Designing a Co-Creative Dancing Robotic Tablet

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Abstract. This paper reports the design and evaluation following user-centered methods of a dancing robotic tablet prototype for co-creative human-robot interaction. An initial exploratory interview study served to obtain requirements for the design and implementation of a first prototype. This prototype was evaluated in a user study and subsequently improved. Two types of autonomous robot behavior were considered as creativity support and evaluated in a second user study. While *imitation* behavior was perceived as more intelligent; the *generation* behavior that attempted to challenge users and be different to the users' input led to a greater variety of gestures. Video recording analysis shows the potential of such autonomous behavior for the creative process, as users were inspired to some extent by the robot's input.

Keywords: dancing robot; co-creativity, creativity support tools; robot creativity; human-robot collaboration, user-centric methods.

1   Introduction

Tangible interactive systems have enabled new forms of creative expressions through playful interactions in diverse areas of application such as education [9] or music performances [13]. When computers become more than just supportive tools in the creative processes, and are given a distinguished ability to contribute pro-actively to the process, they become creative computers [6]. In this sense, Human-Computer Co-Creativity is defined as a creative process where people and computers contribute "in a blended manner" and an interaction occurs [5] in which both human and computer can influence or inspire each other, and the computer acts as a computer colleague. This paradigm has been applied in different domains such as drawing [7], or music improvisation [21]. However, more evidence on how to provide co-creativity functions is still needed to support the development of this kind of systems. Furthermore, user-centric methods could be valuable in the design processes to get deeper insights before implementing fully automated prototypes that typically may include complex and hard to implement computational intelligence techniques.

In this paper, we explore the design of an interactive robotic tablet prototype that allows the user to create a dance for it on a tabletop, intended as a creative and ludic

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activity. We have designed two different co-creative strategies and carried out a study to understand how this collaboration between computer and human unfolds. We found that imitation behavior is perceived as more intelligent, while behavior that is notably different to the users' input leads to a greater variety of gestures. The video recordings analysis showed that users were inspired to some extent by the robot's autonomous input. Our observations contribute to get deeper insight into designing for future interactive co-creative systems.

The paper is structured as follows. Section 2 introduces the background and the work that inspired our research. Section 3 presents the design stages followed by the prototype implementation. Section 4 reports the user evaluation of the implemented co-creative strategies and Section 5 discusses the overall findings and observations. Finally, Section 6 concludes and introduces future work plans.

2   Related Work

The area of co-creative systems pursues developing computer software to contribute to creative processes in collaboration with humans [5]. Mamykina et al. [17] emphasized that a creative product emerges through interaction and negotiation between multiple parties, and that the result is greater than the sum of the individual contributions. To act as an autonomous agent in a co-creative activity, a robot needs to have its own "ideas" and should able to express them. Only by challenging the human, the robot will be experienced as a partner in the creative activity [10]. In this line, there have been several attempts to develop creative machines, using machine learning approaches that for example are able to create music [11], [21], paintings [7] or stories [3]. However, to the best of our knowledge, co-creativity has not been explored in the context of interactive robotic dancing agents yet.

A number of related papers have focused on technical aspects in humanoid dancing robot systems; see [20] for an overview. These include a variety of systems such as the Adonis [18], HRP-2 humanoid robot [19], the Partner Ballroom Dance Robot (PBDR) [14] and the Keepon [15]. However, at the moment it is difficult to to explore co-creativity with such robots, due to the high complexity of possible movements and their currently limited interaction capacities with humans.

Hence, an area of interest is that of interactive tabletop systems for creative play performances or creative playful expression. An outstanding example is the Reactable [13], which is a music instrument and allows users to experiment with sounds through a tangible tabletop interface. TurTan is a tabletop system that helps users to explore Logo programming concepts by interactively producing graphical visualizations [9]. Another project that tries to inspire people to explore in a playful way is GlowBots [12]. Nevertheless, these systems do not include autonomous computer generated input in the underlying creative process. Instead they remain as user tools to enable human creativity, facilitated by exploratory, tangible and direct manipulation interaction styles.

From the areas explored, we believe that to better examine the necessary complicity and relationship of human and computer agents for the development of future co-creative functions, we need a simple robot model that has only a few degrees of freedom and that enables exploratory interaction as in the aforementioned

tabletop systems for creative expression. Moreover, an important remark by [23] is that dancing can be simply understood as the movements that someone carries out in accordance with a music beat, without need for a very complex choreography or repertoire. Hence, we explored the design of a co-creative robot that can move on a tabletop according to the user input, intended as movements that will be executed by the robot in the design of a creative dance.

3 Design and Implementation[2]

The development of the system followed a user-centered design approach and was carried out in three phases. First, an initial study was conducted, in order to get a general idea of how people would interact with a dancing robotic agent to order the dance movements. This study led to the design of a first prototype, which was evaluated in a user study. The results from this evaluation were then used to further improve the prototype. Ultimately, after implementing autonomous behavior, another study was performed to explore how people interact with the co-creative robot. All participants were students at our university, in their twenties, and from diverse disciplines ranging from Health Sciences and Psychology to Industrial Design or Computer Science. They self-reported that they dance "never" or "occasionally" in their free time. The interaction with the different robot prototypes was video-taped. Fig. 1 depicts the overview of the whole design process.
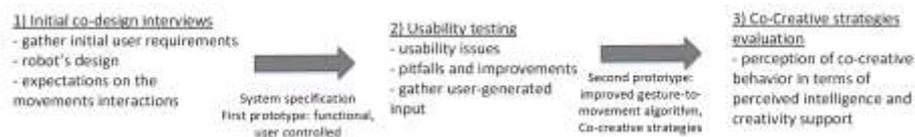

Fig. 1 Overview of the design process.

3.1 Exploratory Interview Study - Gathering Initial User Requirements

The goal of the exploratory study was to gather initial user requirements concerning the robot's design and the users' expectations on the movements as a way to co-design the prototype. The study was carried out with eight participants. For the robot, a Pololu Zumo Robot for Arduino[3] was used. Firstly, participants were given the time to explore the robot's movement capability by controlling it through a mobile application which worked as a joystick. Secondly, participants were handed a cardboard prototype (see Fig. 2-a). They were asked to physically carry out movements with the cardboard proxy that they would imagine the robot to do, while thinking aloud. Third, participants were asked to draw gestures matching their previously performed movements on a tablet (see Fig. 2-b). Finally, they were asked how they would imagine the outer appearance of the robot.

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[2] Video of the final prototype:
https://www.youtube.com/watch?v=A60fLKBpI7Y
[3] Pololu Zumo Robot Specifications: www.pololu.com/product/2510

Fig. 2. a) Cardboard proxy; b) Participant in the exploratory interview study exploring the cardboard prototype and drawing a gesture for the elicited movement; c) Examples of gestures: upper row with some that were given a symbolic meaning; bottom row with some of the free-form samples.

From the information elicited in this stage we observed that participants split the dancing performance into sequences of single gestures, and most of them were free-form gestures rather than symbolic commands (see Fig. 2-c for some samples). Typically, the free-form gestures were more complex and more than half of the gestures included a lot of curves and zig-zag movements. Sometimes participants indicated that they would like to be able to repeat movement steps. The participants' input was used to develop the prototype for the next study, mainly resulting in (1) considering free-style touch input to indicate the dance instead of a predefined gesture vocabulary, (2) treating each gesture as a single but complete path that the robot should carry out, and (3) allowing users to repeat dancing steps. As for the appearance of the robot, most participants mentioned some need to add a more special and fancy case covering the wheels, with a curved shape, smooth trajectories and elements such as fabrics to create a less static look. As a result of these suggestions, we proceeded to add an oval plate with wheel protectors on the Pololu Zumo robot, to which a tablet Samsung Galaxy Tab A 7.0 SM-T280 and a skirt fabric can be attached to meet the users suggestions (see Fig. 3).

Fig. 3. Prototype after considering user comments on the robotic tablet look.

3.2 First User Study - Usability Test on the First Prototype

Taking the physical design of the prototype in Fig. 3, we implemented an Android app to capture free-style dragging gestures to be transformed into robot movements. A gesture consists of a continuous drag without lifting the finger. The gesture drawn is transformed into a list of points. Then these points are transformed into a sequence of timed commands for the motor wheels, which will drive the movement in the physical robot. Fig. 4 shows the setup for user tests. Once the dance step has been completed, the drawing screen is displayed again awaiting new gestures. The coordinates' list of each gesture is saved in a text file, to allow later analysis or re-enactment.

This first prototype was evaluated in terms of usability with twelve participants, who did not participate in the previous study. During user testing, the participants were asked to create a dance by indicating movements on the tablet which would fit with the music being played in the background. Two types of background music (a Mozart sonata[4] vs Gangnam Style[5]) were tested to investigate their influence on the creativity of the movements.

Fig. 4. Setup of the tabletop activity.

The usability of the prototype was evaluated by means of a questionnaire, based on the Post-Study System Usability Questionnaire (PSSUQ) [16]. The results indicated that the overall usability of the system was seen rather positive (3.80/5). It was noted that the gesture-to-movement algorithm was still not optimal, as it could not handle acute angles very well, and the robot could not move backwards. Furthermore, users indicated the need for a stop-button, to stop the movement of the robot whenever desired. This valuable feedback served to improve the implementation for next stages. All gestures performed during this iteration were collected. A selection of these gestures was used for the autonomous behavior of the robot as will be described in Section 3.3. Inspired by the Consensual Assessment Technique [1], the creativity assessment was done by judges who rated the gestures independently to establish an overall rating. As using a robotic tablet to *dance* is an emerging interactive activity, the three raters used a 5-point scale (see Fig. 5) with the following levels, based on Stahl's seminal taxonomy of novel forms of behavior [24]:

Reproduction: The nearly exact replication of a previous movement.

Duplication: A modified version of an already existing movement, which does retain the essential form. Rotations, small changes, deletion of parts of a movement and mirroring of previous gestures are considered duplications as they are duplicating the behavior with small variations.

Fabrication: The rearrangement, re-mixture, or combination of two or more gestures in a way that if you split the gesture again, you retain the original gestures to some degree. Both gestures should have already been made before.

Innovation: The creation of a new movement that retains the core essence of the original gesture but making a clear transformation. It looks different from all other

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[4] Mozart, Wolfang Amadeus (1781). Sonata for Two Pianos in D Major, K. 448 (K. 375a) Allegro con Spirito [Recorded by Murray Parahia and Radu Lupu]. Retrieved from https://www.youtube.com/watch?v=v58mf-PB8as

[5] Park J.S. & Yoo, G. H. (2012). Gangnam Style. Retrieved from https://www.youtube.com/watch?v=9bZkp7q19f0

previous made movements, but it is not perceived as original.

Generation or original creation: The creation of something entirely new, which is not related or limited to the previous gestures.
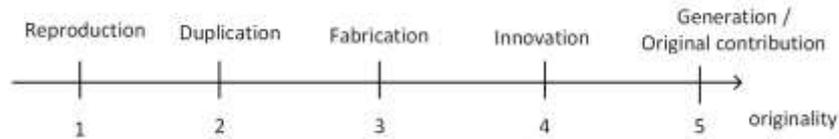

Fig. 5. 5-point scale for rating originality of movements produced by participants.

A total of 361 interactions were gathered, on which the creativity assessment procedure described previously was carried out. The interrater-reliability for the creativity-rating of the movements was calculated between every pair of raters using Cohen's kappa, obtaining $k_{1,2}$=0.621, $k_{1,3}$=0.638, $k_{2,3}$=0.667, leading to an average interrater-reliability of 0.642, which as indicated by Viera and Garret [26] is interpreted as a moderate to substantial agreement. The average ratings by music background were $m_{classical}$=3.10 and m_{disco}=2.88 respectively. As the results are not conclusive, not finding significant differences with a paired t-test (p= 0.57), we decided to use the classical music for our next study, given the previous evidence on its possible effects on creativity performance [22].

Taking into consideration the feedback gathered during the user studies, we refined the application to have the final functional design and related screens depicted in Fig. 6. The main visual difference is that we made the first screen clearly asymmetrical by adding a button *robot movement* in order to prevent confusion in identifying the head and tail of the robot; that button can be used to request a robot-generated movement. Furthermore, we added a different stop button (shown in the last screen) for when the robot is carrying out a robot-generated movement. This capacity related to the co-creative strategies is presented in the next section.
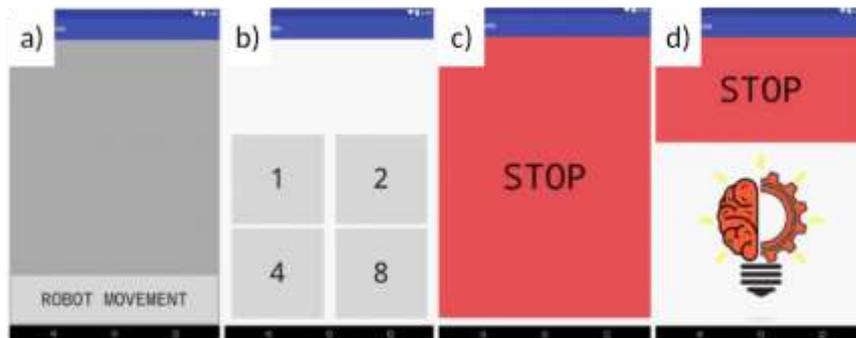

Fig. 6. App screens in the final version of the prototype: (a) input movement gesture screen; (b) repetitions; (c) stop screen during the execution of a user-created movement; (d) stop screen during the execution of a robot-created movement, showing that an *intelligent* move is in progress.

3.3 Implementation of Co-Creative Strategies

Besides the improvements suggested in the previous section, two different kinds of autonomous behavior were implemented in the next version of the prototype, which will be tested in the study in Section 4. These strategies allow the robot to contribute to the dance and thereby make the activity co-creative.

During the interactive activity, the application evaluates every gesture based on a scoring metric to classify it in terms of *length* and *edginess* (i.e. number of edges). Fig. 7 shows sample gestures according to these two dimensions. Both parameters are mapped to be in a range between 1 and 10, and the ratio *edges:length* is considered as the final score of the input gesture. If the standard deviation of the last five gestures is lower than a fixed threshold of 4, which was established after a pilot testing phase, the system enters into the autonomous behavior mode, carrying out a gesture movement according to the strategies described as follows.

The first behavior, *generation*, aims at challenging the user, a feature suggested by [10] for co-creative agents. It is implemented by performing a movement completely different from the last five movements that the user drew. The robot chooses its movement from a pool of 28 pre-saved gestures, arranged in four categories according to the length of the gesture and the number of edges (see Fig. 7 for samples). To form that pool, seven representative gestures of each category from the first study, described in Section 3.2, were included in the robot's movement repertoire.

In the second behavior type, *imitation*, the robot imitates the user, by repeating the movement corresponding to the last gesture of the user. In both conditions, autonomous behavior is triggered when the user provides five similar gestures in a row (in terms of length and edginess). The user can also request autonomous behavior of the robot by pressing the *robot movement* button in the drawing interface.
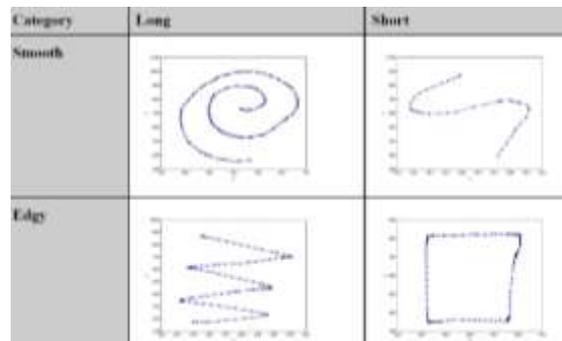

Fig. 7. Example of gestures in the pool of the four categories possible in terms of Length and Edginess.

Because we are interested first in exploring the user understanding of the co-creative strategies, we rely on a pool of pre-saved gesture movements taken from the user testing stage. Implementing complex algorithms to produce the intended co-creative movements, based for example on evolutionary/bioinspired techniques (e.g. [8], [25]), is part of the future work.

According to Stahl's taxonomy, totally novel content corresponds to the most creative input [24] whereas copied content would have a low level of novelty. In line

with this, we can state that the two different types of autonomous behavior are in contrast regarding creativity. The first form introduces movements that are different from what the user previously made. The robot thereby gives new input to the process and challenges the creativity of the user, providing creativity support. The second version of autonomous behavior consists of the ability to memorize the gestures of the user and copying them. Acting in this way disagrees with the definition of creativity as variety and diversity between movements, but still allows the robot to provide active input to the performance.

4   Second User Study - Preliminary Evaluation of Co-Creative Strategies

The second user study was intended to evaluate the participants' appreciation of the autonomous input and to find out to what extent two autonomous robot behavior strategies can support the creative process. Nine participants who did not take part in previous tests participated in this evaluation. They were requested to carry out the same experimental task as in the first study, with the difference of having only the Mozart's sonata as music background and using the final version of the designed application in two conditions corresponding to the implemented co-creative strategies. After the interactive task was completed, the users filled in a questionnaire on creativity support and perceived intelligence, which is explained in the next section. Furthermore, videos of the interaction with the robot were coded and analyzed qualitatively. All participants interacted with both of the autonomous behaviors. The order of the behaviors was switched after each participant to counterbalance order effect.

4.1   Perceived Intelligence and Creativity Support

To assess the perceived intelligence (PI) of the robot, we used the corresponding part of the Godspeed Questionnaire [2], which is a popular questionnaire instrument to measure the users' perception of robots and helps robot designers in their development. We added a couple of items (PIQ6 and PIQ7) for our specific context of use in order to find out more information. Fig. 8 depicts the ratings by strategy in a 5-point scale for the questionnaire items. The PI was overall higher rated (m=3.21) in the *imitation* strategy, compared to the *generation* strategy (m=2.81). The difference is not significant with alpha at 0.05 but could be at 0.1 (paired t-test p-value=0.09). According to the scores reported in the figure, in general terms the robot was considered more competent, less ignorant, more responsible, less unintelligent, more aware and less autonomous when acting with the *imitation* behavior than when implementing the *generation* behavior.

We hypothesize that a possible reason for this is that the behavior challenging the users, i.e. the *generation* strategy, was somehow perceived as sort of random. Some users might not have understood when or why the robot would perform an autonomous movement. This effect was less pronounced for the imitation behavior, because users could figure out more easily that the robot was simply imitating the gestures of the user.

Additionally, the number of movements initiated by the robot was on average

lower in the *generation* condition (11 movements) compared to the *imitation* one (13.17 movements). Since the number of movements initiated by the robot is for a big part determined by the similarity of the gestures proposed by the human, this indicates that to some extent there was a higher variety of gestures made by the human in the *generation* condition. This suggests that users might have been influenced by the robot behavior to try out more different gestures, which is something to take into account in the future development of co-creative strategies as it is intended to favor diversity of ideas.
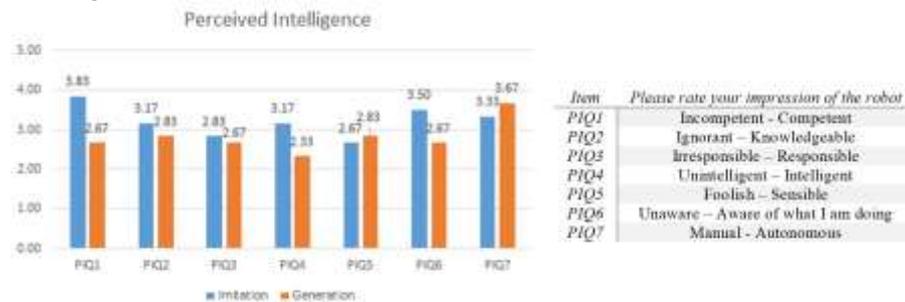

Fig. 8. Perceived Intelligence scores by item.

The Creativity Support Index (CSI) questionnaire [4] was used to assess the creativity support. The users' answers led to similar scores for both strategies ($m_{generation}$= 54.99, sd=13.74; $m_{imitation}$=57.76, sd=14.04). The paired t-test did not reveal significant differences between the different autonomous behaviors (p-value=0.33).

4.2 Video Recording Analysis

In order to better understand the reported perceptions as well as how the interactions were performed, we reviewed the video recordings. We looked for relevant events such as user comments, pitfalls, and any identifiable visible pattern on interactions (e.g. stopping the robot movement). The review did not reveal remarkable differences between the imitation and generation conditions. Three out of nine participants spontaneously reacted when they recognized the autonomous behavior of the robot. For instance, one user exclaimed, "I didn't do that. That's its own movement", when she first noticed that the robot was performing an autonomous movement, despite knowing that could happen during the performance.

In both the *imitation* and *generation* behavior conditions, the robot's autonomous movements were stopped often. Only one participant never stopped the autonomous movements. The main reason for stopping the robot was because the robot was about to bump into the borders of the dance floor. The collisions with the dance floor borders were the result of technical limitations, as the prototype did not have border recognition implemented. Seven out of nine participants repositioned the robot when it first collided with the walls, so that it could continue its autonomous movement. However, most of the times participants stopped the autonomous behavior when the robot was bumping repeatedly during a particular movement.

Other causes for stopping the robot's autonomous behavior could be observed in the interactions. Several users tried to refine their gestures because the execution by

the robot did not result in the exact and accurate movement they really wanted. In this case, the users would repeat similar movements again and again. However, producing several similar movements after each other was the criterion for activating the autonomous behavior, which caused the robot to interrupt the performance with its own autonomous movements. In such cases, the users often stopped the robot's autonomous behavior as it was interrupting their idea generation process, meaning that the co-creation was not always welcome.

A third cause for stopping the autonomous behavior was repetitious behavior of the robot or more generally, long duration of the robot's movements (particularly, during one autonomous movement the robot would repeatedly drive in circles for more than 20 seconds). Participants would first watch the robot perform its autonomous movement and then stop it after a while. Interestingly, some of the users who stopped the circular movement took up the idea of moving in circles. Two participants drew a circular shape immediately after having stopped the robot's autonomous circular movement. This clearly shows that participants did notice and took into account the input of the robot. Stopping the robot's autonomous movement can therefore also be interpreted as a way to take the robot's creative input in some cases.

Users also actively asked the robot for input. Seven out of nine participants used the button that called for autonomous behavior of the robot. Overall, the button was pressed at least once and not more than three times by each participant (mean= 2.14). Different ways of using the button can be observed. Four participants used the button to find out what the robot could do on its own. One participant used the button to reproduce the autonomous behavior of the robot that she had just discovered. Two participants stopped the autonomous behavior enacted by robot to carry it out themselves right afterwards. This type of behavior seems to reflect a desire of being in charge and determining at what time the robot may perform its autonomous behavior.

5   Discussion

We have presented the design process in developing a co-creative dancing robotic tablet involving user-centric methods. We reported how participants reacted to the autonomous behavior of the robot in order to explore how it can support the co-creative activity. The preliminary findings indicate that the system can still be improved in several ways.

First, some technical aspects need to be improved. The inability of the robot to recognize the borders of the dance floor resulted in undesirable collisions of the robot with those borders. This had a disruptive effect on the performance as a whole. Furthermore, the length of the robot movements was not easy for users to foresee.

Second, we found that the current implementation of the autonomous behavior of the robot might not be optimally supporting the creative process, as the CSI scores suggest. Some users tried to create a specific movement they had in mind and thus drew similar movements repeatedly. The similarity was recognized by the robot and it reacted by proposing a movement that was totally different (*generation* condition) or simply a repetition of the participant's movement (*imitation* condition). Thereby, the robot was interrupting the creative process of the user at the wrong moments. A possible improvement would be a change in the criterion for enacting autonomous

movement, in such a way that the interactive development of an idea is not disrupted. A straightforward change would be to allow for more than five similar movements, or to start the autonomous behavior after a certain time of no input from the user. After all, users could always be allowed to request a co-creative action from the robot.

We suggest that the types of autonomous behavior presented by the robot should be improved as well. Interrupting the creative process of the user with an idea that is the total opposite of what he or she had been doing in terms of length and edginess might not lead to a positive experience of the interaction. The robot could have been perceived as not paying attention or as unaware of the user activity, instead of collaborating with the user, and therefore not fully co-creative. Similarly, repeating the previous movement of the user 1:1 does not add variance to the interaction, although it may facilitate recognition of what the robot is doing. In human-human collaboration or a co-creative activity it is important to work with each other's ideas and elaborate on what someone else did. Thus, both behavior types must be combined at different levels, enabling the robot to take the movement proposed by the user and transform it into something new. The user should still be able to recognize his or her original work in the new movement. Gradually, the robot could perform movements that differ more from what the user is doing, thereby carefully providing its own input without disrupting the co-creative process. All these observations are relevant to guide the development of future co-creative interactive strategies, and in particular the development of generative strategies that fulfil the users' expectations and their understanding while making the implementation cost-effective.

6　　Conclusion

In this paper, we have explored the design of an interactive robotic tablet for a co-creative ludic activity, following a user-centered design approach. Two different creativity-support strategies have been implemented: a *generation* behavior, during which the robot challenges the user by performing movements that are different from the user's last five inputs, and an *imitation* behavior during which the robot simply repeats the user's last input. Although the imitation behavior was perceived as more intelligent, the generation behavior is worth exploring in terms of co-creativity as users tried out new ideas and showed a greater variety of inputs compared to the imitation behavior. Users asked the robot for its input several times and took the robot's previous suggestion into account when developing their own gestures. However, the autonomous behavior as implemented in this prototype was not optimal, possibly having a disruptive effect on the creative process of some users.

Overall, the observations and findings along the design process can be transferable to design other co-creative interactive systems, especially concerning timing, recognition of robot contributions by users, using user centric methods and input at several stages to continue developing the interactive system iteratively. They also open directions for future work regarding implementation improvements and research. Firstly, we plan to include an autonomous mechanism for the robot to avoid bumping against the borders based on edge detection using an array of infrared reflectance sensors. This needs to be combined with additional visual feedback on screen to report the position of the robot with respect to the borders using a tracker.

On the co-creative strategies side, there are at least two aspects to address. One is the timing, which implies research exploring when the robots' contributions should be triggered and for how long. The other is the generation process itself. Departing from the gathered gestures for movements, we can now perform a deeper structural analysis to identify patterns and features that can be used as chunks. Then they can be considered in a generative approach guided by an evolutionary computation algorithm to match the required degree of variation to still introduce some originality without damaging certain recognition of the user's original input. The objective function could be parameterized to offer not only the two conditions we have been testing in the present paper, but to provide several levels in between. Finally, with the incorporated changes and improvements, we will carry out a pilot test and conduct a broader user study evaluating the new implemented generation methods.

Acknowledgement

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