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An Expressive Robotic Table to Enhance Social Interactions

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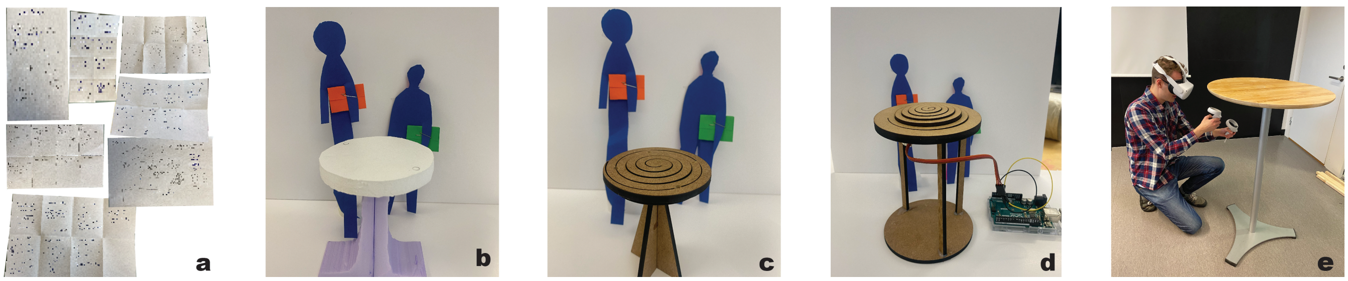

Figure 1: Prototyping techniques used: (a) ideation methods, (b) the first foam-based prototype, (c) laser cute wood-based prototype, (d) upgraded wood-based prototype with implemented motors and Arduino, (e) prototyping using virtual reality.

ABSTRACT

We take initial steps into prototyping an expressive robotic table that can serve as a social mediator. The work is constructed through a rapid prototyping process consisting of five workshop-based phases with five interaction design participants. We report on the various prototyping techniques that led to the generated concept of an expressive robotic table. Our design process explores how expressive motion cues such as respiratory movements can be leveraged to mediate social interactions between people in cold outdoor environments. We conclude by discussing the implications of the different prototyping methods applied and the envisioned future directions of the work within the scope of expressive robotics.

CCS CONCEPTS

• **Human-centered computing** → **Interaction design**.

KEYWORDS

Robotic Table; Social; Expressive Interface

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1 OVERVIEW

Interactive tables are frequently used as a research platform to support and mediate social interactions [22]. Several researchers have attempted to design tables that dynamically move, reshape, or apply actuator adjustments towards users' needs. For example, the works by Leong et al. [10], Takashima et al. [16] and Fu et al. [7] use a shape-changing table to mediate interaction between its participants.

However, we have seen very little research on interactive table designs that mediate social interactions through dynamic robotic behaviors, such as applying expressive behaviors to facilitate users' interactions. Expressive social cues have been researched and used in furniture design in previous literature [13, 17], but to the best of our knowledge, expressive robotic tables are yet to be explored. This has motivated us to take initial steps into prototyping an actuated robotic table that is expressive and can be utilized to mediate social interactions in different contexts. Our main objective in this late breaking report is to demonstrate our prototyping process, describe our lessons learned and outline our future direction to this ongoing research. Thus, we contribute to the HRI community the following:

- An investigation into design options for an expressive robotic table that mediates social interaction
- An exploration of novel features in designing expressive robotic tables using multiple approaches to a rapid prototyping process
- A reflection on the prototyping approaches used in the context of designing a robotic table, while highlighting future research directions.

2 RELATED WORK

In this section, we highlight the main works that encapsulate our motivation and our approach to designing an expressive robotic table that mediates social interaction. One reason for having robots exhibit emotions or expressivity is that it supports communication in modalities that are natural to human users, and should thus support their collaboration [2]. To this end, HRI researchers have focused on studying and designing for several forms of expressivity that are non-verbal. For example, some have focused on facial expression and gaze [11], while others have turned to other, more subtle bodily expressions that convey emotion. One such expressive channel is that of a respiratory pattern. Bucci et al. [3] test the proposition that valence of emotion (i.e. happy/sad) can be read from a robotic agent's varying the complexity of patterns of motion reminiscent of breathing. They also show that from these patterns, humans will try to infer internal states of the agent, or explanations as to why it is breathing as it is. The possibility for using breathing as a communication channel to facilitate collaboration between humans and robots has also been explored [18]. In addition, researchers have also looked at introducing expressive breathing behaviors in everyday objects, for example a pillow to serve as a device for guided breathing [21]. This is interesting as a pillow is a common item already with associations to relaxation and rest, but here its functionality is augmented using interactive breathing motion.

This widespread exploration into breathing as an augmenting expressive feature of robots and everyday objects, and the apparent ability of breathing mimicry in robots to convey a story about their internal state, has motivated us to take initial steps into designing a table that exhibits expressive breathing motions to facilitate social interaction. Additionally, a potential research function of our design is to act as an inquiry as to what breathing can communicate (i.e. comfort/relaxation) which is useful for an everyday artifact (i.e. a table) in serving its role (i.e. facilitating social gathering).

Prototyping is a crucial part of the design process that assesses how the expression of a breathing interface is perceived by users. Prototyping large artifacts such as tables can be rather impractical as they take physical space and require a large amount of building material [8]. These reasons make it hard to rapid prototype large-scale interactive systems, which is an essential driving-force in an iterative design process. In this work, we explore various types of prototyping to construct and simulate large interactive table-like artifacts and reflect on the benefits and limitations of each.

3 DESIGNING A ROBOTIC TABLE

The aim of the presented work is to prototype an expressive robotic table; in particular, employing respiratory movements as the main expressive feature. A rapid prototyping approach allowed us to explore a design potential and features in a quick hands-on fashion [4]. The following section outlines our prototyping process.

Phase One - Ideation/Sketching To initiate the design process, the context of use was set for university students, primarily between 20-26 years old. Five students (aged 19 - 30 years) from Chalmers University of Technology, contributed to defining the general requirements of the table and its context of use. A workshop session (6h long), was set up with two parts: (1) to brainstorm needs and requirements for designing a social table with robotic capabilities, and (2) to generate ideas and prototypes. Several sketches were generated, through Crazy 8 and 6-3-5 Brainwriting methods [14, 19]. Figure 1a illustrates the ideas generated during the workshop. At the end, the group selected the concept that best fit the requirements for further development. One identified need was the ability for students to have comfortable outdoor breaks despite a cold climate, so a requirement was for the table to communicate warmth and comfort. Thereafter, the requirements were progressively refined throughout the prototyping process.

Phase Two - Initial Mockup In another prototyping workshop session (2h long), physical prototypes were created of the concept, as seen in Figure 1b. The first iteration was created with foam to explore the shape and proportions between the elements of the table. The prototype did not possess any functionality, therefore, a refined prototype was then created out of wood using a laser cutter, as seen in Figure 1c. Appropriate materials were 3 mm thick masonite, as this is flexible enough to allow for dynamic movements. A spiral originating from the centre of the 100 mm wide circular cutout was traced and cut. A second circular piece was cut with a hole in the centre to make space for installation of electrical components. The cutouts were then attached by gluing the outer rims together. This allowed the middle part of the spiral to rise while the rim stayed level. This prototype allowed exploration of the dynamic parts and demonstrated the breathing pattern assigned to it.

Phase Three - Dynamic Mockup In a third workshop session (6h long), the five students made another iteration of the prototyping by adding a combination of servo motors and an Arduino to automate the movement. This setup is shown in Figure 1d. Initially, the table had a rapid shake function to mimic the physical behavior of someone shivering in the cold and desperate for company. However, the design participants evaluated this to be intimidating and inconvenient rather than warm and accommodating. Instead, the Arduino was programmed to simulate breathing patterns that are exhibited in humans in different states of mind [1, 3]. Please refer to the supplementary video[1] to watch the breathing motion.

Phase Four - Video Prototype A video prototype was created to visualize a user scenario. The video was planned using a storyboard and then recorded using a phone's camera, with four authors as actors in the scenario. The table was first animated using the Wizard of Oz technique, placing a piece of cloth on a round standing table and using a stick to move the cloth up and down to resemble breathing motions. This was later replaced with a digital 3D animation overlay.

Phase Five - Mixed Reality Prototypes The final prototype used Virtual Reality (VR) to deliver visuals and audio to testers, along with a physical table and Wizard of Oz methods for tactile and temperature sensations. The VR environment was created using the Unity game engine and presented in a Quest 2 headset with associated packages for Unity development. A breathing sound was synthesized from white noise in real-time from a C# script which used Unity's onAudioFilterRead() function. We then applied a low pass filter and two audio envelopes to modulate the volume in a rhythmic fashion; one for the in-breath and one for the out-breath. The envelope curves could be evaluated at different speeds and were

[1] https://youtu.be/SJaog6gJ_No

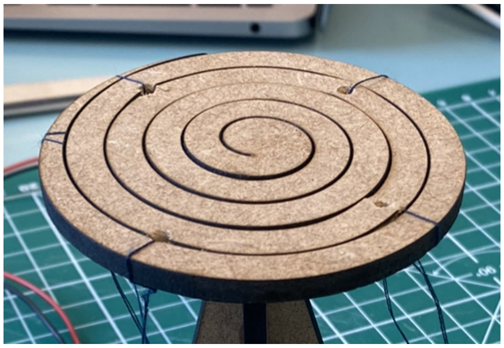

Figure 2: First wooden prototype with a swirl-shaped cut to enable physical motion through shape-change.

Figure 3: A screenshot of the video prototype using a digital overlay to visually communicate the tabletop heating feature.

synchronised to the motion of the table surface. The physical part of the prototype was a standing table which matched the form factor of the VR 3D model, and was positioned so that touch interaction was consistent with visuals for the tester. Figure 1e illustrates the setup.

3.1 Generated Concept

The result of the five prototyping phases was the concept of a robotic table that expressively invites people in an outdoor environment to gather around it. This is done via expressive breathing motion cues as seen in Figure 1. A spiral-shaped cut in the surface lets the table raise and lower its centerpiece to appear as if it is breathing. The deep and slow breathing mechanism is designed to invite people roaming outside to gather around it, and is intended to have the effect of alleviating stress, bring positive emotions, and perhaps foster connections between people [6, 15]. In addition, during the workshops it was revealed that people in colder environments pursue physical warmth and social affiliation since interactions with warm objects are associated with memories of warm feelings such as trust and comfort. In contrast, cold temperatures are shown to subconsciously affect people's behaviors and impressions of other people more negatively [5, 20]. Thus, the design participants incorporated heating of the surface together with the breathing motion (as visually highlighted in 3).

The heating element was also complemented by a warm shifting color lighting to the table. According to research, colors such as red, orange and yellow are primarily considered to be warm and grab attention, resulting in excitement compared to cold colors [9, 12]. The combination of the warm colors and the heating creates the association of a "campfire" concept, which many recognize as a peaceful social activity. The colors will therefore shift through different shades of red, orange and yellow.

4 RAPID PROTOTYPING REFLECTIONS

This section will reflect on the prototyping techniques explored in the making of the expressive robotic table; in particular, reflecting on each technique with its benefits and drawbacks which can support our future development in this project. A summary of the pros and cons for each of the techniques used is shown in Table 1.

4.1 Ideation and Tangible Prototypes

Sketching: The first method used was to sketch conceptual ideas on the design of a robotic table. Sketches were useful to quickly generate as many ideas as possible, diverging from the rapid design process without investing too much effort into individual ideas. Its low cost and minimal material requirements allowed for many quick iterations used to refine the general look and feel of the design. An illustration of the ideas generated can be seen in Figure 1a.

Foam model: In our prototyping process, we used a foam model to explore the physical attributes of the design. Although this requires more efforts than sketching, it is still considered to be a quick and cheap way of creating a low-fidelity tangible mock-up. The main drawback of the foam prototype was its instability, which prevented any upscaling or attachment of electronics. It was abandoned in favor of a wooden model, as it could not be used to accurately test techniques to deform the tabletop.

Laser-cut model: To develop interactive functionality of the table we laser cut a wooden scale-model. The first laser-cut prototype was made to test the deformation of the table through a swirl-shaped cut surface, as visible in Figure 2. The laser-cutting technique allows for great precision and accuracy which made it possible to have complex shapes such as the swirl and to embed electronic components in the physical build. Using a laser cutter for the prototype also made it easier for us to demonstrate expressive behaviors on the table. However, laser cutters are only capable of cutting flat and thin pieces of material, resulting in a certain aesthetic reflected in the prototype. Up-scaling to a more aesthetic oriented design requires more stable techniques in this regard.

4.2 Digital Prototypes

In order to convey a higher-fidelity experience that is still experimental, we explored multiple digital prototyping techniques to further support the physical prototypes. The prototyping techniques used fulfill three main purposes: (1) communicating a more realistic representation of the intended design, (2) simulating interaction with a larger scale model, and (3) contextualizing the design by simulating a virtual environment in which the table exists.

Video: Through video prototyping we could communicate a potential scenario of how the expressive robotic table could be used in a real world context. Minimal props were needed as preparation,

Table 1: Pros and cons of attempted prototyping techniques.

Prototype technique	Pros	Cons
Sketch	Quick, easy, disposable. Minimal resources required.	Merely outlines ideas.
Foam model	Quick, cheap, Physical 3D form.	Not scalable.
Laser-cut wooden model	Fast, precise, scalable, distinct aesthetic.	Access to the machine, distinct aesthetic.
Video	Easy to make. Added augmented digital effects. Provides a narrative.	No interactive user experience.
Virtual Reality	Creative freedom and flexibility. First-person perspective. Large-scale representation of objects. Object and user situated in simulated environment.	Lacks physical materiality. Requires time and experience. Requires VR equipment.
Mixed Reality	Almost realistic interactive user experience.	Requires VR equipment.

as we could digitally augment a simple non-interactive table with video effects to recreate the breathing motion and visualize the temperature changes in post-production, as illustrated in Figure 3. This would be hard to recreate in a low-fidelity mock-up. Acting the scene allowed us to play out a scenario that we deemed realistic and easily allowed us to communicate a potential user experience in third-person view. Showing the video at a workshop session allowed us to get quick impressions on the overall concept and design of the robotic table. One of the drawbacks of the video format is that it is not interactive; the viewer cannot engage with the prototype in an active manner. Hence, it does not reveal any insights in terms of user behavior with the design and feedback stays at a speculative and imaginary level.

Virtual Reality: To compensate for the lack of interactivity in the video, we 3D modeled a virtual table for use in Virtual Reality (VR). This technique is highly versatile, offering a high degree of creative freedom and limited only to the creative potential and amount of effort from the designer. Since the 3D model of the table is virtual, we could easily change the size of the object, allowing us to reconstruct a life-sized table that would require a lot of material to build physically. Another benefit of VR is that users can examine and interact with the 3D model in first-person perspective using a VR headset and controls, increasing the fidelity towards a more realistic user experience. In addition, we could simulate the context of an outdoors environment, and situate the table in that intended environment to make the first-person experience more immersive. Some drawbacks of this technique are that the prototype does not reveal any insights about the physical materiality of the table, such as the haptic feedback of the changes in temperature and shape-change of the breathing motion. Another drawback is the availability and access to VR equipment which can be costly.

Mixed Reality: A mixed reality (MR) prototype is a prototype that combines the physical and virtual world. To make up for the lack of physical touch in the VR setup we augmented our VR simulation with a physical table, as seen in Figure 1e. We pre-heated a cloth resting on the table's tabletop surface using a hot iron to Wizard-of-Oz the temperature aspect of our concept design. The virtual table was modeled to match the size, appearance, and spatial placement of the physical table. This allowed the user to touch the 'virtual' table and feel the heat, elevating the levels of realism.

Audio: Finally, we supported the digital prototypes with synthesized sounds to try and make the expressive motion of breathing more seamless. Altogether, the audio allows the table to have an effect on the user even when outside the field of view, and with stereo audio the user can detect and orient themselves towards the table as it starts making sounds.

5 CONCLUSIONS AND FUTURE WORK

The purpose of this work was to initiate and investigate the design options of an expressive robotic table that mediates social interactions. We applied a rapid prototyping approach that is based on giving the table means of expression by means of a breathing motion and sound. The choice of the modality of expression is motivated by research suggesting breathing patterns can be used in robots to engage the user in the inference of affective states and causes of these. The rapid prototyping process allowed us to also explore several prototyping techniques that proved useful in our investigations and ideas for future directions of the work.

To draw conclusions on the impact of the presented design, future work must be taken into consideration. One future aim is to use an iterative approach to progress our expressive table design by including user evaluations. This can include both quantitative and qualitative user studies on the different prototypes generated, such as standardized questionnaires or focused group workshops. Furthermore, we aim to develop a full-scale prototype to be deployed in field studies to determine its usability and effects on social behavioral dynamics. Moreover, in this work we had students as the intended users, while future work will be more inclusive of other user groups to allow for a more universally accessible table design.

Finally, the prototyping process can be coupled with a more holistic UX design approach that considers the aesthetic choices of form, function, and interaction, and considers the ethical consequences of placing an expressive table in a socio-cultural context.

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