Embracelet: a wearable interface providing haptic feedback to increase social and co-presence with a personal virtual agent

Ulrike Kulzer
Saarland Informatics Campus
Saarland University
Saarbrücken, Germany
u.kulzer@posteo.de

In human-agent interaction, effective interaction with a virtual agent relies on the user's feeling of social presence, i.e., being socially connected to the agent, and co-presence, i.e., being together with the agent. To simulate this, we propose a wearable interface that provides haptic sensations to represent a personal virtual agent and its state. Through haptic feedback, we aim to generate a persistent connection between the user and their virtual agent in an unobtrusive manner. In this paper, we provide an overview of the current state of our project and future research goals.

I. Introduction / Background

Virtual agents (VA) are becoming more and more integrated into our everyday lives. For example, voice assistants enable an intuitive way to interact with smart homes [1], smartwatches monitor our health, artificial intelligence models like ChatGPT are used to solve a wide range of tasks, VAs can act as companions in virtual reality (VR) games, and audio-visual agents guide through mixed reality exhibitions in museums [1].

Previous work has shown that the effectiveness of human-agent interaction relies on the user's perceived feeling of *social presence*, i.e., being socially connected to the agent, and *co-presence*, i.e., being together with the agent [1]. However, effective interaction with a VA is also influenced by the representation of a VA and the means to interact with the agent, which can differ significantly throughout different applications. This might negatively affect the communication between the user and the agent, as for each representation, a different set of partially natural and partially artificial cues has to be interpreted by the user to derive the VA's current state and interaction possibilities. Especially in dynamic scenarios where a user transfers between different spaces, e.g., virtual reality and the real environment, the persistence of the agent remains crucial. It is therefore essential to provide an awareness of the state of the VA, i.e., if it is available for interaction, and if the agent has correctly responded to a previous inquiry.

While others address this problem by giving the VA a human-like representation and behaviour in VR/AR to increase social and co-presence, real world VA implementations mainly rely on a combination of visual and auditory cues, e.g., Amazon Echo[1] or Apple HomePod[2]. Such cues are highly limited in their expressiveness, and demand direct attention from the user.

To build a consistent feeling of social and co-presence to a VA, we propose a wearable interface that enables haptic communication between the VA and the user. Our interface

a. can be taken everywhere by the users,
b. clearly and intuitively communicates the agent's current state with haptic feedback, and
c. uses the same communication means across different spaces, i.e., reality, AR and VR.

Our interface is based on a bracelet, as this agent representation gives the user the feeling that the agent is always with them (co-presence). Besides, a purely haptic communication of the agent's state is also expected to add to the user's feeling of being socially connected with the agent (social presence), as humans use touch for social communication [3]. Similar to related work presented in the next section, our interface concept focuses on force feedback that imitates social gestures. In section III, we present insights from our initial design exploration, as well as different concepts and sketches that helped us refining the design requirements. Our final design will use haptic feedback for communication, specifically location-based touch, dynamic and permanent squeeze, and vibrotactile feedback, clearly conveying the agent's actual state. We then plan on conducting a user study with our device to investigate the user's feeling of social and co-presence.

II. Related Work

Our work builds upon haptic feedback provided by wearable interfaces. We base our implementation on the following state-of-the-art.

[1] Amazon Echo lights (last accessed on 14/05/2025): https://www.amazon.com/gp/help/customer/display.html?nodeId=GKLDRFT7FP4FZE56

[2] Lights of Apple HomePod (last accessed on 14/05/2025): https://support.apple.com/en-us/101607

A. *ServoSqueeze and ServoTap*

In 2010, Baumann et al. explored how a wearable device giving haptic feedback using simple mechanism can imitate human social communication to get the attention of a user [3]. Their final prototype, which can be seen in Fig. 1(a), consists of a bracelet with two servos: One tightens the wristband to simulate being squeezed by someone (*ServoSqueeze*), and another one controlling a foam-tipped finger to imitate the feeling of being tapped (*ServoTap*).

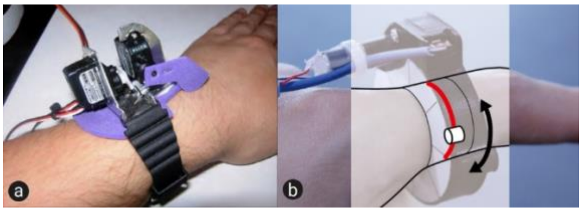

Fig. 1. Two wearable haptic feedback devices: (a) Baumann et al.'s prototype that combines *ServoSqueeze* and *ServoTap* [3]; (b) Je et al.'s *tactoRing* [4].

B. *tactoRing*

Je et al. developed *tactoRing*, a smart ring that provides haptic feedback by rotating a small tactor around the finger [4]. The feedback system builds upon the tactor covering different distances, going back and forth, on which different information is mapped that had to be learnt by the users before taking part in the study. *tactoRing* is shown in Fig. 1(b).

C. *HexTouch and TactorBots*

Zhou et al. proposed *HexTouch*, a wearable haptic feedback device to supplement the visual and auditory feedback of a virtual agent in a VR game which aimed to increase the user's feeling of *social* and *co-presence* [5]. The haptic device expressed a total of eight social cues, e.g., by gentle tapping, squeezing or swinging. *HexTouch* and one example cue (directional hint to the right) are presented in Fig. 2.

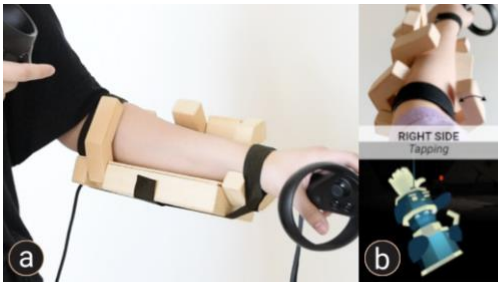

Fig. 2. Zhou et al.'s *HexTouch* [5]: (a) The haptic feedback device; (b) gentle tapping as haptic feedback to give a directional cue to the right with the virtual representation of the agent below.

Zhou et al. continued their research in this area and developed an open-source haptic feedback design toolkit with so-called *TactorBots*, wearable modules that offer different types of force feedback, such as stroke, squeeze and tap [6]. The toolkit offers an easy access to the realisation and exploration of robotic touch gestures without having to create complex hardware devices, as all modules are 3D printed with open access to all necessary files[3]. Fig. 3 shows the modules and how they can be worn on the arm.

[3] Ran Zhou TactorBots (last accessed on 14/05/2025): https://www.ranzhourobot.com/#/tactorbots/

Fig. 3. Zhou et al.'s *TactorBots [6]*: (a) Several modules are worn on the arm; (b) the different modules.

III. Imagined or existing prototype sketches/drawings/photos

We envision a wearable that uses haptic communication to inform the user about the VAs actual state in an unobtrusive manner. This builds an awareness of the agent and enforces the feeling of co-presence elicited by knowing that the agent is always there. The haptic feedback aims to imitate social touch to make the user accept the VA as a full-fledged interaction entity, adding to their feeling of social presence. Haptic feedback allows for an unobtrusive way to communicate information without interrupting a situation like ongoing conversations or media consumption, minimizing distractions. Our implementation aims to use metaphors that can be related to the social behaviour of human or animal beings, for example continuous breathing to show that something is sleeping, i.e., not active.

A. *Design Requirements*

Our wearable is devised as a bracelet worn on the forearm, as this is a socially accepted form of a smart device, like a smartwatch or fitness tracker. To keep the hardware small and simple, we focus on location-based force feedback that can be extended with vibration, excluding feedback types that require more complex hardware, such as pneumatic or thermal feedback. During the kick-off session of the project, we came up with the following metaphors illustrated in Fig. 4 for the communication of possible states:

- Sleeping for being present but not available for interaction
- Repeated pings for being active and/or waiting for input
- Showing progress for working on a task
- Going to sleep to indicate that an interaction/task has ended
- Notifying the user about an event, e.g., that a process has been finished
- Waking up for preparing to interact

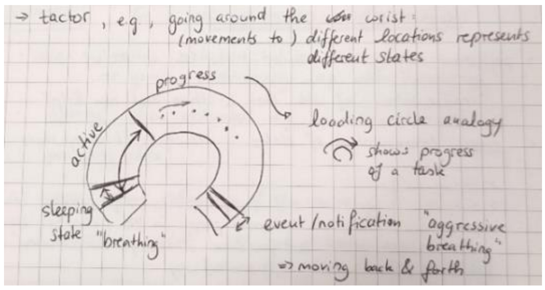

Fig. 4. Sketch of a first concept with an actuator giving location-based haptic feedback around the arm.

Our bracelet aims to provide consistent haptic feedback that augments other modalities, such as auditory and visual information, across blended spaces and representations, building consistent awareness of a VA's actual state.

B. Exploration of different designs

Our first design idea was to create a bracelet with one actuator that moves along and around the forearm.

In a brainstorming session we investigated if this idea could be realised by using one of Le Goc et al.'s Zooids [6], i.e., a tiny robot initially created to be used in a swarm of Zooids, that drags an attached bracelet up and down the forearm or turns it around the arm. This design idea is sketched in Fig. 5.

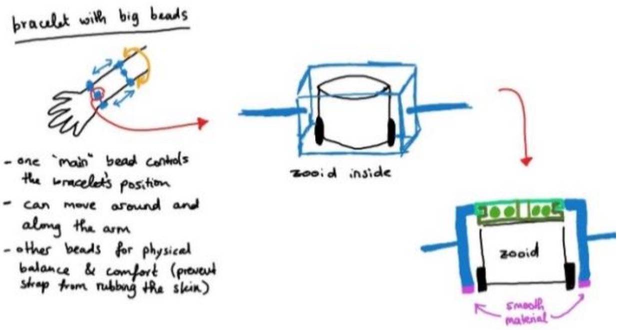

Fig. 5. Sketch of how we could make use of a Zooid [6] to move a bracelet along and around the forearm.

Another possible implementation we were thinking of was a bracelet with two strings, an elastic one that fits the user's arm, and another one that hangs loose, potentially with a small weight like a bead. Both strings are connected to a motor that controls the movement along the forearm (elastic string), and another motor that pulls the other string around the forearm. The bead can be fixed to a specific position of the string so that at a certain point of rotation the bead touches the arm and gives additional cutaneous feedback, or it can be loose so that it stays on the string according to gravity. This gives the bracelet the potential to gently remind the user of the VA's presence when the user moves their arm around, because the bead moves together with the arm and can randomly give cutaneous feedback. A sketch of the design can be seen in Fig. 6.

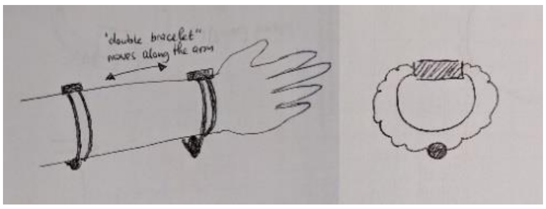

Fig. 6. Sketch of a bracelet with two strings that are pulled to move along and around the forearm. A bead gives additional haptic feedback.

To get a better understanding of different mechanisms and materials used in common bracelet designs, we first conducted extensive research on bracelet designs in jewellery industry. Fig. 7 shows some of the design sketches inspired by this research.

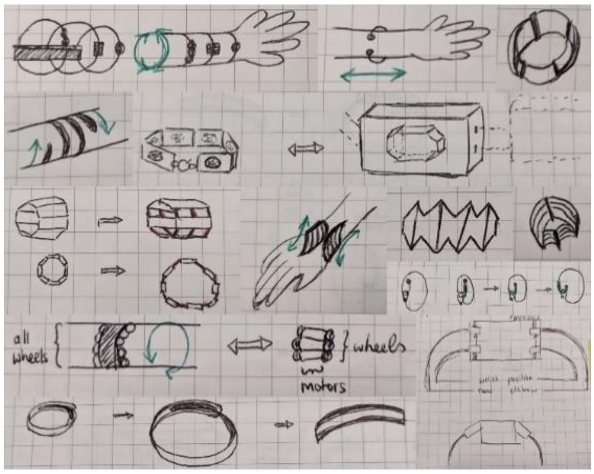

Fig. 7. Sketches of different bracelet mechanisms and their potential regarding the design requirements.

We then 3D printed different styles of bracelets and stretching mechanisms to explore the flexibility that is needed to cover the difference in the circumference of the forearm between the wrist and the elbow. The 3D printed bracelets can be seen in Fig. 8. Except for one model that was custom created based on the mechanism of a ring with an adjustable band, all designs were free available models on MakerWorld[4].

Fig. 8. Different 3D printed mechanisms/patterns and bracelets.

C. Outcomes of the explorative work

As we could not find a simple and lightweight solution to overcome the anatomical difficulties (sizes, edges), we abandoned the idea of a bracelet that moves along and around the forearm. Instead, we did another brainstorming session and came up with a cuff-like design, which is shown in Fig. 9. This helped us refining our haptic feedback requirements to make the following design decisions: The bracelet should be worn near the wrist and should be able to give haptic feedback in the form of *dynamic squeezing*, *permanent squeezing*, (fixed) *location-based feedback*, and *vibrotactile feedback*. These different types of haptic feedback should be used to express metaphors to communicate the different states of the agent. While we are currently focusing on building a prototype, some example metaphors are listed in TABLE I. for a better understanding.

[4] MakerWorld (last accessed on 13/05/2025): https://makerworld.com/

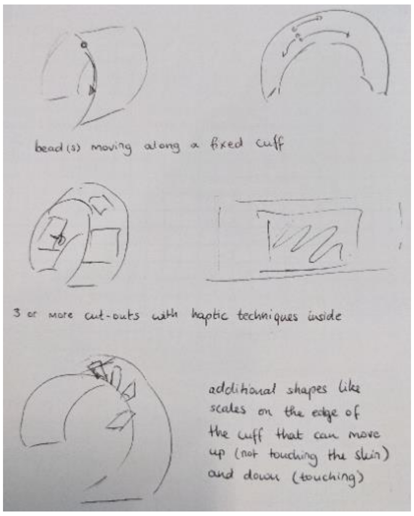

Fig. 9. Sketch of a cuff-like design that was used to refine the haptic feedback requirements.

TABLE I. THE DIFFERENT FEEDBACK TYPES MAPPED TO AGENT STATE METAPHORS

Feedback Type	**Metaphor**	**Meaning**
Dynamic squeezing	Regular breathing, e.g., while sleeping	The agent is present, but not active (raises the awareness of the agent being present).
Single or sequent location-based feedback	*Single tapping:* Being tapped by someone, e.g., to get their attention *Repetitive tapping at regular intervals (same location):* Imitating a reachability ping test in networks *Sequent tapping (different locations):* Imitating ongoing movement	*Single tapping:* An event occurs, e.g., the agent has finished its task. *Repetitive tapping at regular intervals (same location):* The agent shows that it is active and waiting for instructions (raises the awareness of the agent being present). *Sequent tapping (different locations):* The agent shows that it is working on a task, which can potentially also indicate its progress.
Vibrotactile feedback	Purring, or excitement about something	Can be used as a pet-like reaction to support the user when achieving goals.
Permanent squeezing	Being grabbed and hold by someone, e.g., to direct one's attention	A major event occurs, e.g., the agent had to abort the current task. Can also be used as an enhancement if the user doesn't react to the single tapping.

Having refined the haptic feedback requirements, we conducted research on how existing wearable haptic feedback devices implement our four feedback types. The most matching projects are presented in section II.

D. Final design

The idea for our final design is highly inspired by Zhou et al.'s *TactorBots* [6]: We took a closer look to the design of the tap module and reprinted it. The basic concept was to create a bracelet with multiple of these tactors which would enable the implementation of our feedback requirements. However, the original design of the tactors is quite big due to their use of servos, so we thought about how we can keep the concept of the tap module but reducing its size. That was when we switched to the intended use of solenoids instead of servos. We then developed the design concept of a bracelet consisting of multiple tap modules that are powered by solenoids and are connected through a clip-like mechanism so that the bracelet can easily be adjusted to different wrist sizes. This concept can be seen in Fig. 10. Regarding the connecting mechanism, we plan on examining the previously 3D printed bracelets again in detail to find a stable and simple way to connect the modules. We will also explore different shapes and surfaces for the actuator that is activated by a solenoid: Zhou et al. added the triangle shape to their tap module for a better differentiation from the pat/hit module. As we only use tap feedback in our design, such a specific shape is not needed, which allows for an exploration of its surface.

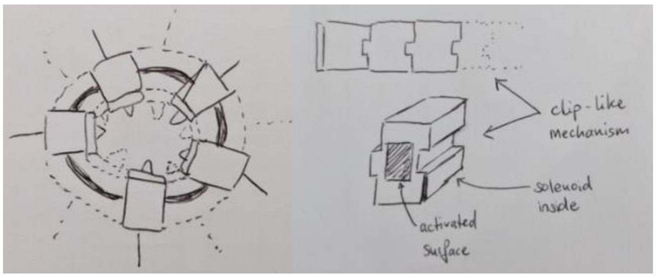

Fig. 10. The final design concept: The bracelet consists of multiple modules (left) that are powered by solenoids and can be connected to each other through a simple click-like mechanism (right).

E. Envisioned User Study

Using our wearable interface, we will investigate the following research questions:

- Can a physical and wearable representation of a VA increase social and co-presence in the VA?
- How should this representation look like in AR/VR, e.g. humanoid, like a pet, like a humanised object, or something abstract?
- Can the current state of the VA be communicated in an intuitive and haptic-only way so that the user does not have to learn a pattern or similar?

IV. Responsible Innovation

With our research on building a healthy relationship between a user and their personal virtual agent by strengthening the user's feeling of social and co-presence, we aim to make our society more open to the use of agents in our everyday lives, as well as to increase the social acceptance of using VAs. This can be achieved by a purely haptic communication, as this offers a subtle integration into our daily routine without interrupting ongoing activities. The wearable design also makes the need of taking a smartphone everywhere redundant, which, for example, resolves the problem of clothes without pockets that fit a smartphone, or of forgetting the smartphone at the desk. Focusing on simple mechanisms and 3D printed designs, we intend to create a wearable device that can be easily reproduced so that other interested people can try our bracelet without circumstance.

V. Author bio / experiences

I hold a master's degree in media informatics from Saarland University, Germany, and a bachelor's degree in media informatics from Ulm University, Germany.

My master's thesis investigated multimodal approaches to disguise hand redirection during reaching motions in Virtual Reality (VR). For this work, I built an arm-mounted bracelet to provide directional wind feedback, which I used in a psychophysical study to determine detection thresholds. The results of this study were published in a poster at IEEE VR 2025[5] [8] together with Dr. André Zenner and Dr. Donald Degraen.

I am fascinated by research that improves user experience in immersive environments, specifically through haptic feedback, and I am to pursue an academic career in the field of Human-Computer Interaction. This will also enable me to increase the outreach of computer science and inspire a wide and diverse audience, a topic that is very important to me since I worked as a computer science outreach assistant during my undergraduate studies. During my studies, I have built a broad range of academic skills such as literature research and academic writing, basic prototyping with 3D prints, embedded electronics and microcontrollers, user study design, VR and systems programming, and statistical analysis of experimental data.

To deepen my knowledge, I'm currently doing a research internship at the HIT Lab NZ with Dr. Donald Degraen and Dr. Susanne Schmidt, where I initiated the project presented in this short paper. In October 2025, I will start a PhD on haptics in virtual and augmented reality at HCI Lab Saarbrücken, supervised by Prof. Dr. Jürgen Steimle. To kick-start my PhD, I hope to attend this summer school which will allow me to hone my prototyping skills and connect to other students in the community.

VI. Acknowledgements

I'm very grateful to Dr. Donald Degraen and Dr. Susanne Schmidt who support this project and share their knowledge of virtual agents in blended spaces (Dr. Susanne Schmidt), and haptics, 3D printing and prototyping (Dr. Donald Degraen). Both will be co-authors of future publications resulting from this project. Special thanks also to Michael Kulzer who suggested to use solenoids instead of servos.

VII. References

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