including Skype and other existing research systems [1] – [3] is a lack of physical interaction, and consequently a restricted feeling of connection for users. For example, those telecommunication systems cannot allow remote users to move pieces of a board game while playing with a local user. We propose that installing a robot arm and teleoperating it can address the problem by enabling remote physical interaction. (See Fig. 1)

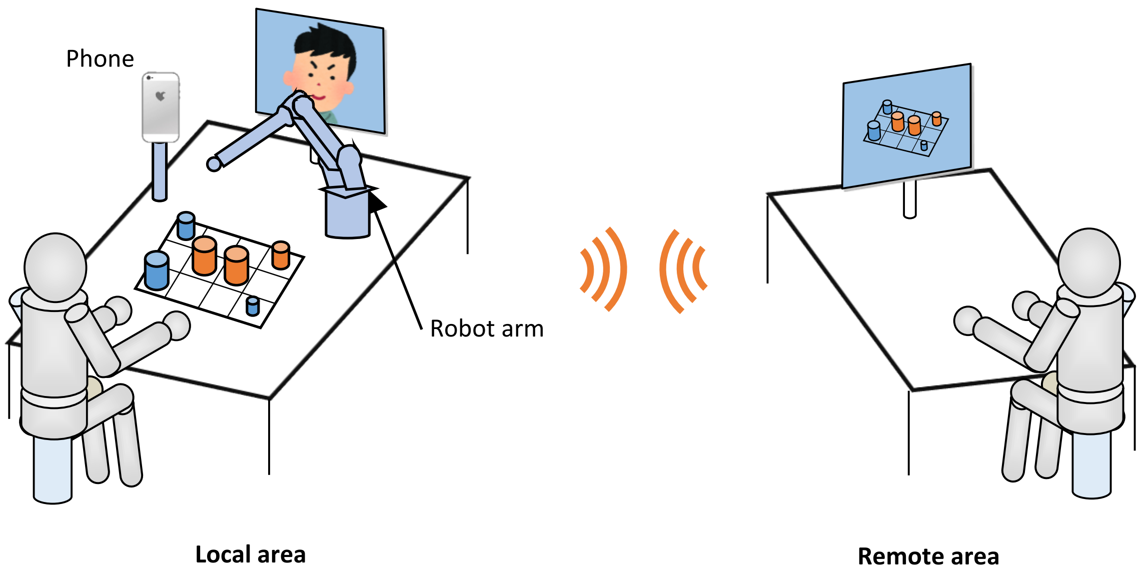


Fig. 1 Installing a robot arm to realize physical interaction

Teleoperation is found to be challenging and can induce excessive mental workload [4]. For example, teleoperation degrades work efficiency more than 50% compared with boarding operation in the construction machinery case [5]. Thus, some autonomy can help humans perform tasks well [6], and many researchers have achieved high efficiency teleoperation by increasing autonomy level. For example, master-slave interfaces have been proposed to allow teleoperators to input only hand position [7]. Additionally, AR-based interfaces have been developed which allow teleoperators to input only the goal position [8].

However, higher levels of autonomy lead to humans feeling less sense of agency, which refers to the ownership of the actions [9]. There is a tradeoff between sense of agency and level of autonomy. Lack of sense of agency can cause lack of connection with local area and people, because a remote person does not feel they caused actions. Numerous research addresses levels of robot autonomy [10] – [12], and some research examines using robots to realize physical interaction [13], [14]. However, they focus on efficiency. There is limited prior work examining how sense of connection relates to agency and different autonomy levels. Therefore, we investigate the relationship between autonomy level and sense of connection of a remote person with local area and people. (See Fig. 2.) Among many possible physical interactions, we focus on a pushing task for two reasons. First, pushing is one of the major functions in hand and arm use [15], and second, pushing something including buttons activates some exhibits in many places such as museums and theme parks.

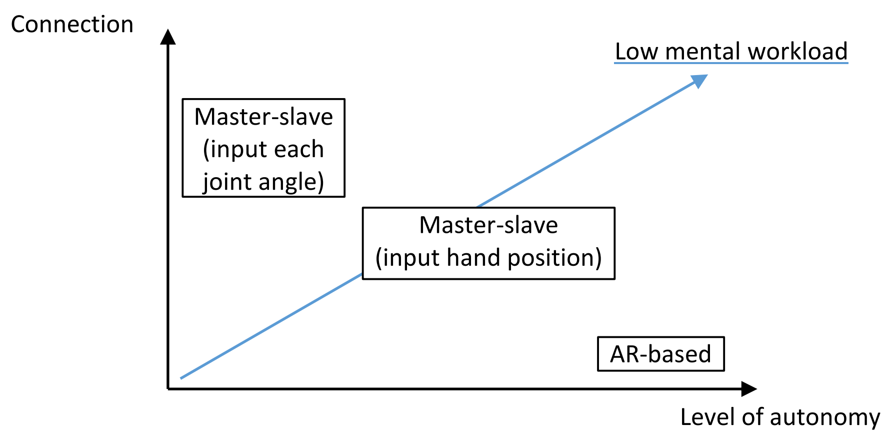
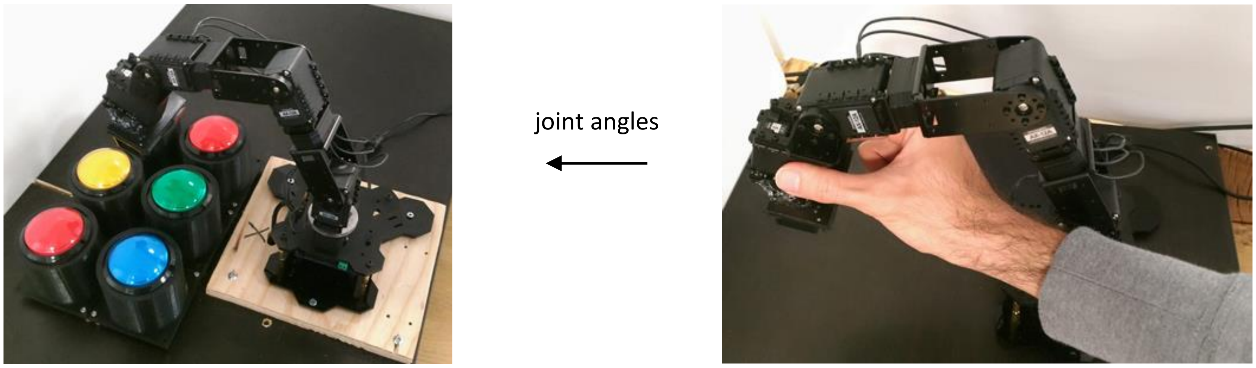


Fig. 2 Tradeoff between connection and autonomy level

Sense of agency can be categorized into the Feeling of agency (FOA) which is not conceptual and the Judgement of agency (JOA) which is conceptual [16]. For example, when people push buttons, they do not consciously consider all the joint angles of their upper limbs, associated with FOA, although they think about which buttons to push, which impacts JOA. In the pushing case, humans must decide which objects to push, mentally plan trajectories, calculate each joint angle for the planned trajectories [17]. We hypothesize that FOA associated with control of trajectories and joint angles affects the sense of connection that subjects feel with remote area and people.

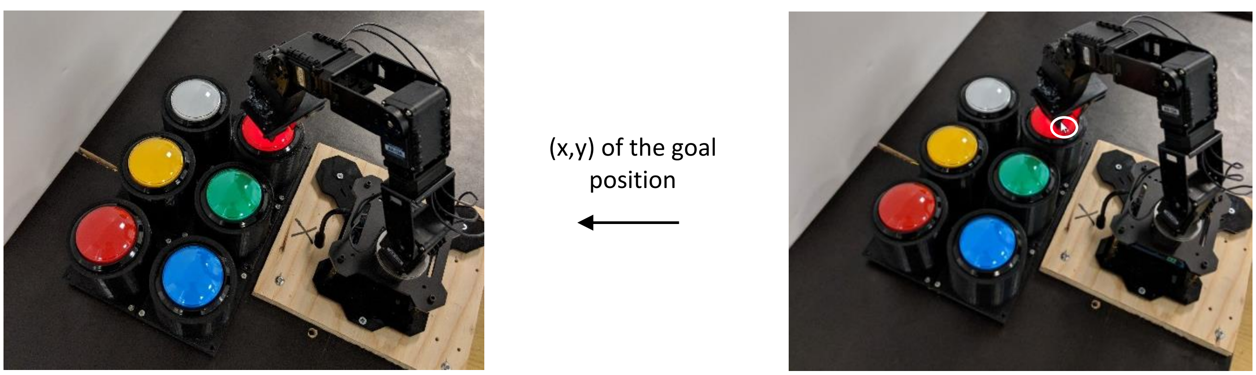
We are conducting experiments to investigate the relationship between FOA and sense of connection. The experimental tasks, shown in Fig. 3, are for a local person to select which button will light, and for a remote person to control the robot to push the illuminated button. We used “PhantomX Pincher Robot Arm” with 4 degrees of freedom because pushing buttons does not require roll and yaw. We developed two master-slave and one touch-based interfaces for the experiments, shown in Fig. 4. For one master-slave interface, the user controls all joint angles by moving another matching robot arm as shown in Fig. 4 (a). The input of the other master-slave interface is the hand position and pitch angle tracked using a leap motion as shown in Fig. 4 (b). The input of the touch-based interface is the goal hand position of the robot by touching the screen as shown in Fig. 4 (c). We measure the number of correct buttons pushed, mental workload assessed by NASA-TLX [18], and sense of agency and connection assessed by a questionnaire. In informal preliminary experiments, 6 subjects controlled the robot arm. The results suggest that remote users prefer the master-slave interface for inputting the hand position and pitch angle because it reflects their own hand movements. However, the results also indicate that work efficiency is lower than for the touch-based interface. Thus, some information support systems including AR [19] could be helpful. The final paper will report on the completed experiments with more subjects.

Fig. 3 Experimental setup



(a) Master-slave interface using another robot arm

(b) Master-slave interface using leap motion



(c) Touch-based interface using clicking on screen

Fig. 4 Experimental comparison

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