Research Statement - Ryo Suzuki

My research in Human-Computer Interaction (HCI) focuses on the design and development of novel **tangible interfaces with interactive robots**. During my PhD, I designed interactions between humans and swarm robots to explore how distributed robots can be embedded and co-exist within our everyday environments. By leveraging techniques from both robotics and HCI, my research aims to *make the physical environment more adaptive using distributed swarm robots at all scales* (i.e., from mm- to m-scale).

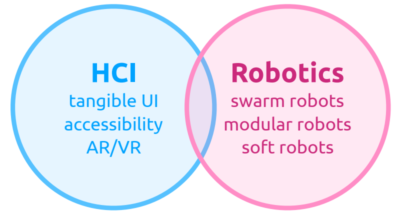

Figure 1: My research focus lies in the intersection between human-computer interaction and robotics.

Developing interactive interfaces with swarm robots introduces unique challenges in both mechanical (i.e., robotics) and interaction design (i.e., HCI). In **mechanical design**, existing swarm robots are often limited by the speed of reconfiguration (e.g., too slow to be used for interactive systems), available size of the element (e.g., difficult to scale down to mm-scale), and functionality (e.g., cannot construct shapes beyond 2D in real-time). From the **interaction design** perspective, most of the current robots follow pre-programmed behaviors, and it is unclear how the user can interactively specify the behavior, other than coding on a computer screen. My work contributes to overcoming these challenges by 1) introducing **self-transformable swarm robots** at different scales to enhance functionality and expressiveness, 2) developing a technique to externally actuate **mm-scale swarm elements** for high-resolution tactile output, and 3) developing an interaction technique to enable **on-the-fly swarm programming** with tangible interactions in the real world.

Figure 2: ShapeBots [1] is an example of context-aware swarm assistant.

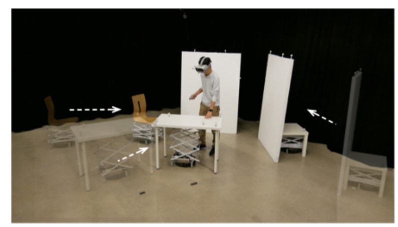

Figure 3: RoomShift [2] is a swarm of furniture-moving robots.

Through my work, I have identified two potential application areas enabled by these swarm robots: 1) a **context-aware swarm assistant**, in which the distributed swarm robots serve as ambient assistants to support our everyday activities, 2) a **dynamic tactile and haptic interface**, in which the robots provide tactile and haptic sensation for blind users and users in virtual reality, so that they can touch, feel, and manipulate digital information with their hands and bodies.

Figure 4: LiftTiles [3] collectively reconfigure the space for ambient assistant.

1. Context-aware Swarm Assistant

In ubiquitous computing, a context-aware assistant refers to an approach that computationally controls the environment based on the user's needs and situation. Today, computers and IoT devices are increasingly embedded in the environment to intelligently control heating, air-conditioning, and lighting for users. My work pushes the boundary of this context-aware assistant to *physically* adaptive systems. Traditionally, *physically* adaptive assistants (e.g., automatic door

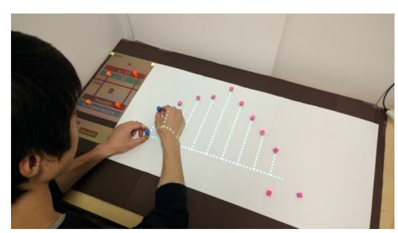

Figure 5: FluxMarker [4] and Reactile [5] uses externally-actuated passive magnets as mm-scale swarm elements.

or robotic furniture) require a tremendous cost for installation. Assistants based on distributed swarm robots can minimize this cost as they can be easily deployed without the need for replacing the built elements. Also, by leveraging collective behaviors and locomotion capabilities, these robots can adapt to different tasks and environments. My work demonstrates how these distributed swarm robots can serve as a context-aware, physically-engaging assistant that autonomously weave themselves into the fabric of physical environments.

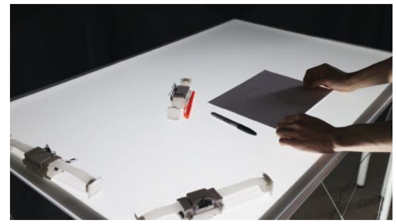

Figure 6: ShapeBots can bring a pen for the user.

Adaptive Physical Assistant with Tabletop Swarm Robots

ShapeBots [1] is an example of an adaptive assistant with tabletop-size swarm robots. This system shows how a swarm of small self-transformable robots can support various types of everyday activity. For example, Figure 2 and 6 show that these robots can collectively transform and move on top of a table to bring a tool or clean up a desk for the user. Also, by collectively reconfiguring their shape, they can *physicalize* a digital object, so that, for example, the user check the actual size and design of the CAD software (Figure 7). These robots can also provide context-aware *affordances*. For example, when the user pours hot coffee into a cup, the robots surround the cup and create a vertical fence to indicate that the user should not yet touch it (Figure 8). Once it is ready to drink, the robots start dispersing and allow the user to grab the cup.

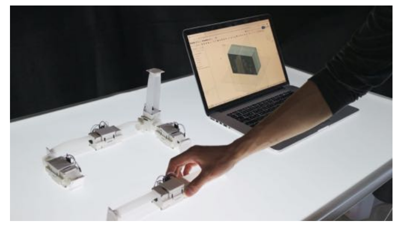

Figure 7: ShapeBots physicalize the CAD model and the user can interactively change the design.

Figure 8: ShapeBots indicates the coffee cup is too hot by creating a vertical fence.

Spatial Reconfiguration with Room-scale Swarm Robots

Beyond tabletop-sized robots, I explore how large-scale swarm robots can support our everyday life. Inspired by shelf-moving warehouse robots (e.g., Kiva robots), I developed RoomShift [2] swarm robots that can move furniture to autonomously rearrange the spatial layouts of a room. By mounting a mechanical scissor lift on top of the Roomba, the robot can go underneath a piece of furniture and vertically extend the structure to lift, move, and place it. By collectively rearranging spatial configurations, these robots can make a physical environment more adaptive, such as arranging chairs and desks for a meeting based on a calendar event. Similarly, LifTiles [6, 3] leverages its inflatable structure and pneumatic actuation to physically reconfigure a space. Because the inflatable structure is robust and can withstand heavy objects, the user can step on or sit down on the robot (Figure 4).

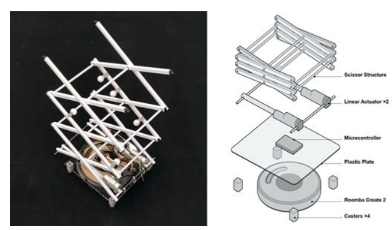

Figure 9: RoomShift's mechanical design.

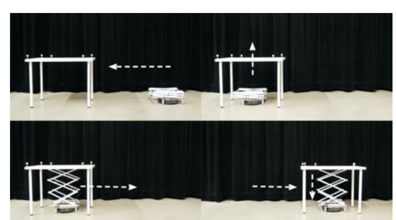

Figure 10: The robot can go beneath a piece of furniture to lift, move and place it.

2. *Interactive Tactile and Haptic Feedback with Swarm Robots*

One benefit of a physical interface is its ability to provide rich haptic and tactile sensation. Recent advances in virtual and augmented reality (VR/AR) promise immersive experience, but objects rendered in these scenes are only visual: the user cannot touch, feel, or grasp objects in the virtual environment. This limits both the immersive experience and the human's innate capability of manipulating objects. Interfaces made of swarm robots provide one solution to this problem by dynamically constructing and reconfiguring physical shapes to align with virtual objects. In addition, this dynamic tactile sensation makes digital information accessible to people with visual impairments. Motivated by these possibilities, I explore how large- and small-scale swarm robots can provide dynamic tactile and haptic feedback.

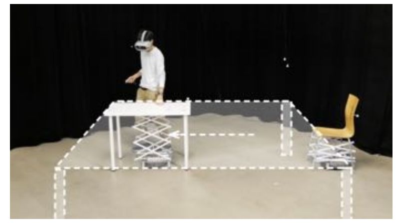

Figure 11: The robots can provide dynamic haptic feedback for VR by moving furniture.

Providing Room-scale Haptic Sensation for VR

Built on top of our furniture-moving swarm robots, I developed a room-scale dynamic haptic environment for VR. This system can provide haptic sensation that extends beyond existing finger-tip or on-body haptic feedback. The system tracks the position of the user, the furniture, and the robots, and synchronizes the physical environment with the virtual scene by continuously reconfiguring the physical space. By augmenting virtual scenes with physical objects, users can sit on, lean against, and step onto the rendered elements. This enables the promising application in real estate virtual tours in which the user can explore a virtual home and office as if they were actually in the physical space. The space continuously reconfigures as the user moves or teleports, such that the user can explore a larger area than the actual room. I developed and evaluated a technique that efficiently supports this scenario. For example, by dynamically moving existing furniture, the system can flexibly match the virtual scene with a small set of prepared furniture (e.g., mimicking a large desk by moving small desk in Figure 12).

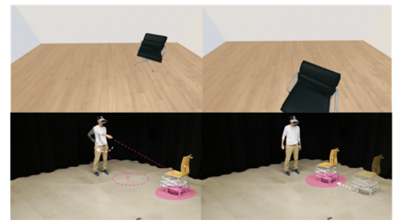

Figure 12: The physical scene can be synchronized with the virtual scene.

Figure 13: FluxMarker actuates magnetic markers to enable the blind user to touch the information.

Making Information Tangible for Blind Persons

FluxMarker [4] is a system to augment static tactile graphics for people with visual impairments. Tactile graphics are images that use raised surfaces (e.g., embossed images on swell paper or thermoformed plastic sheets) so that a blind user can touch and feel the image. Our system is designed to enhance static tactile graphics with a swarm of small markers that can render dynamic content for annotation. For example, a blind user can ask "Where is the nearest coffee shop?" Then, dynamic tactile markers can annotate the location to help the user identify a spatial position quickly (Figure 13). For this purpose, the size of the markers needs to be small (e.g., smaller than 1 cm). To achieve this goal, I designed and fabricated electromagnetic coil arrays with a printed circuit board (PCB in Figure 15). Running

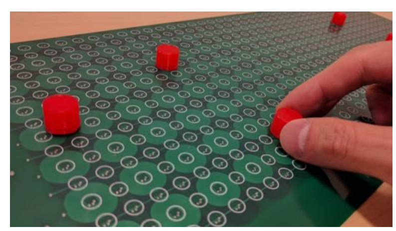

Figure 14: The electro-magnetic coil array of the custom designed printed circuit board (PCB).

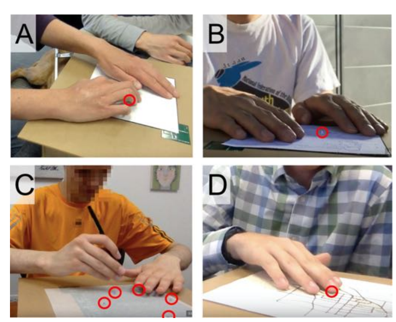

Figure 15: Evaluated the system with blind users.

current through each coil can generate magnetic force, so that the system can sequentially move small passive magnets (e.g., 3mm - 8mm) on an X-Y grid.

On-the-fly Swarm Programming with Direct Manipulation
Finally, I explore a programming paradigm for swarm robots. Most of the systems that I described assumes pre-programmed behavior designed for a specific application. When actually deploying these robots, it is also important for the user to specify or reprogram the behavior on-the-fly. To this end, I built Reactile [5], a programming environment for swarm user interfaces. Reactile combines two approaches—constraint-based programming [8] and programming by demonstration [9]—to allow programming with direct manipulation. The user can construct and animate a shape made of swarm robots through physical demonstration while allowing the user to define the interactivity with dynamic constraints (Figure 16). I demonstrate an application enabled by this approach (e.g., data visualization) in Figure 5.

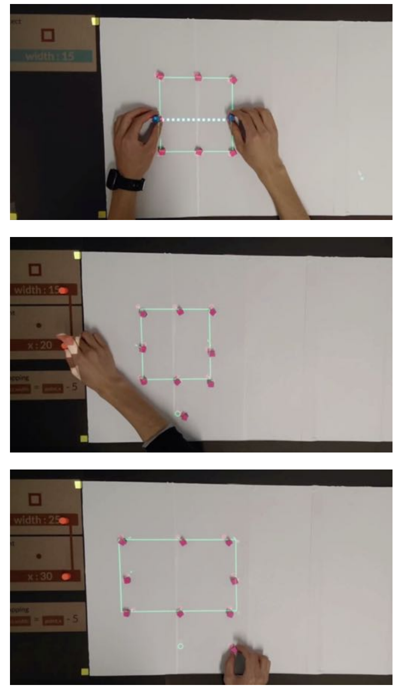

Figure 16: Reactile allows the user to program swarm behaviors with direct manipulation.

Research Agenda

How can we construct 3D shapes in seconds with swarm elements? Inspired by the science fiction—such as microbots in the Big Hero 6 movie—researchers have sought to construct dynamic 3D shapes with swarm robots. I approach this problem with the combination of internal and external assembly. For example, Dynablock [7] demonstrates arbitrary and instant 3D shape construction by assembling thousands of tiny passive magnetic blocks (Figure 17). To extend this work, I am interested in creating swarm robots that can automatically assemble and disassemble shapes in seconds.

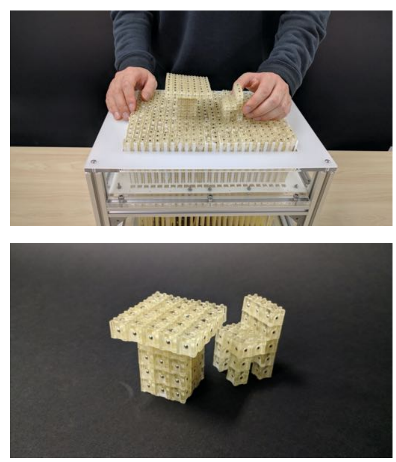

Figure 17: Dynamically construct 3D shape in seconds by assembling thousands of tiny magnetic blocks [7].

How can users see the program or intention of the robots? To achieve on-the-fly swarm programming, there remain many fruitful research opportunities. For example, it is important for the user to see the internal state or relationship between each robot. In future work, I will leverage our AR-based visual guides [5, 8] to help users see the state of swarm robots in order to understand and program behaviors.

How can swarm robots adapt to different environments? Most of my work can operate only on a flat surface. To achieve the vision of *swarm robots that autonomously weave themselves into physical environments*, we must improve locomotion capability. I am currently developing swarm robots that move on a ceiling grid, such that the capability to traverse walls or ceilings can reveal new possibilities.

How to scale the manufacturing of swarm robots? One of the bottlenecks of hardware research is its scalability; it is usually very time-consuming to manually make thousands of swarm robots. For my long-term research direction, I envision automating this process by inventing *swarm robots that make swarm robots*. I have built a fabrication machine to create an interactive system [10]. By leveraging insights from my previous works, I will explore customizable swarm robots with plug-and-play functionality kits; I will then seek to autonomously fabricate, assemble, and disassemble swarm robots with using the machinery of other swarm robots.

Figure 18: Program soft robots by demonstration. The user can program the simple behavior by physically deforming the soft robot [9].

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