machines

MDPI

Article

Yōkobo: A Robot to Strengthen Links Amongst Users with Non-Verbal Behaviours

Siméon Capy [1,*,†], Pablo Osorio [1,†], Shohei Hagane [1,†], Corentin Aznar [1,2], Dora Garcin [1,2], Enrique Coronado [1,3], Dominique Deuff [4], Ioana Ocnarescu [2], Isabelle Milleville [5] and Gentiane Venture [1]

1 Faculty of Engineering, Department of Mechanical Systems Engineering, Koganei Campus, Tokyo University of Agriculture and Technology (TUAT), Tokyo 184-8588, Japan
2 Strate Ecole de Design, 92310 Sèvres, France
3 National Institute of Advanced Industrial Science and Technology (AIST), Tokyo 135-0064, Japan
4 Orange Labs, 22300 Lannion, France
5 Laboratory of Digital Sciences of Nantes, 44321 Nantes, France
* Correspondence: s192106v@st.go.tuat.ac.jp
† These authors contributed equally to this work.

Abstract: Yōkobo is a *robject;* it was designed using the principle of slow technology and it aims to strengthen the bond between members (e.g., a couple). It greets people at the entrance and mirrors their interactions and the environment around them. It was constructed by applying the notions of a human–robot–human interaction. Created by joint work between designers and engineers, the form factor (semi-abstract) and the behaviours (nonverbal) were iteratively formed from the early stage of the design process. Integrated into the smart home, Yōkobo uses expressive motion as a communication medium. Yōkobo was tested in our office to evaluate its technical robustness and motion perception ahead of future long-term experiments with the target population. The results show that Yōkobo can sustain long-term interaction and serve as a welcoming partner.

Keywords: social HRI; human-centered robotics; software–hardware integration; design; human factors

Citation: Capy, S.; Osorio, P.; Hagane, S.; Aznar, C.; Garcin, D.; Coronado, E.; Deuff, D.; Ocnarescu, I.; Milleville, I.; Venture, G. Yōkobo: A Robot to Strengthen Links Amongst Users with Non-Verbal Behaviours. *Machines* **2022**, *10*, 708. https://doi.org/10.3390/machines10080708

Academic Editor: Huosheng Hu

Received: 19 May 2022
Accepted: 20 June 2022
Published: 18 August 2022

1. Introduction

Social robots (SR) are designed to achieve many purposes, such as care [1], entertainment, education, or personal assistance [2]. Their modes of interaction with humans are diverse, e.g., voice, screen, or gestures. Generally, SRs are designed with the main task to perform, where motion is used as a tool rather than a part of the interaction that can help transmit social cues [3] and express emotions [4].

We propose a new SR using a specific HRI approach called human–robot–human interaction (HRHI), where the robot is an intermediary between two persons. Using this method, our robot, named Yōkobo (Figure 1), was designed to be included in a smart home with the central purpose of strengthening the bond between people (e.g., a couple). To this end, its task is to welcome family members or visitors at the home entrance and transmit some user's actions by moving its motors (called *motion messages*) from one person to another, while still having non-robotic functions: to serve as a 'key bowl'. Its name is a portmanteau word from the Japanese word *yōkoso* (welcome) and the French pronunciation of the word *robot* (the *t* is silent). Considering the smart home context, Yōkobo takes advantage of available sensors, such as temperature or humidity, and incorporates those data into its behaviours. Unlike most SRs for homes sold on the market, Yōkobo was designed to have an abstract shape. Moreover, its sole communication medium is through its movements and lights. Yōkobo's design approach follows the principles of *slow technology* [5]. It is a concept where time plays a role in the adoption of the object and encourages the user to reflect on technology. By favouring this design approach, Yōkobo is designed in a way that allows its user to slow down, be surprised, and be reminded of the environment and their significant other. It was proven by Odom et al. [5] that this approach can "create feelings of anticipation, open spaces for questioning the role of technology and even help to change routines".

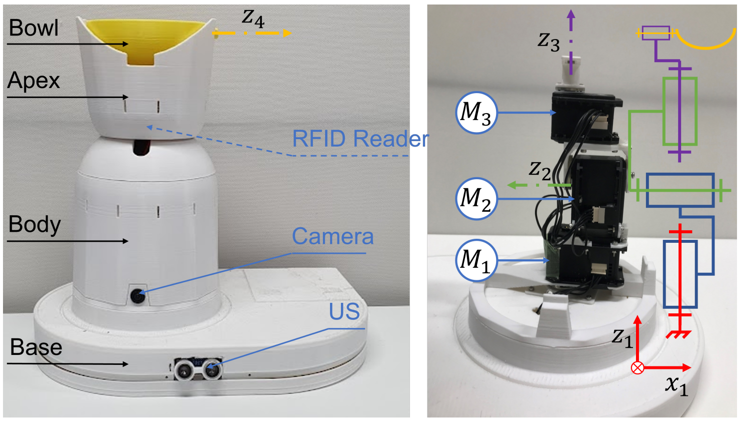


Figure 1. Parts and kinematic diagram of Yōkobo. Dimensions of the robot in centimeters: H = 33; L = 36; W = 24; ø = 15.

Regarding home devices, vocal assistants (VAs) have progressively entered the home. Similar to VA, robot assistants (RAs) can accomplish several tasks, such as checking emails and calendars, or controlling smart home devices. Contrarily to VAs, they have a physical presence thanks to their movement abilities. For example, Elliq used LEDs and body language to facilitate communication with users. A RA can be more expressive than a VA thanks to its *expressive motions* [4] or facial expressions, such as Haru [6], who can express its mood by changing the positions/shapes of its eyes. Studies showed that RA use is more enjoyable [7] than VAs and that they are often preferred due to their social embodiment [8]. Another difference between HRHI robots and RAs is that the latter provide direct interaction between the user and the robot, and no third party is included in the loop, even if the whole family can use it, contrary to HRHI ones.

In HRHI, the robot is **designed** to be at the heart of the relationship between two or more persons, functioning as a catalyst in their relationship. Those robots are designed to create encounters between the users, not just to serve as communication tools, such as social networking robots [9]. We can distinguish them from telecommunication robots, which are also part of the HRH relationship, where the robot is more of an extension of the human, serving as an enhanced phone.

Although Yōkobo uses motions, such as an RA, it has the particularity of being a *robject*: "embedding useful robotic technologies within everyday life objects" [10]. In our case, Yōkobo has been built around a key bowl. It is integrated into the room to serve a purpose besides its robotic function; hence, even if it is not working, it can still be used.

2. Contribution

We propose a novel approach in social robotics, with a robot aimed to serve as a link between two persons living together in their home, by using greeting movements and interacting with the users at the home entrance. The semi-abstract design approach allows our robject Yōkobo to be self-effacing in the HRH relation, supporting Yōkbo's overall goal, being just a medium, avoiding strong attachment at the partner's expense.

We also propose a protocol to test the previous aspects during two different sessions of mid-term experiments (2 weeks) conducted *in the wild*, where we let participants interact with Yōkobo without any specific scripted scenario. We propose a set of tools to analyse the interactions, the robustness of the robot, and the users' perceptions.

3. Related Works

3.1. Creating Encounters and Links between Persons

Recent efforts have been made to enable the formation of social encounters, such as the Abstract Machine by Anderson-Bashan et al. [11], which brings the greeting process usually only implemented for humanoids [12,13] to new forms. Other examples are *weak* robots [14], which, by displaying signs of weakness, attract humans to interact with them. Similarly, the Ranger robot [15] captivates the attention of children and helps them organise their rooms. These examples have proven to enhance HRI or help with tasks. However, one crucial notion to consider when developing encounters is to tackle any possible feeling of ostracism that the user may have due to the perceived rejection when a robot is fixated on a task or with another user [16].

One example of an applied HRHI formulation is telepresence robots, as done with Haru in [17]. In this case, the robotic embodiment is here to serve as a user's extension in real-time communication. Nevertheless, the robotic agent does not act as a bridge for communication, instead, it acts as a tool to provide an almost physical video chat experience.

Robots made to improve social interactions in autistic children [18] have led to improvements in the relationships between the children and the therapists. These robots could be considered using HRHI. However, it is a one-way relationship. The purpose of these robots is to help the children communicate. They generally do not help people communicate with children. It is more of a H→R→H relationship than a HRHI, besides being for a specific target.

Research on an extended relationship with a robot has been conducted by Rifinski et al. [19]. They studied the effect of a robot on a human–human–robot interaction (HHRI), where the robot was not central in the discussion, instead, it acted as a third-party observer. They experimented on robotic influence and its associated movement when two people talked.

Jeong et al. [9] went deeper by creating what they called a social networking robot (SN-Robot) named Fribo to decrease the feeling of loneliness. They are using HRHI to transmit information about user actions in their homes to their friends. The robot acteds as a *middleman* to notify, with voice, the group (three friends equipped with their robot) when one, for instance, opened the fridge; everything was shared anonymously. During the experiment, the participants became attached to the robot, notably because of the voice, and the robot catalysed conversation in the group of friends. However, this robot was static and used only voice and screen to communicate, no movements were involved.

3.2. Form Factor

According to Campa [20], SRs are mostly humanoid or animal-like. Still, we could extend this classification, based on their form factors, into four categories [21], i.e., humanoids, zoomorphic, semi-abstract, and abstract ones.

The **humanoid** shape facilitates social interactions as the user can rely on their own experience to interact with the robot. Nevertheless, the human figure can create distress in the person [22]. That is why people may feel more comfortable with **zoomorphic** robots [23]. Their forms are diverse, ranging from a dog, such as AIBO, to a sea urchin [24]. With these forms, people are driven to interact with the robot as they would with a pet [25]. However, both latter categories have psychological consequences, such as creating strong attachments [26]. The **semi-abstract** robots do not look similar to any living creatures, but the users can imagine some human or animal shape and behaviour by pareidolia or anthropomorphism. They can also be inspired by either a real or imaginary animal. One example is Lovot [27], which might share characteristics close to a penguin but with a face closer to an anime character. The **abstract** robots resemble nothing biological, yet, while interacting with them, it is possible to extrapolate their behaviours, as shown in [11]. Both previous form factors allowed the designers to be less constrained, and the users have fewer expectations about the robot's behaviours [28]. However, their interpretations could differ because of their personal backgrounds [29].

3.3. Perception through Reduced Robotic Movement

Duarte et al. [30] studied the concept of non-verbal behaviour (NVB) to communicate intentions with a humanoid robot. They showed the possibility of perceiving intention solely with motion. Participants could understand the robot's intent thanks to the gaze, head, or arm movements. This interpretation is not limited to human-like body parts, but also other robotic embodiments, as Broers et al. [14] showed with a trash-can-like robot and Bevins et al. [31] with drones. Lehmann et al. [32] proved that non-anthropomorphic robot movements are crucial to help users perceive engagement. Indeed a 2-DoF robot, ref. [11], showed that people could see social cues with simple motions.

Hoffman et al. [33] showed the importance of NVB for a robot, emphasising the design process merit. They demonstrated that a robot with expressive motions and positive emotions could be more easily accepted than a complex anthropomorphic robot with "unaffectionate motion". Most of the studied robots are non-anthropomorphic, such as Travis [34], a robotic speaker dock, and listening companion. With a single DoF, this robot was designed with music-aided movement to create a soothing environment. Similarly, Luria et al. [7] designed Vyo, a smart home assistant robot with five DoFs. Its motions were designed to be respectful or reassuring. Incorporating such design notions during the conceptual stage makes it possible to create a pleasant atmosphere around the robot, emphasising movement.

4. Design and Implementation

Yōkobo was created with a three-stage design process. The first stage enables the greeting concept identification. The second focuses on Yōkobo's modelling, with shape and behaviour designs. The last one is aimed at realising the functioning prototype, applying the Agile method [35].

4.1. Yōkobo's Shape Design

Yōkobo's shape was imagined alongside its movements. It is centred around two imaginaries: Japanese ceramic and robot-like depictions, organic and mechanic ones, mixing circular shapes (on the main pieces) and angular (on the edges). The ceramic imaginary provides Yōkobo with more precious, personal, and unique attributes. While the robotic one evokes the popular trend known as *mecha*, via its edges and vents.

Based on previous fieldwork [36], it was essential to design a discreet, yet useful, object. Yōkobo's physiognomy is an object that blends effortlessly in a home, specifically in the entrance. Its shape is composed of four parts: a **base**, a **body**, an **apex**, and a **bowl** (Figure 1). Its dimensions were chosen considering its ideal placement.

4.2. Services and Associated Functions

Yōkobo's concept, as a *robject*, allows it to function as a standard key bowl, for objects such as keys or coins, or as a medium for house members to interact with each other. Its primary communication means are movement and light. We drive the user to focus on Yōkobo's interaction by dismissing the vocal notions, instead of just listening. The main question we had to answer to build its functionality was, *how to condense the richness of human greeting into a robject?*.

Heenan et al. [13] showed that the greeting process was formed by a series of physical states, such as handshakes or nods, coupled via a transition sequence using proxemics. Guided by the above notions, the proposed solution focuses on proximity levels that serve as communication guidelines for how Yōkobo responds. It results in four levels of interaction that serve as the bases for designing the behaviours of the robot: **standby**, **state of the house**, **mimic**, and **record**.

Standby is the robot status when nobody is in the entrance hall; Yōkobo is *active* and has periodical movements, guided by the atmospheric pressure (AP) and air quality (CO_2) data. **State of the house** starts once a person is near the robot, it continues the periodical movement and expresses the home state through movements. **Mimic** is triggered when someone is close to the robot. The robot then follows and reproduces human gestures. **Record** allows the user to leave a gesture message by saving the data from the mimicking process to later show to the other person. The lights, placed in the robot's **apex** change when a message is played or recorded.

4.3. Behaviour Design

Previous research found that minimal robotic movement allows humans to perceive social cues and can cause feelings of surprise or engagement, according to the robot's attributes [11,29]. Inspired by these results, the designers chose to shape Yōkobo's animations based on human reactions to the ambient conditions [37]. Therefore, the reactions are:

Humidity inside: when the value is high, Yōkobo displays characteristics of human sleepiness, hinting at slowness and human body stretching.

Humidity outside: it displays a movement, combining the **body** and **apex**, to suggest a human sneeze.

Temperature: depending on the temperature variation, it shakes the **body** and **apex**, or has slow movements.

CO_2 and AP: these values are used through Yōkobo's periodical movements to increase or decrease the motor speed. They are used to imply the human breathing alteration by a higher concentration of CO_2 or AP increments.

4.4. Hardware

Yōkobo has four DoFs, driven by three Dynamixel motors (Figure 1). M_1 yaws the body around axis z_1, M_2 bows the apex, and M_3 yaws the apex around axis z_3. The three motors are located inside the body, and the bowl freely rolls by gravity.

Figure 2 describes the hardware architecture. The central units are two Raspberry Pis (RPi) 4B, one for the control, and the other for the sensors. The latter is upgraded with a USB Intel Neural Compute Stick 2 (NCS) to run a human pose estimation algorithm (HPEA) on the OpenVINO toolkit [38]. The LED strip and sensor (RFID reader and two ultrasonic sensors (USs)) connection is made via the RPi2 GPIO pins through a two-layer self-made printed circuit board (PCB). The motors are connected directly to the RPi1 with USB and powered via the PCB. A 12 V-8 A power supply is used. The PCB dispatches that power to the motors (12 V-5 A) and the RPis (5 V-6 A) with a Traco. All the electronics are hidden inside Yōkobo; only the power cable is visible.

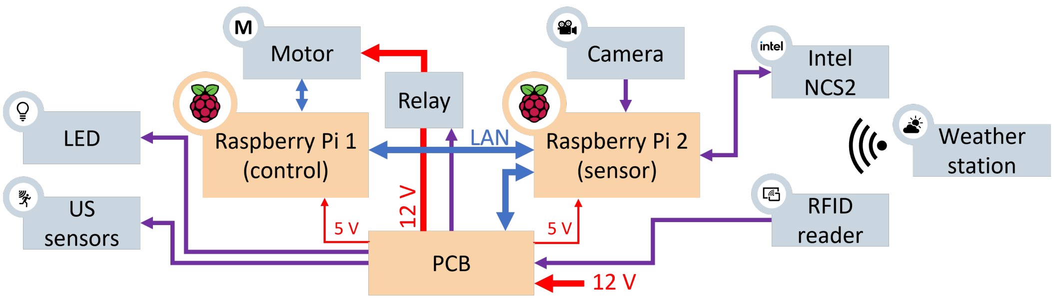


Figure 2. Hardware architecture. The red arrows symbolise the power link, the blue ones the data, and the purple ones both.

To detect when someone is nearing the robot, we use two USs around the base. To identify a user personally. We use the house keys with an RFID tag to detect whether the key is in the bowl. A wide-angle camera embedded in the body uses the RPis *camera port*. It is used for the mimicking procedure.

4.5. Software Control

By improving the work in [13], two finite state machines (FSMs), one named the main decision loop (MDL) and the other the motor control (MC), were constructed. The central software architecture can be seen in Figure 3. It encapsulates the data acquisition process, along with the central automata. Based on current sensor values, the first (MDL) decides how to switch between behaviours. The MC receives the commands from the MDL to send to the motors. All data transfers are done via the NEP framework we developed [39]. Since our approach follows a sequential loop of actions, there was no need for parallelisation in the main state machines, the only subsystem running in parallel to MDL and MC is the data acquisition, which constantly reads the sensors and publishes the data through NEP topics. These data are read whenever the FSM calls for it. The parallel process is in charge of acquiring the data and writing it to two specific buffers where the most up-to-date sensor values will reside. One buffer is uniquely given and accessed per FSM. Inside each FSM, to avoid reading the buffer while the parallel program is writing, a semaphore method is implemented as a precaution. As a proof of concept, all programs are coded in Python, except for the HPEA, which runs natively in C++.

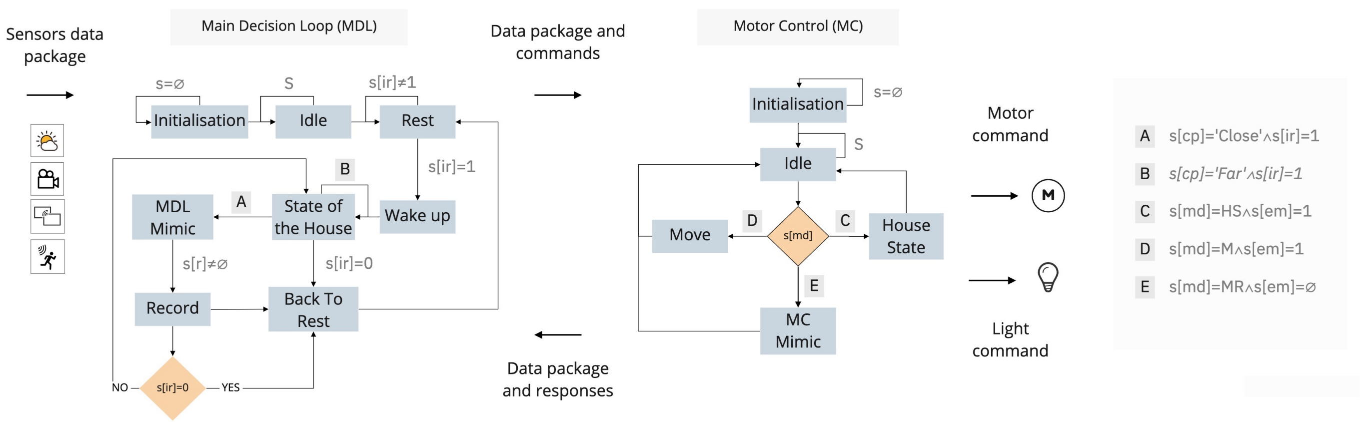


Figure 3. Finite state machines designed to command Yōkobo's services and behaviours.

Yōkobo's movement is either conducted by predefined motions or by a periodical movement guided through a sinusoidal wave linked to its **apex**. This generator, in the MC, has the formula $hm = \alpha \cdot sin(\omega \cdot t)$, where α is a value between 5 and 35 in proportion to the AP, ω is chosen from a range, 0.4–1.4, based on the CO_2 readings, t is the current time value.

The MDL state (Figure 3) switch is guided by variable *s*; it belongs to the set of weather data (*wd*), USs (*ir*), RFID sensor (*r*), and the person's distance to the robot (*cp*).

To summarise the MDL states:

1. **Initialisation**: it ensures the correct system boot-up and coordination among FSMs.
2. **Idle**: pause state while the first sensor's data package is gathered.
3. **Rest**: the robot **apex** follows the movement defined by *hm*.
4. **Wake-up**: Yōkobo displays an animation selected based on the current house temperature.
5. **State of the house**: Yōkobo's motion is guided by *hm*. It can also do pre-defined animations based on the two humidity sensor readings.
6. **Go back to rest**: an analogous process to the *Wake-Up* state, the difference being that the motion is selected based on the outdoor temperature.
7. **MDL mimic**: The MDL commands the MC to enact its mimic behaviour or play a recording of the previous trace. If *r* has no value, the robot mimics the user's motion. Otherwise, it moves to play a trace provided that the current RFID tag is not the same as the one that left the message. The system then plays the current trace before recording. The light colour (blue) signals the user the trace is playing.

8. **Record**: still mimicking, but now the person's movements are saved for 10 s and the light is set to green.

For the MC (Figure 3), s is outlined by the weather conditions (wd), HPEA body points (bp), motor commands (em), and the MDL command (md), with values MR for mimicking or record, M for playing an animation, or HS for house state.

The MC's first state opens the motor ports, pre-loads all animation files, and sets the initial positions for all joints. After the preparation finishes, the *Idle* state starts. Inside, the MC waits for the MDL commands to either go to:

1. The *Move* state, where the animation data points are sent to the motors.
2. The *House State*, the node in charge of using the humidity-guided planned trajectory, applying the hm generator.
3. Continue *Idle*.
4. Move to the *MC Mimic* subprocess.

Furthermore, if the automaton keeps the same state, the periodical movement is enabled. The motors are controlled through the Python Dynamixel SDK. The commands are given as a motor's position, then the Dynamixel motors reach the commanded position using their inner PID controllers.

Lastly, the **MC Mimic** subprocess recognises and reproduces the following human movements: sidesteps, bowing, and twisting. These movements are also the ones used to record the trace message. The algorithm reproduces the person's motion by using the bp data and, in response, outputs a valid motor command for the robot. The method is outlined below:

Sidesteps: the system obtains the human waist centre XY coordinates from the image data and rotates the base motor so that the human is always seen in the field of (centre) view.

Bowing: the application checks the vertical motion of the user's shoulders, neck, and hips. If one of the first two is lowered below a given threshold, and the hip position has not changed, the second motor lowers the apex.

Twist: the system captures the human shoulder width (Ls) and the torso length (Lt), viewed from the front. It also continually calculates the shoulder width to torso ratio (Ls/Lt). This ratio decreases when the user turns to the side because Ls becomes smaller. When this situation is detected, the program determines there is a twist. It then rotates the top motor 90° and reproduces the gestures.

5. Experimental Validation

Two two-week experiments were conducted at the entrance of the lab offices (Figure 4) (TUAT, Japan). They were used to evaluate Yōkobo's technical stability, performance, and first impressions. The experiments were done to evaluate Yōkobo's readiness for field experiments with the target population. The research questions that drove the experiment were: *How long is Yōkobo capable of running continuously? Are the users capable of perceiving motion qualities from their partner by using the non-verbal gestures and the proposed mimic algorithm?*

The first experiment (E1), a pilot study, allowed us to gather initial quantitative data regarding the interactions and help us retrieve technical issues we had (both at the hardware and software levels). Following the initial evaluation, the robot received an upgrade, ensuring its overall stability. The second experiment (E2) was performed using the same experimental procedure. In both experiments, the qualities that were studied were:

- i The technical robustness over multiple days;
- ii People's perceptions of the robot motions;
- iii The users' receptions toward Yōkobo;
- iv The usability and user experience.

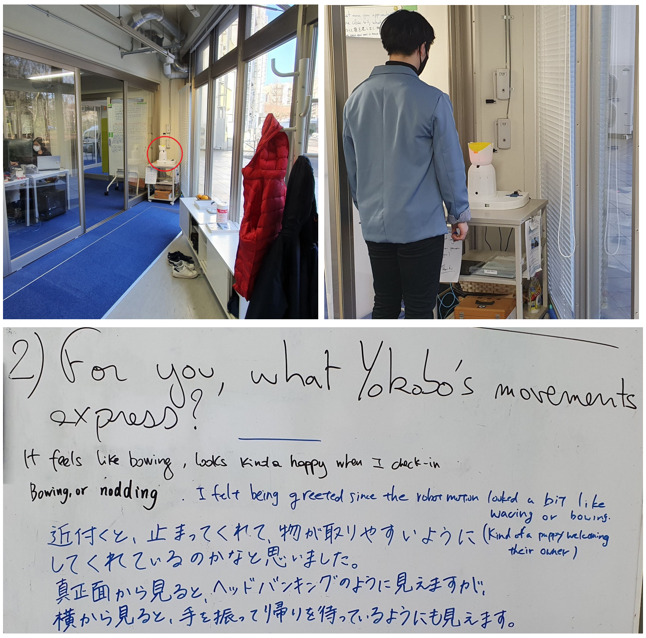


Figure 4. Yōkobo in the experimental condition, and the *graffiti wall*, with, in this case, question 2 and the answers. The translations for the Japanese answers are: "I thought Yokobo thoughtfully stops its head as I approach to it so that I can pick stuff from the bowl easily." and "It appears to be shaking the head hard from front point of view, however, it looks like waving the hand and waiting for people from side point of view."

5.1. Experiment Preparation

The purpose of the experiment was to validate Yōkobo's technical stability. Given that it is designed for the home entrance, focusing on the human greeting, it is possible to formulate an experiment with the available resources without using the target population.

We should note that there were unusual office situations due to the pandemic, which opened up new opportunities for Yōkobo. The laboratory ran on a system of shifts (mornings and afternoons); each group could not meet the other. Lab members were notified manually via the office's Slack channel when they arrived or left the office. We used the groups' isolation to replicate the 'couple's link', by using the messaging function when entering and leaving the office.

We created two participant types: **Selected participants** (SPs), which received RFID tags and **visitors** (V). The SPs were split into couples, and their tags were paired together. With this tag, they could record or read messages to/from their other partner. Pairs were active during the second week of both experiments. The group consisted of 10 persons, from 21 to 31 years old and 8/2 male/female for E1, and from 21 to 25 years old and 9/1 male/female for E2. Six out of the ten participants cooperated in both experiments. The **V** group contained any other person in the office (about 10). They could interact with Yōkobo without the message functionality. Although the number of participants was small (20), it was possible to retrieve 80% of the usability problems with as few as 5 users, according to [40]. A usability problem was defined by Manakhov et al. [41] as "a set of negative phenomena, such as user's inability to reach his/her goal, inefficient interaction and/or user's dissatisfaction, caused by a combination of user interface design factors and factors of usage context". This definition, in unison with the SUS metrics, will allow us to find the points where Yōkobo's interaction goals are not achieved.

5.2. Modifications Made for the Experiment

It was planned for Yōkobo to be in ceramic, but for the experiment, it was 3D-printed in plastic. We also made some minor modifications to facilitate its effectiveness with a larger group, to be better suited for the office. First, in order to not ask participants to leave their own keys in the bowl when they were in the office, we moved the RFID reader to the base so they could tag easily. We triggered the 'play/record a message' whenever the user clocked in/out for longer than 5 s. To merge Yōkobo in our workplace, automated messages were sent to the office's Slack channel for the **SPs**, informing that they clocked in/out.

5.3. Tools and Protocol

Four tools were used to evaluate the qualities described before. The first one (T-GW) was the *graffiti wall* method [42]. We placed a whiteboard next to Yōkobo with questions on it. It allowed participants to express their impressions freely in the context of use. The questions were replaced every two days for the first week. These were asked in English, and the participants could answer by drawing or writing in any language. This tool was available to all participants. We asked four questions to retrieve information regarding the *feelings*, *experiences*, and *perceptions* they had about Yōkobo. A sample of the participants' answers is available in Appendix A.2.

The second tool (T-Q) was a semantic test based on Kansei Engineering [43,44] and the semantic differential [45], combined with custom questionnaires. The semantic differential allowed us to obtain an object or robot characterisation, given a number of concepts represented through bipolar adjectives [46]. The 18 adjectives used for this semantic test were chosen by following the recommendations presented in [43,47]. The word selection was crucial to ensure that they were relevant to the design of the product. These words sets were gathered after consulting experts in the domain or reviewing state-of-the-art articles. The proposed semantic assessment uses the semantic scale to measure the concepts of interest, *Behaviour*, *Interaction*, and *Appearance*. The semantic scale uses two bipolar adjectives with a scale between 1 and 5; 1 means the answer is close to the *positive* adjective, and 5 is closer to the *negative* one. All concepts, along with their bipolar dimensions can be seen in Table 1. These questionnaires were only sent to SPs at the end of the second week for E1 (one questionnaire, QW2). For E2, three questionnaires were sent, at the start (QS), at the end of the first week (QW1), and the end of the experiment (QW2); the latter was sent only to SPs. The difference in the number of questionnaires relied solely on an additional semantic analysis and the evolutive metrics we wanted to observe. These were used to collect feedback regarding *behaviours*, *motions*, *design*, and *experience*, and to evaluate the *curiosity*, *fearfulness*, and *confusion* sentiments experienced by the users throughout the two weeks of experimental sessions. The latter metrics used the Likert scale. The questionnaires are available in Tables A1 and A2 of the Appendix A.1, the different scales used for each question are indicated.

The third tool (T-SUS) measured Yōkobo's usability with the system usability scale (SUS) [48] as a post-assessment evaluation filled by the **SPs**. With a 0–100 grade, it evaluated the system's success, while also providing data about the trends regarding the interaction flow and primary users' takeaways. The questions are available in Table A3 of the Appendix A.1.

The fourth tool (T-L) was composed of the interaction logs collected by the robot. These were used to verify the hardware and software robustness and provide quantifiable evidence regarding the interaction time, sensor variations, and motor usage.

Table 1. Semantic analysis results (second experiment). Lowest score—positive adjective; highest score—negative adjective.

Cpt	Dimension (Score)		Semantic Evaluation $\mu^{(\sigma)}$		
	Positive (1)	**Negative (5)**	**QS**	**QW1**	**QW2**
Behaviour	Dynamic	Static	$2.7^{(1.0)}$	$2.2^{(1.0)}$	$2.6^{(1.0)}$
	Smart	Stupid	$2.2^{(0.8)}$	$2.7^{(0.7)}$	$2.4^{(0.5)}$
	Simple	Complicated	$2.5^{(0.9)}$	$2.3^{(0.9)}$	$3.0^{(0.9)}$
	Responsive	Slow	$3.1^{(0.9)}$	$2.9^{(1.2)}$	$3.2^{(0.8)}$
Interaction	Lifelike	Artificial	$3.2^{(0.8)}$	$2.7^{(0.9)}$	$3.4^{(1.1)}$
	Emotional	Emotionless	$2.7^{(1.2)}$	$2.6^{(1.0)}$	$2.9^{(0.9)}$
	Familiar	Unknown	$2.1^{(0.8)}$	$2.6^{(1.1)}$	$2.1^{(0.9)}$
	Useful	Useless	$2.4^{(0.5)}$	$2.7^{(0.7)}$	$2.0^{(0.7)}$
Appearance	Desirable	Undesirable	$2.9^{(0.8)}$	$3.0^{(1.3)}$	$2.6^{(1.1)}$
	Cute	Ugly	$1.5^{(0.5)}$	$1.9^{(0.3)}$	$1.6^{(0.5)}$
	Modern	Old	$1.5^{(0.5)}$	$1.9^{(0.8)}$	$1.5^{(0.5)}$
	Attractive	Unattractive	$1.9^{(0.5)}$	$2.1^{(0.3)}$	$2.1^{(0.7)}$
	Like	Dislike	$1.8^{(0.6)}$	$2.1^{(0.9)}$	$1.7^{(0.7)}$

5.4. Instructions to Participants

Since the experiment was split into two different weeks, with no SPs during the first one, we first gave instructions to all of the lab members. We sent a message on Slack, telling everyone what expected them to do: interact with Yōkobo on their own, whenever they wanted, and answer the questions on the graffiti wall. We did not explain how to interact with Yōkobo (to let them discover). For E2, we also sent QS. Additionally, we asked participants to tell us during the first week if they wished to become SPs during the second one.

At the end of the first week, we sent the questionnaire QW1 (only during E2) to everyone. We then held a live explanation session with the SPs. We first gave them the key tags they had to use. Then, we showed them how to proceed to read and record messages, in order to exchange them with their partners. We required them to attempt to exchange messages at least two times during the week (still, whenever they preferred).

At the end of the experiment, we sent to SPs the questionnaire QW2 and the SUS one.

6. Results and Discussion

6.1. Differences between Experiments

E1 was designed to serve as a preliminary test. It allowed us to gather initial stability characteristics, reception metrics, usability score, and first perceptual accounts. During this experiment, Yōkobo ran non-stop for the first week. However, several issues arose once the mimic/record state was enabled. The main difficulty was with the motors, which had trouble receiving commands from the MC due to a faulty middleware that converted the motor data package to commands. Despite these errors, the situation was swiftly handled, and it was possible to continue the test for three days (12–16 h/d) and two reduced days (6–10 h/d).

This experiment showed the necessary technical changes that Yōkobo required to improve its stability and user reception. From the experimental tools, it was possible to observe that the problematic aspects involved the message handling procedure and the sudden motor stoppage. These hindered the user's possibility of fully interacting with the robot.

To tackle the problems described above, we decided to amplify the hardware structure. This change provided more computational resources for the HPEA and the motor control. Furthermore, the software received an upgrade to avoid false sensor triggers and improve the transition functions logic. These changes enabled a faster interaction among motors and data acquisition, which translated to optimised behaviours.

After the previous updates were integrated, we proceeded to realise E2. Contrary to E1, Yōkobo was able to run non-stop during both weeks of E2, except for a few resets during the weeknights needed to prevent motor failure in case of wrong positioning. An additional situation presented itself on the last day of the experiment. A false switching between the states of the FSM occurred while an animation ran. The previous situation reduced the experimental day by two hours, yet did not impact the results since it was resolved before most of the participants arrived at the office.

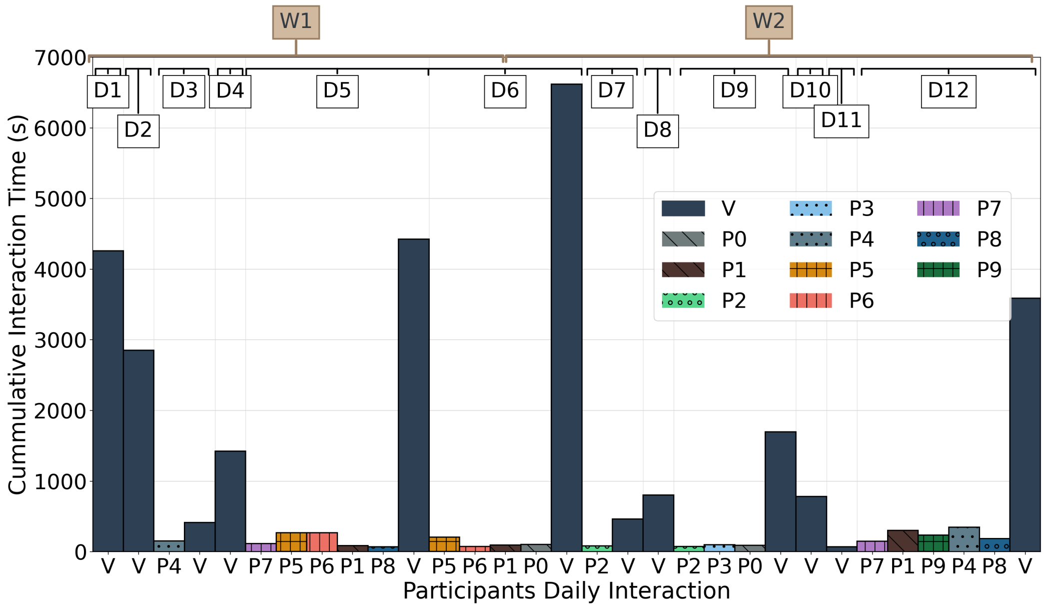
The following sections detail the experimental results. A comparative analysis is also presented, which shows the upgrade's impact on Yōkobo's overall qualities and capabilities.

6.2. Regarding Robustness, Stability, and Usability

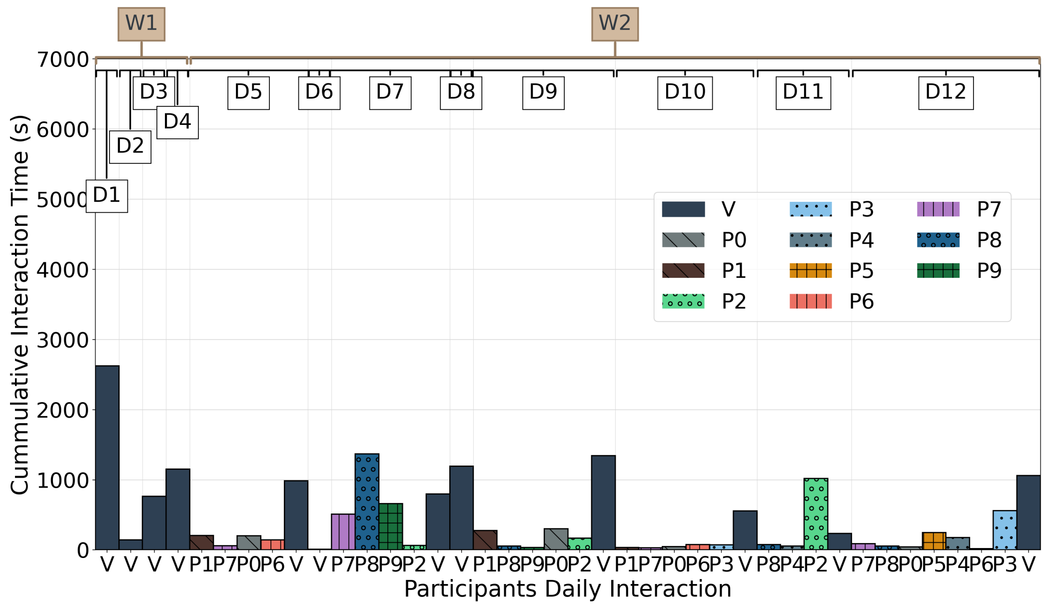
A total of 6/10 participants for E1 pointed out that the recording process was complicated and not straightforward (from T-GW, and discussions with the participants at the end of the experiment). They did not understand at which state the robot was from the light signal. The time lag between the person's motion and Yōkobo's replication was too long and did not seem to follow the user movement concurrently. The log files showed that movements and messages were being recorded; however, the motors' unexpected failure impacted the delivery. The questionnaire (T-Q) for E1 showed that three participants could not send or receive messages, and two couples managed to do both. The log reports support the previous statement since 7/10 participants tried to send at least one message, (Figure 5). On the other hand, regarding E2, all participants interacted with Yōkobo. A total of 9/10 managed to send and receive the same quantity of messages with a mean of two messages sent with a standard deviation of ± 1, meaning one partner sent one, and the other member received it and sent it. The one participant that suggested that s/he did not receive messages (from T-Q) may have confused the motion message by the usual robot movements, explaining why it was the only case that presented this situation. The logs also support this idea since both users appeared (sending the messages), and the motion played was related to the actual body point data observed in their movements. It is worth noting that 6/10 participants also indicated the movement as coming from Yōkobo rather than their partners, which can be due to the animations that may have been triggered as part of the mimic and recording sub-process. In E2, 40% of participants agreed that Yōkobo helped them perceive their partners and 30% were neutral (T-Q), acting as a bridge between them, validating the possibility of transmitting the presence of someone through a robot. Even if some of the results may hint toward a deficient result, it was the opposite. If we leverage the difference between E1 and E2 results, 6/10 participants agreed that the recording process was more intuitive, directly related to the upgrades performed on the robot and the light cue between the state's switch. The time lag between the robot movement and the human was more in sync, which translated to further exploration of the robot's capabilities and an increment in the average interaction time, which had an increase of 38.85 s (denoted with the red line in Figure 6). The latter can be observed as a partition by participants and daily cumulative interaction time in Figure 5, where it can be seen that there is an increment of the interaction time by participants in E2.

Yōkobo's SUS score after E1 was **66.11**; as for E2, Yōkobo obtained an average grade of **63.25**. However, once it was taken between the participants who were part of the first and second experiments, it was **61.43**, while the new users rated it with a grade of **67.5**. The old participants' group decreased its rating on average by 2.5 points, with two edge cases with decrements of 10. Although the grade seems low, the value is a passing grade. On average, a system rating was about 68; an example of a grade 61 product is the Apple Watch [49]. The difference between the two groups can be related to the previous experience that the participants already had with the robot and the expectation of what the current version might have had as an added feature. Both grades reflect that the interaction still needed tuning to be more reflective of the pairs. Overall, 5/10 participants agreed the robot was easy to use, intuitive enough to learn by themselves, would like to continue using it, and was well integrated but needed further improvement while recording; 2/10 were neutral;

3/10 rated that the system needed further improvement. With this feedback, it is likely that by improving the recording behaviour and filtering which points are saved on the message (disregarding the animation), Yōkobo's *usability* could increase.

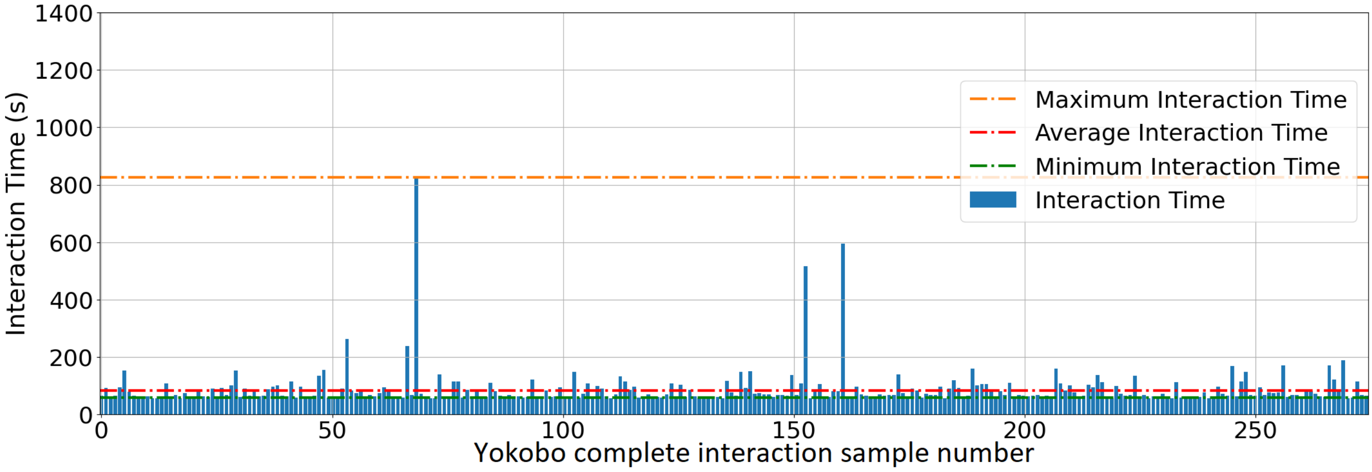


(**a**) First experiment.

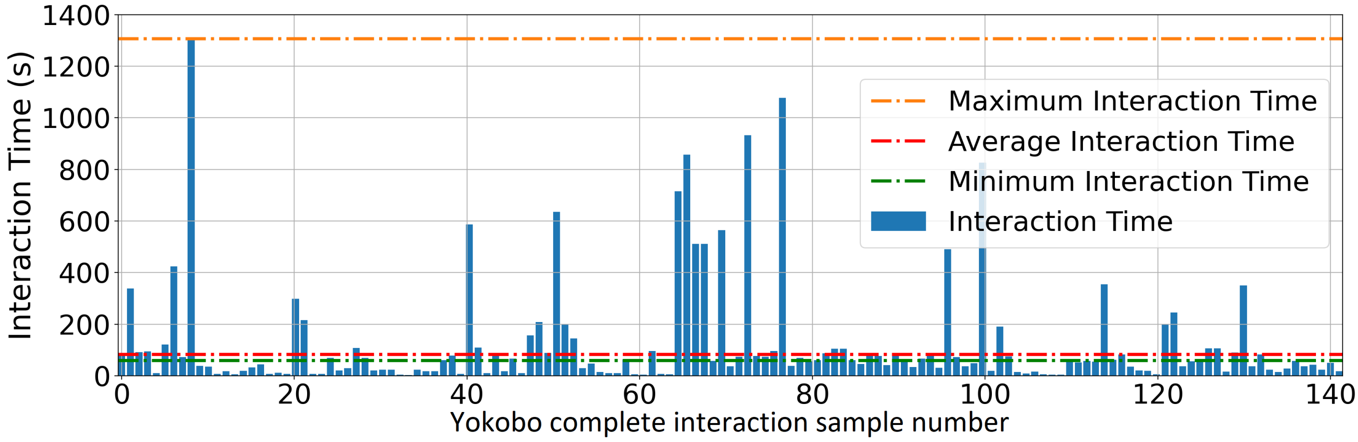


(**b**) Second experiment.

Figure 5. Participants cumulative interaction time for both experiments (from T-L), **D** for days (from 1 to 12), **W1** and **W2** for weeks; each bar corresponds to a user. New participants for E2 are denoted as **P2** plus their respective tag numbers. The pattern for each participant represents the couple they belong to. Each bar corresponds to the cumulative interaction time that each SP and the V group had with Yōkobo per day. The V group is also considered since their interaction is valuable to differentiate between groups and how each one decides to interact with the robot. The graphs also show that, on average, each SP left at least one message per experiment. This result, in combination with the data acquired through the questionnaire, allows us to discern patterns associated with the robot's interactions, robustness, or personal perceptions, which (later on) is beneficial to discover the pain points associated with Yōkobo's interactions and qualifies the perceptual impacts it had on the user.



(**a**) First experiment.



(**b**) Second experiment.

Figure 6. Interaction time throughout both experiments. Each sample represents an interaction with Yōkobo that completes the states loop, i.e., *Wake-Up* trigger to the start of the *Go Back to Rest* state. This interaction time is measured second and composes every interaction without differentiating between SPs or V. The values associated with the minimum, maximum, and average times for both experiments are also shown. The maximum interaction time spent for E1 is 826 s, the minimum is 16 s, and an average of 76 s. For E2 the average is 113.24 s, the maximum is 1307 s, and the minimum is 13.39 s.

6.3. Regarding Perception and Reception

The graffiti wall showed a positive perception of the greeting motions. Participants liked being welcomed by Yōkobo. Some even interpreted them (i.e., the greeting motions) as good manners, though it was not programmed so. For example, two participants thought the bowl moved down to interact with it more easily.

From the log, the time users spent interacting with Yōkobo, from the *Wake-Up* to the start of the *Go Back to Rest* state (Figure 6) was analysed. The maximum interaction time spent for E1 was 826 s, the minimum was 16 s, with an average, over the two weeks, of 76 s. It can be noted that this time for the second week showed an average increase of 21.9 s; this corresponds to more *V* interacting with Yōkobo, as can be observed in Figure 5a. For E2, the average was 113.24 s, with a maximum of 1307 s and a minimum of 13.39 s. The minimum time corresponded to a person detected but not a complete interaction in both cases. The main difference that could be seen in Figure 6a between experiments is an increment in the average exchange and significantly fewer faulty sensor triggers. It shows how the upgrades manage to reduce this false interaction, which also explains the reduction in the sample quantity. The trend also demonstrates that extensive exchanges appeared during the week and were not condensed to single days. In contrast to E1, the average visitor interaction time for the second week did reduce; this can be partly attributed to the experimental days being in the middle of the holiday sessions and the ending of the school semester. Still, there was a significant increment in the SP interaction when comparing Figure 5a,b. Nonetheless, the maximum time can be associated with the mimic procedure and the participants' curiosity; measured with the questionnaire, by the end of week two of both experiments, were high, with an average rating of 3.7/5.

Participants had longer interactions with Yōkobo during E2 with an average increment of 37.24 s, not only the new participants but also the ones that participated in E1. For example, participant 2 (P2) presented more extended and frequent interactions than before. In general, this trend and the increment of the average interaction time plus the improvement of the semantic analysis evaluations (*Useful* and *Familiar*) showed that the user wanted to use the robot continuously. However, in both experiments during the second week, the visitors, especially for lengthy interactions, may have had a perceptual bias due to their *desire* [50] and perceived *scarcity* [51] to use the robot to its full capabilities as the SP could. Nonetheless, both experiments provided enough arguments to show that participants wanted to further interact with the robot, providing a clear guide towards surpassing the novelty effect. However, more data are needed to make a conclusive argument. Due to the slow technology principles used for Yōkobo, the more time the users spend interacting with the robot, the better it is. We are looking for them to discover the functioning of the robot by themselves, we are not looking for efficiency (as it can be with usual robots or products).

Another interesting fact from the logs of both experiments is that several participants split into subgroups of two or three users. This formation introduced an increase in interaction time. Yōkobo may have been a conversation starter and a tool for users to find common ground. By creating these social scenarios, the participants further understood Yōkobo's capabilities on their own or in their subgroups, making the interaction with the robot clearer. This may explain the average 'decreasing' rating for the fearfulness sentiment.

A related observation is that the extended interactions happened when clocking out with the RFID tag, meaning between 16:00 and 18:00. We hypothesise that one possible explanation is because of the daily schedule situations. When users first tag in, they might be rushing to start their daily activities; however, when tagging out, they may have extra time to spend with Yōkobo and their colleagues.

The collected data from the semantic evaluation are shown in Table 1. The *Concepts* (Cpt) that were analysed are presented, along with their respective *Dimensions*. Dimensions tend to the positive side (lower than 3) with a standard deviation around one. When comparing the different concepts, we found that the reception towards *Behaviour* was positive. A total of 6/10 participants agreed that the system was dynamic, smart, and straightforward, in line with the proposed design notions; 2/10 were neutral, and the other two participants thought it was static and unintelligent. *Responsiveness* is the dimension with the highest grade, indicating that the robot's system flow was not yet appropriate, and users expected a more fluid interaction. The latter was associated with the recording process difficulties described above and the transitional animations between the states, which may be perceived as too *artificial*. Concerning the dimensions of *Interaction*, although on the positive side, they presented a negative tendency with the *lifelike* and *emotional* dimensions having a mean value near 3. As seen in the semantic analysis (T-Q), the logs and the messages recorded (T-L), and the behaviours were not fully understood. Participants were neutral regarding the emotional content of the animations, with an average value of 2.9 and a small standard deviation. On the other hand, *Appearance* followed the same positive trend as *Behaviour*, with desirability being the least positive dimension. The first two concepts (*Behaviour* and *Interaction*) could be improved by making the robot more intuitive (legible trajectories or special gestures) and adding other perceptual signals for the user, such as a sound or a clearer light display.

Interestingly, 7/10 users found Yōkobo more complicated over time, especially for E2. The *Confusion* sentiment by the end of E2 increased by 0.3. It would be necessary to improve the message cues and sequences for the user to understand it better and differentiate between Yōkobo states, movements, and animations. Similarly, the *Curiosity* increased once the recording functionality was enabled before decreasing at the end of E2. This may have appeared to hinder the overall results; however, it was, in fact, the opposite. Yōkobo is designed with the notion of slow technology, such that the users cannot fully understand the robot in a single interaction. Instead, it is a medium or a reminder of what is around them [5]. The users may be surprised or confused by the robot at different moments of their interactions and have continuous shifts in their perceptions.

Moreover, participants were asked about the word they would use for each part of Yōkobo. A total of 7/10 used anatomic words, such as head, body, and torso. Using these words to describe the robot, they identified it as a living creature, utilising pareidolia. The qualities participants used to describe Yōkobo were *smart*, *modern*, and *cute*.

According to the graffiti wall, participants seemed interested in Yōkobo, and the shape was trustworthy. The concept of *robject* was also evaluated. We regularly observed in the answers some mentions about the bowl. Some users wrote about what was inside: words such as "pick up" or "offering" were used.

Finally, regarding Yōkobo's office integration, 8/10 participants described its interaction as welcoming and 2/10 were neutral. After setting their RFID tags on the reader, they felt it displayed a *greeting attitude*, *energetic*, and *whimsical*. A total of 8/10 found the clock-in–out function useful, and preferred to do it this way; the other two participants were neutral about it.

7. Conclusions and Future Work

We developed a semi-abstract robot with an HRHI approach, using expressive motions as interaction means. Then, we performed two different experiments in our office to test Yōkobo's robustness, perception, reception, and usability. It proved its ability to work for extended periods of time. Moreover, participants felt welcomed and greeted by it. Through small movements, aided by different sensors and mimicking processes, it was possible to create the perception that the robot was intelligent and a "welcoming partner".

Longer experimentations were ongoing with the target population to confirm some points of the findings. As mentioned in the discussion section, the novelty effect seemed to have been overcome somehow. However, with a longer experiment, over several weeks, we hope to observe what happens when a routine settles and the usage of the robot becomes seamless. Another point is the feeling of the partner. During our two-week experiment, 40% of the participants could feel him/her, proving the capability of this concept. However, this number might seem low; one reason may be that building up this feeling may take time. Moreover, one of the limitations of our experiment was in using arbitrary couples, i.e., real couples in the ongoing experiments would have stronger inter-connections; and it will probably be easier for them to feel their partners through Yōkobo. The realised experiments gave us some clues about the validity of some of our concepts, as a first step.

Including modularity in the design made it possible to extend Yōkobo's capabilities to suit the office environment, even if its original purpose was for the home.

In addition to making the messaging functionality and motion more legible, we plan to add pressure sensors to enable tactile interactions and object identification inside the bowl. Moreover, to detect some ambient sounds or greetings, we will add a microphone. Another way to improve the usability of Yōkobo will be to add sounds linked to the movement of the robots. Even if the SUS gave us a good score, around the average, some improvement can still be made, especially concerning the recording process. However, since our goal was to be a part of the slow technology movement with Yōkobo, it is not necessary to have efficient and straightforward usability. Finally, the software architecture requires multiple modifications to make it more robust and to build a more responsive framework to further develop the HRI.

Author Contributions: Conceptualization, D.D. and G.V.; methodology, C.A., D.G., D.D. and G.V.; software, S.C., P.O. and S.H.; validation, G.V.; formal analysis, S.C., P.O., S.H. and G.V.; investigation, S.C., P.O., S.H., C.A., D.G., D.D. and G.V.; resources, D.D. and G.V.; data curation, S.C., P.O. and S.H.; writing—original draft preparation, S.C., P.O. and S.H.; writing—review and editing, E.C., D.D. and G.V.; visualization, S.C. and P.O.; supervision, D.D., I.O., I.M. and G.V.; project administration, D.D. and G.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study followed the guidelines of the Ethics Committee of the Tokyo University of Agriculture and Technology, Tokyo, Japan.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AP	atmospheric pressure
DoF	degree of freedom
E1, E2	experiments 1 and 2
FSM	finite state machine
HPEA	human position estimation algorithm
HRHI	human–robot–human interaction
HRI	human-robot interaction
LED	light-emitting diode
MC	motor control
MDL	main decision loop
NVB	non-verbal behaviour
PCB	printed circuit board
QS, QW1, QW2	questionnaire (start, end week 1, end week 2)
RA	robot assistant
RFID	radio frequency identification
RPi	Raspberry Pi
SP	selected participant
SR	social robot
SUS	system usability scale
US	ultrasonic sensor
VA	vocal assistant

Appendix A. Experiment

Appendix A.1. Questionnaires

In this section, the different questions asked with the three questionnaires (QS, QW1, and QW2) are presented in Tables A1–A3. The questions for the first one (QS) were asked in the future tense since the participants answered them before any interactions.

Table A1. Questions asked in QS, QW1, and QW2. The text in square brackets was added for this article and was not present in the questionnaire.

Question	**Answer Choice**
Personal questions	
Student ID [1]	*number*
How old are you? [2]	*number*
What is your gender? [2]	Female, Male, Prefer not to say
What is your nationality? [2]	*text*
What is your level of knowledge about robots? [2]	Not Familiar (1)–Familiar (5)
What is your knowledge about Yōkobo? [2]	I was involved in the first experiment I already interacted with Yōkobo on my own I know how it works and already saw it I only saw it I don't know about Yōkobo
About Yōkobo and its behaviour	
How much has Yōkobo welcomed you? [Likert scale]	Not at all (1)–I felt welcomed (5)
Did you see intelligence in Yōkobo? [Likert scale]	Not at all (1)–Totally (5)
Did you see life in Yōkobo? [Likert scale]	Not at all (1)–Totally (5)
What is your feeling about Yōkobo? (1: not at all ; 5: totally [Likert scale])	Curious Happy Afraid Enthusiastic Confusion Friendly
Yōkobo is[*positive adj.* ①②③④⑤ *negative adj.*—semantic scale]	Smart (1) Stupid (5) Simple (1) Complicated (5) Dynamic (1) Static (5) Lifelike (1) Artificial (5) Responsive (1) Slow (5) Emotional (1) Emotionless (5) Useful (1) Useless (5) Familiar (1) Unknown (5) Desirable (1) Undesirable (5) Cute (1) Ugly (5) Modern (1) Old (5) Attractive (1) Unattractive (5)
I ______ Yōkobo [semantic scale]	Like (1)–Dislike (5)
Design	
Name with your word, in the next questions, the different parts of Yōkobo. Numbers 1 to 4 point to the whole part. Numbers 5 and 6 point to the holes.	
How do you (will) call mark 1 [3]	*text*
How do you (will) call mark 2 [3]	*text*
How do you (will) call mark 3 [3]	*text*
How do you (will) call mark 4 [3]	*text*
How do you (will) call mark 5 [3]	*text*
How do you (will) call mark 6 [3]	*text*
Interactions	
How many times did you interact with Yōkobo? [4]	*number*
Additional remarks	
Do you have any additional remarks or comments about Yōkobo? [5]	*text*

[1] The student ID is used to match the answers of the three questionnaires. [2] Only for QS. [3] The number refers to Figure A1. [4] Only for QW1 and QW2. [5] Only for QW2.

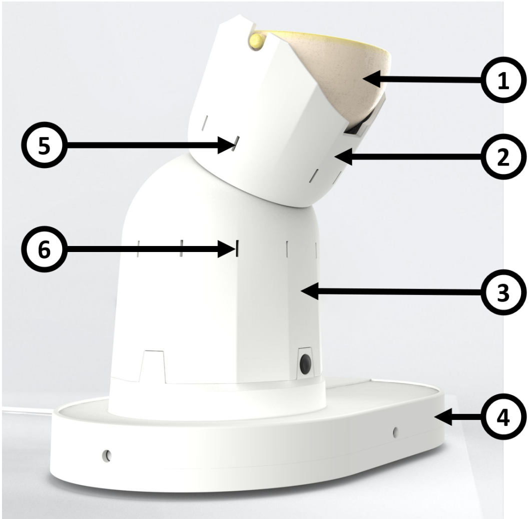


Figure A1. Picture of Yōkobo used in the questionnaire—to know the vocabulary used by participants to describe the robot. The numbered marks refer to the question in Table A1.

Table A2. Questions in QW2 for the selected participants. The text in square brackets was added to this article and was not present in the questionnaire.

Question	Answer Choice
Messages	
How many messages did you receive from your partner?	*number*
How many messages did you send to your partner?	*number*
How would you rate the recording of a message? [semantic scale]	Hard (1)–Easy (5)
How much did you feel the existence of your partner during this week? [Likert scale]	Does not exist (1)–Exists (5)
Do you think Yōkobo helped you to feel your partner? [Likert scale]	Not at all (1)–A lot (5)
What does Yōkobo represent in the connection with your partner?	*text*
Did you have the impression that the movement of the robot was Yōkobo's behaviours or was coming from your partner?	*text*

Table A3. SUS questions in QW2 for the selected participants, using a Likert scale.

Question	Answer Choice
I think I would like to use Yōkobo frequently	Strongly Disagree (1)–Strongly Agree (5)
I found Yōkobo unnecessarily complex	
I though Yōkobo was easy to use	
I think I would need the support of a technical person to be able to use Yōkobo	
I found the various functions in Yōkobo were well integrated	
I thought there was too much inconsistency in Yōkobo	
I would imagine that most people would learn to use Yōkobo very quickly	
I found Yōkobo very cumbersome to use	
I felt very confident using Yōkobo	
I need to learn a lot of things before I could get going with Yōkobo	

Appendix A.2. Graffiti Wall

Sample of the answers to the graffiti wall.

Question 1

What do you think about Yokobo? Can you give us your first impressions?

1. (E2) Friendly (Yokobo seems to greet me).
2. (E2) 見た目が可愛い、全体的に小動物っぽい (It looks cute, it looks like a small animal overall) ゆらめくLEDがきれい、周囲を動くと目で追ってきて愛らしい (The shimmering LED is beautiful, and when I move around, It can follow me with its eyes and it's adorable).
3. (E2) It feels that Yokobo notices you when you step close since the LED pattern and color change. It also follows you with the camera which is cute. However, I wasn't too sure on how to interact and play with Yokobo.

Question 2

For you, what do Yokobo's movements express?

1. (E1) 水槽の中で泳ぐ魚みたい (It moves like a fish in an aquarium).
2. (E1) I felt being greeted since the robot motion looked a bit like waving or bowing (kind of a puppy welcoming their owner).
3. (E2) Exciting.
4. (E2) stare at me, nod.

Question 3

Just now, you approached Yokobo and were close to it, what was your experience?

1. (E1) I was curious about what it would have done and waited a bit to see its "reaction".
2. (E1) The robot was tilting and moving its head in a offering kind of manner. I was able to feel that it detects me and can change how to behave wen the situation changes.
3. (E2) ロボットとコミュニケーションをすること自体が初めてで新鮮かつ可愛かった (It was my first time to communicate with a robot and it was fresh and cute).
4. (E2) 意外に動きに幅があり、驚いた。合わせて動くのが面白かった。 (I was surprised that there was a wide range of movements. It was fun to move together).

Question 4a (participants with a tag)

Do you feel connected to Yokobo and/or your partner? After 2 weeks, does Yokobo bring something to your daily life?

1. (E1) It's nice to have a welcoming "partner" when entering the lab. I think since I know there might be a message from my partner, I am not sure if it's Yokobo moving or my partner, but in principle I think more that it's my partner. Not knowing who he/she is, make me feel a bit less connected, I think. So more connected to Yokobo than my partner.
2. (E2) I couldn't feel the exist of partner (*sic*).
3. (E2) 相手がいるというのは分かった (I understand there was a partner).
4. (E2) 何かが起きた (something happened).

Question 4b (participants without a tag)

Do you feel close to Yokobo? After 2 weeks, does Yokobo bring something to your daily life?

1. (E1) 人の方を向いてくれるため、インタラクションを実感できた (I was able to feel the interaction because it turned to people).

References

1. Mišeikis, J.; Caroni, P.; Duchamp, P.; Gasser, A.; Marko, R.; Mišeikienė, N.; Zwilling, F.; de Castelbajac, C.; Eicher, L.; Früh, M.; et al. Lio-a personal robot assistant for human-robot interaction and care applications. *IEEE Robot. Autom. Lett.* **2020**, *5*, 5339–5346. [CrossRef]
2. Intuition Robotics. Elliq, the Sidekick for Healthier, Happier Aging. Available online: https://elliq.com/ (accessed on 22 June 2022).
3. Knight, H. Eight lessons learned about non-verbal interactions through robot theater. In Proceedings of the International Conference on Social Robotics, Golden, CO, USA, 14–18 November 2011; Springer: Berlin/Heidelberg, Germany, 2011; pp. 42–51.
4. Venture, G.; Kulić, D. Robot expressive motions: A survey of generation and evaluation methods. *ACM Trans. Hum. Robot. Interact.* **2019**, *8*, 1–17. [CrossRef]
5. Odom, W.T.; Sellen, A.J.; Banks, R.; Kirk, D.S.; Regan, T.; Selby, M.; Forlizzi, J.L.; Zimmerman, J. Designing for Slowness, Anticipation and Re-Visitation: A Long Term Field Study of the Photobox. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI'14, Toronto, ON, Canada, 26 April–1 May 2014; pp. 1961–1970. [CrossRef]
6. Gomez, R.; Szapiro, D.; Galindo, K.; Nakamura, K. Haru: Hardware design of an experimental tabletop robot assistant. In Proceedings of the the ACM/IEEE International Conference on Human-Robot Interaction, Chicago, IL, USA, 5–8 March 2018; pp. 233–240.
7. Luria, M.; Hoffman, G.; Zuckerman, O. Comparing social robot, screen and voice interfaces for smart-home control. In Proceedings of the the Conference on Human Factors in Computing Systems, Denver, CO, USA, 6–11 May 2017; pp. 580–628.
8. Ostrowski, A.K.; Zygouras, V.; Park, H.W.; Breazeal, C. Small Group Interactions with Voice-User Interfaces: Exploring Social Embodiment, Rapport, and Engagement. In Proceedings of the the ACM/IEEE International Conference on Human-Robot Interaction, Boulder, CO, USA, 8–11 March 2021; pp. 322–331. [CrossRef]
9. Jeong, K.; Sung, J.; Lee, H.S.; Kim, A.; Kim, H.; Park, C.; Jeong, Y.; Lee, J.; Kim, J. Fribo: A Social Networking Robot for Increasing Social Connectedness through Sharing Daily Home Activities from Living Noise Data. In Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction, HRI '18, Chicago, IL, USA, 2–8 March 2018; Association for Computing Machinery: New York, NY, USA, 2018; pp. 114–122. [CrossRef]
10. Vaussard, F.; Bonani, M.; Rétornaz, P.; Martinoli, A.; Mondada, F. Towards autonomous energy-wise RObjects. In Proceedings of the Conference Towards Autonomous Robotic Systems, Lincoln, UK, 8–10 September 2021; Springer: Berlin/Heidelberg, Germany, 2011; pp. 311–322.
11. Anderson-Bashan, L.; Megidish, B.; Erel, H.; Wald, I.; Hoffman, G.; Zuckerman, O.; Grishko, A. The Greeting Machine: An Abstract Robotic Object for Opening Encounters. In Proceedings of the IEEE International Symposium on Robot and Human Interactive Communication, Nanjing, China, 27–31 August 2018; pp. 595–602. [CrossRef]
12. Trovato, G.; Zecca, M.; Sessa, S.; Jamone, L.; Ham, J.; Hashimoto, K.; Takanishi, A. Cross-cultural study on human-robot greeting interaction: acceptance and discomfort by Egyptians and Japanese. *Paladyn J. Behav. Robot.* **2013**, *4*, 83–93. [CrossRef]

13. Heenan, B.; Greenberg, S.; Aghel-Manesh, S.; Sharlin, E. Designing social greetings in human robot interaction. In Proceedings of the Conference on Designing Interactive Systems, Vancouver, BC, Canada, 21–25 June 2014; pp. 855–864.
14. Broers, H.A.T.; Ham, J.; Broeders, R.; de Silva, P.R.; Okada, M. Goal Inferences about Robot Behavior: Goal Inferences and Human Response Behaviors. In Proceedings of the ACM/IEEE International Conference on Human-Robot Interaction, Tokyo, Japan, 3–6 March 2013; IEEE Press: Piscataway, NJ, USA, 2013; pp. 91–92.
15. Mondada, F.; Fink, J.; Lemaignan, S.; Mansolino, D.; Wille, F.; Franinović, K. Ranger, an example of integration of robotics into the home ecosystem. In *New Trends in Medical and Service Robots*; Springer: Berlin/Heidelberg, Germany, 2016; pp. 181–189.
16. Erel, H.; Cohen, Y.; Shafrir, K.; Levy, S.D.; Vidra, I.D.; Shem Tov, T.; Zuckerman, O. Excluded by Robots: Can Robot-Robot-Human Interaction Lead to Ostracism? In Proceedings of the the ACM/IEEE International Conference on Human-Robot Interaction, Boulder, CO, USA, 8–11 March 2021; pp. 312–321. [CrossRef]
17. Brock, H.; Šabanović, S.; Gomez, R. Remote You, Haru and Me: Exploring Social Interaction in Telepresence Gaming With a Robotic Agent. In Proceedings of the the ACM/IEEE International Conference on Human-Robot Interaction, Boulder, CO, USA, 8–11 March 2021; pp. 283–287. [CrossRef]
18. Ricks, D.J.; Colton, M.B. Trends and considerations in robot-assisted autism therapy. In Proceedings of the International Conference on Robotics and Automation, Anchorage, AK, USA, 3–7 May 2010; IEEE: Piscataway, NJ, USA, 2010; pp. 4354–4359.
19. Rifinski, D.; Erel, H.; Feiner, A.; Hoffman, G.; Zuckerman, O. Human-human-robot interaction: robotic object's responsive gestures improve interpersonal evaluation in human interaction. *Hum. Comput. Interact.* **2020**, *36*, 333–359. [CrossRef]
20. Campa, R. The rise of social robots: a review of the recent literature. *J. Evol. Technol.* **2016**, *26*, 106–113. [CrossRef]
21. Ramírez, V.; Deuff, D.; Indurkhya, X.; Venture, G. Design Space Survey on Social Robotics in the Market. *J. Intell. Robot. Syst.* **2022**, *105*, 25. [CrossRef]
22. Mori, M.; MacDorman, K.F.; Kageki, N. The Uncanny Valley [From the Field]. *IEEE Robot. Autom. Mag.* **2012**, *19*, 98–100. [CrossRef]
23. Li, D.; Rau, P.P.; Li, Y. A cross-cultural study: Effect of robot appearance and task. *Int. J. Soc. Robot.* **2010**, *2*, 175–186. [CrossRef]
24. Paschal, T.; Bell, M.A.; Sperry, J.; Sieniewicz, S.; Wood, R.J.; Weaver, J.C. Design, Fabrication, and Characterization of an Untethered Amphibious Sea Urchin-Inspired Robot. *IEEE Robot. Autom. Lett.* **2019**, *4*, 3348–3354. [CrossRef]
25. Latikka, R.; Turja, T.; Oksanen, A. Self-efficacy and acceptance of robots. *Comput. Hum. Behav.* **2019**, *93*, 157–163. [CrossRef]
26. Feil-Seifer, D.; Matarić, M.J. Socially assistive robotics. *IEEE Robot. Autom. Mag.* **2011**, *18*, 24–31.
27. GROOVE X. LOVOT. Available online: https://lovot.life (accessed on 22 June 2022).
28. Haring, K.S.; Watanabe, K.; Mougenot, C. The influence of robot appearance on assessment. In Proceedings of the ACM/IEEE International Conference on Human-Robot Interaction, Tokyo, Japan, 3–6 March 2013; pp. 131–132. [CrossRef]
29. Levillain, F.; Zibetti, E. Behavioral objects: The rise of the evocative machines. *JHRI* **2017**, *6*, 4–24. [CrossRef]
30. Duarte, N.F.; Raković, M.; Tasevski, J.; Coco, M.I.; Billard, A.; Santos-Victor, J. Action anticipation: Reading the intentions of humans and robots. *IEEE Robot. Autom. Lett.* **2018**, *3*, 4132–4139. [CrossRef]
31. Bevins, A.; Duncan, B.A. Aerial Flight Paths for Communication: How Participants Perceive and Intend to Respond to Drone Movements. In Proceedings of the the ACM/IEEE International Conference on Human-Robot Interaction, Boulder, CO, USA, 8–11 March 2021; pp. 16–23. [CrossRef]
32. Lehmann, H.; Saez-Pons, J.; Syrdal, D.S.; Dautenhahn, K. In good company? Perception of movement synchrony of a non-anthropomorphic robot. *PLoS ONE* **2015**, *10*, e0127747. [CrossRef] [PubMed]
33. Hoffman, G.; Ju, W. Designing robots with movement in mind. *J. Hum. Robot. Interact.* **2014**, *3*, 91–122. [CrossRef]
34. Hoffman, G. Dumb robots, smart phones: A case study of music listening companionship. In Proceedings of the IEEE International Symposium on Robot and Human Interactive Communication, Paris, France, 9–13 September 2012; IEEE: Piscataway, NJ, USA, 2012; pp. 358–363.
35. Ashmore, S.; Runyan, K. *Introduction to Agile Methods*; Addison-Wesley Professional: Boston, MA, USA, 2014.
36. Deuff, D.; Ocnarescu, I.; Coronado, L.E.; Rincon-Ardila, L.; Milleville, I.; Venture, G. Designerly way of thinking in a robotics research project. *J. Robot. Soc. Jpn.* **2020**, *38*, 692–702. [CrossRef]
37. Deuff, D.; Garcin, D.; Aznar, C.; Ocnarescu, I.; Milleville, I.; Capy, S.; Osorio, P.; Hagane, S.; Coronado, E.; Rincon-Ardila, L.; et al. Together alone, Yōkobo, a sensible presence robject for the home of newly retired couples. In *Designing Interactive Systems Conference*; ACM: New York, NY, USA, 2022, in press.
38. Cao, Z.; Hidalgo, G.; Simon, T.; Wei, S.; Sheikh, Y. OpenPose: Realtime Multi-Person 2D Pose Estimation using Part Affinity Fields. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Honolulu, HI, USA, 21–26 July 2017; pp. 7291–7299.
39. Coronado, E.; Venture, G. Towards IoT-Aided Human–Robot Interaction Using NEP and ROS: A Platform-Independent, Accessible and Distributed Approach. *Sensors* **2020**, *20*, 1500. [CrossRef]
40. Nielsen, J.; Landauer, T.K. A Mathematical Model of the Finding of Usability Problems. In Proceedings of the the Interact and Conference on Human Factors in Computing Systems, Amsterdam, The Netherlands, 24–29 April 1993; pp. 206–213. [CrossRef]
41. Manakhov, P.; Ivanov, V.D. Defining usability problems. In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, San Jose, CA, USA, 7–12 May 2016; pp. 3144–3151.
42. Martin, B.; Hanington, B.; Hanington, B. *Universal Methods of Design: 100 Ways to Research Complex Problems, Develop Innovative Ideas, and Design Effective Solutions*; Rockport Publishers: Beverly, MA, USA, 2012.

43. Coronado, E.; Venture, G.; Yamanobe, N. Applying Kansei/Affective Engineering Methodologies in the Design of Social and Service Robots: A Systematic Review. *Int. J. Soc. Robot.* **2020**, *13*, 1161–1171. [CrossRef]
44. Nagamachi, M. *Kansei/Affective Engineering*; CRC Press: Boca Raton, FL, USA, 2016.
45. Verhagen, T.; Hooff, B.V.D.; Meents, S. Toward a better use of the semantic differential in IS research: An integrative framework of suggested action. *J. Assoc. Inf. Syst.* **2015**, *16*, 1. [CrossRef]
46. Stoklasa, J.; Talášek, T.; Stoklasová, J. Semantic differential for the twenty-first century: Scale relevance and uncertainty entering the semantic space. *Qual. Quant.* **2019**, *53*, 435–448. [CrossRef]
47. Nagamachi, M.; Lokman, A.M. *Innovations of Kansei Engineering*; CRC Press: Boca Raton, FL, USA, 2016.
48. Brooke, J. SUS: A retrospective. *J. Usability Stud.* **2013**, *8*, 29–40.
49. Liang, J.; Xian, D.; Liu, X.; Fu, J.; Zhang, X.; Tang, B.; Lei, J. Usability study of mainstream wearable fitness devices: Feature analysis and system usability scale evaluation. *JMIR Mhealth Uhealth* **2018**, *6*, e11066. [CrossRef] [PubMed]
50. Palaver, W. *René Girard's Mimetic Theory*; MSU Press: East Lansing, MI, USA, 2013.
51. Cannon, C.; Goldsmith, K.; Roux, C. A self-regulatory model of resource scarcity. *J. Consum. Psychol.* **2019**, *29*, 104–127. [CrossRef]