LevPet: A Magnetic Levitating Spherical Pet with Affective Reactions

Josune Sorbet
UpnaLab, Public University of Navarre
Pamplona, Spain
sorbet.120883@e.unavarra.es

Sonia Elizondo
UpnaLab, Public University of Navarre
Pamplona, Spain
sonia.elizondo@unavarra.es

Naroa Iriarte
UpnaLab, Public University of Navarre
Pamplona, Spain
naroa.iriarte@unavarra.es

Amalia Ortiz
UpnaLab, Public University of Navarre
Pamplona, Spain
amalia.ortiz@unavarra.es

Asier Marzo[*]
UpnaLab, Public University of Navarre
Pamplona, Spain
asier.marzo@unavarra.es

ABSTRACT

LevPet combines affective computing and magnetic levitation to create an artificial levitating pet with affective responses and novel ways of moving to express emotions. Our interactive pet can recognise the user's emotional status using computer vision, and respond to it with a low-level empathy system based on mirroring behaviour. For example, if you approach it with a happy face, the pet will greet you and move in a nimble way. A repulsive magnetic levitator is attached to a mechanical stage controlled by a computer system. On top of it, there is the pet playground, where a house, a ping-pong ball,a xylophone and other accessories are placed. Two cameras allow to capture the user's face and the objects placed on the playground, so that the pet can interact with them. LevPet is an exploration of how to communicate internal state with only a levitating sphere; it is a platform for experimentation and an interactive demo that brings together an outer-worldly levitating metallic sphere with familiar things like emotions and a playground made of traditional items.

CCS CONCEPTS

· **Computer systems organization → Embedded systems**; Robotics.

KEYWORDS

Affective computing, empathetic pet, magnetic levitation

1 INTRODUCTION

Previous research in the field of human-animal interaction has shown multitude of benefits of this relationship on human health and well-being [21]. Some studies point out that interacting with a pet may positively impact elderly people [22] as well as the young population. For example, children and teenagers with a pet suffer from less depression and anxiety [32].

However, it is not always possible to have a pet due to allergies, economical resources, lack of space or time. Robotic pets can also provide positive effects [25]. Some studies examined the potential of commercial robotic pets with special emphasis in the emotional experience, such as Sony Aibo [11] and the Golden Pup [15]. Here, the creation of a levitating spherical pet which expresses its emotions through the levitation patterns by adapting its direction, speed and acceleration is explored.

For creating the levitating pet, named Sr. Boliche, we mixed the fields of affective computing and levitating robots. As the levitating object that represents the pet, we chose a sphere to remove the effect of pet appearance and focus on its behaviour. The magnetic levitation uses repulsive electromagnets [9, 29]. The levitator is attached to a Computer Numerical Control (CNC) X-Y stage to move it horizontally. A playground is placed on top of the magnetic levitator and the sphere levitates on top of it, the playground defines the space where Sr. Boliche can move. The stage and the magnetic levitator are hidden by the playground to give the impression that Sr. Boliche is levitating and moving on its own (1).

Affective Computing encompasses a system capability to recognize a user's emotional states, express its own emotions, and respond to the user's emotions [26]. Accordingly, LevPet is capable of: recognising a user's emotional states using a computer vision system, respond to this state using a low-level empathy system based on mirroring behaviour, and express its own emotions by adjusting the levitation movement.

Section 2 covers previous studies and implementations of affective pets. Section 3 explains the implemented Levpet system, which is divided in different subsections: In subsection 3.1 the designed hardware is explained in more depth, in subsection 3.2 the software design is explained, this subsection is divided into: interaction manager 3.2.1, affective expression generator 3.2.2, the path generator module 3.2.3, user detection module 3.2.4, and ping-pong ball detection module 3.2.5. Lastly, in section 4 we discuss the result and possible future work.

Figure 1: The LevPet system. Sr. Boliche is levitating above its playground. At the left, the xylophone and the webcam to recognize the user. At the right, the house where the pet can take cover or go to rest.

2 RELATED WORK

People interact with robotic or virtual pets for the advantages of having a pet when they cannot afford a real one. There are several options on the market such as Aibo [10], Moflin [16] or Tamagotchi [13]. Despite the existence of various commercial options, the interaction between people and non-real pets is still an interesting research area since they can provide benefits when complementing medical treatments [25], acting as companion robotics [28], supporting learning processes [34] or supporting elderly care [25].

Most of those works are focused on improving the emotional experience during the interaction by applying advances in Affective Computing. This discipline was born in the 1990s and was consolidated in 1997 with the publication of the first book on Affective Computing, written by Professor Rosalind Picard (MIT) [26]. Affective Computing describes computational approaches for the detection and deliberate induction of affect [27]. In the beginning, the advances in this field were scarce, but thanks to the advancements in technology, this topic is gaining strength on its three main components: Recognition, Expression and Dynamic Generation of Emotions.

There are two main ways to identify user's emotions: by measuring the physiological changes or by analyzing the expressive behaviour. Nowadays, computer-aided emotion recognition systems using physiological signals have attracted increasing academic interest [19]. Nonetheless, this technique requires the user to wear sensors. A contactless method is to analyse user's expression channels, such as speech and facial features, with the help of microphones or a video camera [20]. In this work, we have focused in recognising facial expressions via computer vision, open source projects have been created for this task, e.g., OpenFace2.0 [3] and RealTimeEmotionDetection [4].

To let machines express emotions, the first step is to design the set of emotions. There are complex classifications of emotions which define a set of 19 [30] or 22 [23] discrete emotions, or systems that operate in a continuous 2D emotional space enabling a wide range of intermediate emotional states to be obtained [14]. However, since our aim is to provide a low-level empathy interaction with a pet, we selected the six basic emotions defined by Ekman [7]. Ekman also defined the way humans facially express these set of basic emotions [8], but this study can only be applied to robots with anthropomorphic appearance. As our pet is a levitating sphere, the way of giving it an emotional behaviour is by making changes in its motion. Following this approach, there is research which study the effect of the amplitude, acceleration and duration of motion for different emotions [36]. Other studies analyse the variation on heart [33] or breath rate [17] to match each rhythm variation with its corresponding emotion. The emotions that Sr. Boliche expresses are based on breath rhythms; moving fast for happiness or fear, and moving slow for showing sadness.

Finally, the last aspect of Affective Computing refers to the machine capabilities to respond appropriately to the user emotions. The system needs a reasoning mechanism which allows it to select the emotion to express based on the interaction with the user. The links between emotions and rationality have been extensively studied and discussed [1]. There are mainly four different perspectives on emotion: the Darwinian, the Jamesian, the social constructivist and the cognitive [6] but cognitive architectures are the most developed [35]. Social robots are based on cognitive-affective models, which allows them to communicate with people following social behaviours and rules [5]. Although animals do not understand what aroused an emotional state in another being [2], they are able to respond properly to the user's emotions using empathy mechanisms. These mechanisms are not only specific to humans, but are also present in and across other species [24].

The manifold facets of empathy are explored in neuroscience; from simple emotional contagion, to higher cognitive perspective-taking. Emotional contagion enables animals to share their emotional states and does not require reasoning about what caused the emotions in others [2]. Emotional contagion can be reflected in showing a similar facial, vocal or postural expression [12]. We follow the emotional contagion approach giving Sr. Boliche the ability to respond to the user's emotions using a low-level empathy system based on mirroring behaviour.

As explained before, the way Sr. Boliche expresses its emotions, is by levitating at different speeds, direction and acceleration; whereas other virtual pets express their emotions using different techniques. We note the existence of other magnetically levitated spheres in interactive systems [18] but the sphere is a passive object controlled by the humans for architectural simulations, physics simulations and entertainment.

3 SYSTEM

In this work we have designed and implemented a levitating pet which is able to interact empathically with the user. At the beginning, Sr. Boliche is at home waiting for a person to come and meet it. When a person arrives, the system is able to recognise their position and emotion using computer vision. Then, the levitating pet gets out from its home and greets the person (i.e., comes near the person). Afterwards, it reacts to the user's recognised emotions by moving in a certain way throughout the playground, playing music on its xylophone or playing with a ping-pong ball.

Figure 2 shows a summary of the modules and their interconnections. The system inputs is a set of cameras and the output motors are controlled by a microcontroller. The main software module is the Behaviour Manager that is in charge of controlling the interactive flow by analyzing the inputs of the system and determining the behaviour of Sr.Boliche. The inputs are coming from other two software modules. Both of them are vision control systems developed for detecting the position of the ping-pong ball in the playground and analysing the user's emotions and position. An Arduino UNO is used as the microcontroller to interact between the stage, end-switches and other hardware systems with the Behaviour Manager. Both detectors are written in Python and communicate with the Behaviour Manger using the OSC protocol. To interact between the Arduino UNO microcontroller and the main program, a serial connection is used.

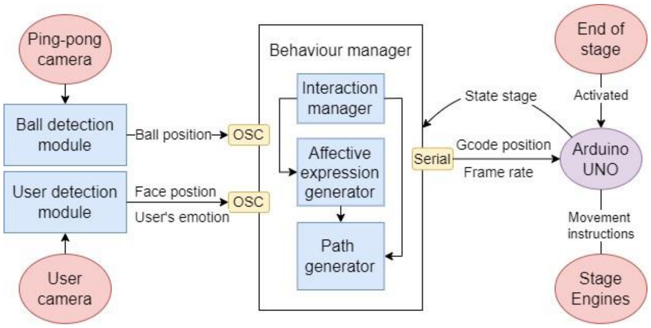

Figure 2: Communication diagram of the different hardware and software modules. The hardware components are shown in pink, software modules are blue, microcontroller is purple and communications are yellow.

3.1 Hardware

LevPet is made of a playground for the magnetically levitated sphere (Sr. Boliche), multiple pieces of hardware are hidden below the playground. Additionally, there are two cameras, one above the playground pointing down to it , this one is in charge of detecting the ping-pong ball so that Sr. Boliche can play with it. The other camera is placed on the playground pointing frontwards, it is in charge of detecting if a person approaches and captures their face for emotional recognition. This way, Sr. Boliche can interact and react to the emotions of the user. The playground is compossed of Sr. Boliche's house were it rests and hides if it is afraid, the xylophone which it plays when it feels happy, and a ping-pong ball. The playground defines the space where Sr. Boliche can move.

To provide movement to the levitated magnet, the magnetic levitator was mounted on a stage, below the floor of the playground (Figure 3). Since the floor is made of wood it does not affect the levitation. This stage is a CNC machine with 2 axis and 3 motors. The controller receives G-code to indicate the target coordinates and the speed at which the movement has to take place, G1 commands were used for this purpose. We added extra end-switches at the stage axes to allow easier homing, also it was a security measure to avoid the stage go out of the limit of the machine.

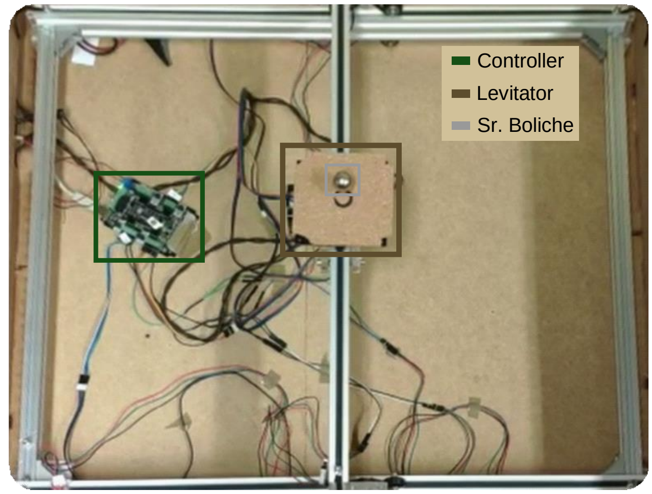

Figure 3: The hardware that is hidden below the playground. A microcontroller for controlling the stage. A levitator and the magnetic ball that is usually above the playground floor.

3.2 Software

LevPet software runs in a PC computer (i5 with 8Gb of RAM) and is composed of multiple parts.

3.2.1 *Interaction Manager.*

This module controls the flow of interaction between the user and the pet (Figure 4). Based on the events that occurs during the interaction, it decides what is the most appropriate behaviour that the pet should have. The different interactions that Sr. Boliche (the pet) supports are:

- **Empathize with the user emotion**: After detecting the emotion of the user that is interacting with the system (Section 3.2.4), Sr. Boliche will express its own emotions, by changing the way it moves. When the Interaction Manager decides that Sr.Boliche should empathize with the user's emotion, the system calls the Affective Expression Generator Module (Section 3.2.2) in order to decide which emotion to show and how to express it.
- **Play with a ping-pong ball**: If Sr. Boliche detects that there is a ping-pong ball on the playground, it will go and play with it pushing it around (explained in section 3.2.5).
- **Go greet**: if Sr. Boliche has spent an amount of time without interacting with a user, when someone appears, it will go greet them. It will move to the person's position (explained in section 3.2.3).
- **Play the xylophone**: When Sr. Boliche has been feeling happy for a period of time, it will go and play the xylophone (explained in section 3.2.3). See figure 6.
- **Go Home**: Sr. Boliche goes home if the user is scared or angry (see figure 5). It also goes home if some time has passed without detecting any users. The path for going home is calculated by the Path Generator (explained in section 3.2.3).

As it is shown in Figure 2, the Interaction Manager also communicates with the Affective expression generator (explained in

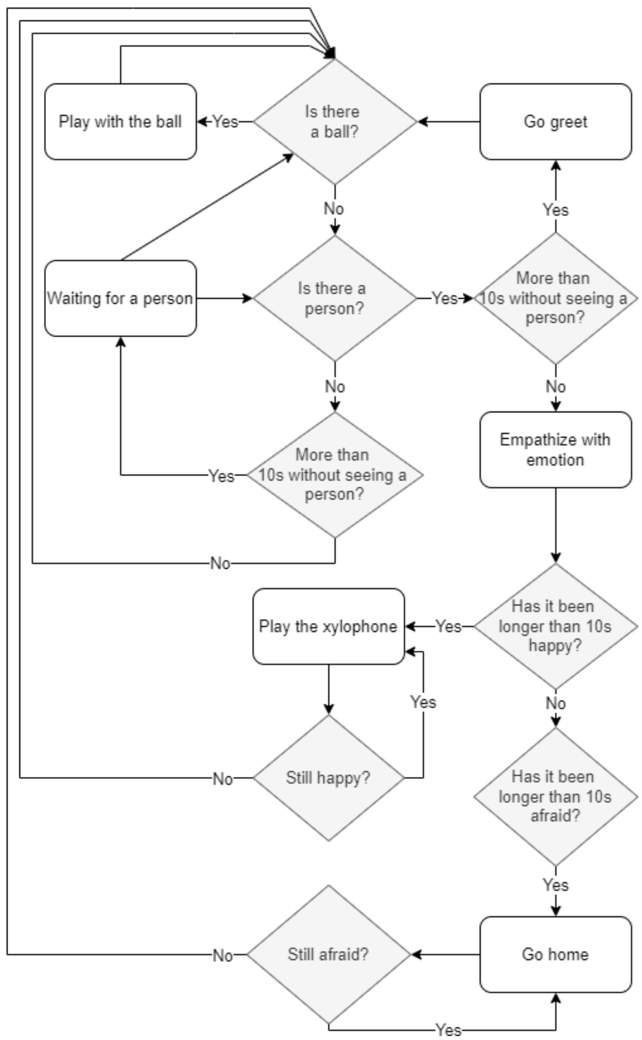

Figure 4: Flow chart diagram that defines the behaviour of the levitating pet (also called Sr Boliche).

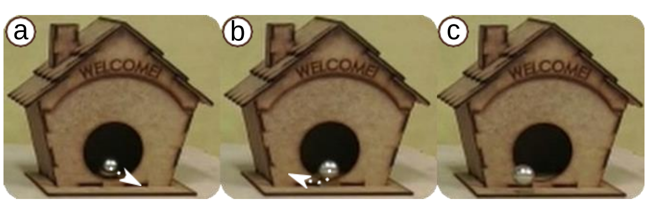

Figure 5: The movement that Sr. Boliche follows to get out of its house.

section 3.2.2) and with the Path Generator (explained in section 3.2.3) to send them the kind of movement that Sr.Boliche should express.

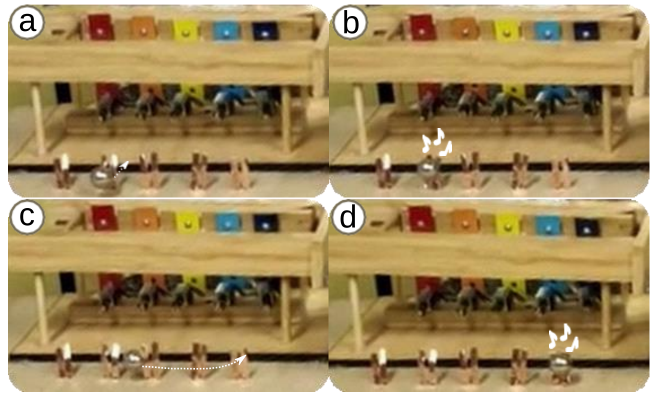

Figure 6: The path that Sr. Boliche follows to play different keys on the xylophone.

3.2.2 Affective Expression Generator. The Affective Expression Generator Module which works at two levels, first to decide what emotion to show and then to decide how to express it.

First, the pet decides the emotion to express using a low-level empathy mechanism mainly based on emotional contagion which enables animals to share their emotional states without requiring any reasoning about what caused the aroused emotions in others [2]. As Emotional contagion can be reflected in showing a similar facial, vocal or postural expression [12] we provide to Sr. Boliche a basic mirroring behaviour following the Özge Nilay approach [37] which provides mimicry based on the detected user's facial expressions.

To design the pet empathetic reactions, it is mandatory to distinguish between the emotions that a person feels from the ones Sr. Boliche feels. As it generally happens in the real life relationships between a person and animal, Sr. Boliche imitates whatever it percieves; for example, if the user feels happy, Sr. Boliche will be happy as well. But, there are other kind of emotions that it will not imitate if it perceives it in the user. For example, if the user is angry, the pet will not become angry, it will become scared. These are emotions that Sr. Boliche expresses to empathize with the user's emotions:

- Neutral emotion: Sr. Boliche will also express a neutral state.
- Joy: Sr. Boliche will express joy.
- Surprise: Sr. Boliche will express joy.
- Sadness: Sr. Boliche will express sadness.
- Disgusted: Sr. Boliche will express sadness.
- Anger: Sr. Boliche will express fear.
- Fear: Sr. Boliche will express fear.

Once the system knows which is the emotion to show, the pet must physically express it with its body movements. We have designed a set of emotional movements having into account that our pet is a levitating sphere, so we cannot follow previous research about body language. As we explained in section 2, the way of giving Sr. Boliche an emotional behaviour is by making changes in its motion in terms of direction, speed and acceleration. Our approach is based on calculating the speed and acceleration by making a correlation with the variations that exist in the breath

Table 1: Movement characterisation

Pet's Emotion	Speed	Direction change timer
Neutral	1	1s
Joy	1.5	0.5s
Sadness	0.25	1s
Fear	1.5	0.005s

rhythms when a person feels an emotion. In order to express an emotion, the speed and the acceleration that Sr. Boliche uses to get to a new path in the playground are modified as shown in Table 1. To select these values, we followed Jerath and Beveridge research [17]:

- When Sr. Boliche is feeling neutral,the acceleration and speed remains normal, with no changes.
- The happy movement is more energetic and fast than the normal one, then the speed goes up and so does the acceleration, trying to simulate the higher arousal of that emotion.
- Jerath and Beveridge do not show the sad breath rhythm in their spectrum of emotion but we apply the same rhythm as the meditation one since both states have similar arousal but different valence [31]. The sad movement is slower and less energetic, and that is why the movements will be considerably slower and the change of direction will be similar to that of a normal movement.
- The most characteristic and visual part of fear are shivers. When a person experiences fear or high levels of anxiety, their body activates all the mechanisms to react to a dangerous situation: the heartbeat rises to prepare the body for fighting, the breathing accelerates to oxygenate the body and reflexes increase. This makes the movements faster, and that is why the velocity will be high and the changes in the movement frequent. To simulate fear, the speed is also increased and the acceleration too, that way a shaking effect is generated.

3.2.3 Path Generator. The levitating pet needs to move throughout the limited playground to specific positions depending on what is expected from it. These paths are generated as described for the following actions:

- **Go greet:** this interaction begins when a user comes see Sr. Boliche. It needs to go from home to this user. As a camera is placed to detect the user's placement and emotions, this position is sent from the 'User detection module'. In this way, Sr. Boliche moves from home to the received position where the user is waiting. It is a straight path to the point that is detected by the face detector.
- **Play xylophone:** Sr. Boliche starts to play a tune whenever the user is feeling happy for a long period of time. Thereby, the pet mirrors the happiness of the user and it even expresses its own similar emotion by playing a song. Firstly, the levitating pet needs to move to where the xylophone is placed in the playground; and then, play the melody. The position of the xylophone keys is known by the system and the song is predefined as a subjectively happy tune.
- **Go home:** Sr. Boliche goes back home if it feels alone, i.e. no user is playing with it, or scared, i.e. it has detected anger in the user. In these two cases, as the position of the house is known, the path is calculated from the pet's current position to that final destination.

3.2.4 User detection module: Face position and basic emotions recognition. The tool that is used to detect the face position and facial landmarks is the Vggface library. The emotion detection is done using an already implemented classifier [4] and using a camera which is placed in the top side of the playground. For this project, neutral, happy, surprised, sad, disgusted, angry and afraid emotions have been used. Messages containing the face position and detected emotion are sent via OSC only when they change . In Figure 7 the detection of two different expressions is shown.

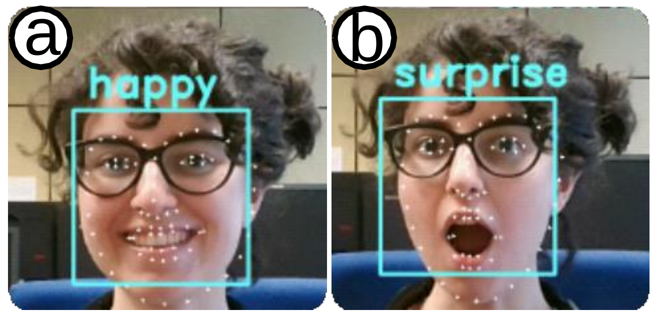

Figure 7: Different facial expressions of a user: a) happy, b) surprise.

3.2.5 Ping-pong ball detection module. To detect the position of the ping-pong ball in the playground, a webcam is located on top of a tripod to take a full image of the playground. To detect the ping-pong ball, a Gaussian filter is applied to reduce the image's noise; afterwards, the image is changed to HSV space. An orange colour mask is created to distinguish it from the rest of the elements this is done with color thresholding in the HSV space. After, the image is eroded and expanded to remove the little spots that could still be present in the shape. We filter the contours by size to select the largest one. From this chosen contour, we fit a circle, and its central point is saved. This central point provides the position in which the ping-pong ball is in the top camera coordinates. A change of basis was used to change from camera coordinates to playground coordinates, the four points that limit the playgroud area where Sr. Boliche is moving are used as reference to achieve this. Then, the function *getPerspectiveTransform* from the *OpenCV* library is used to calculate the matrix for the basis change. For the communication with the simulator, OSC is used. A message 'noBola' is sent when no contours of the ball are detected, and coordinates in playground space are sent when the ball is detected. Figure 8 shows how Sr. Boliche plays with its ping-pong ball.

4 DISCUSSION AND FUTURE WORK

We have designed and developed LevPet which combines affective computing and magnetic levitation to create an artificial levitating

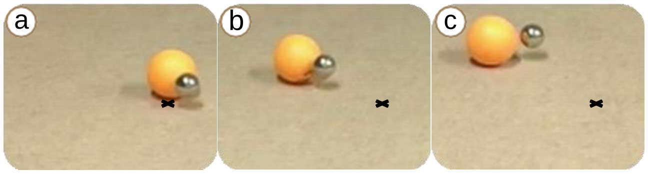

Figure 8: Movement of Sr. Boliche when it plays with the ping-pong ball. The X denotes the starting position of the ping-pong ball.

pet with affective responses and novel ways of moving to express its internal state.

As future work, it would be interesting to improve Sr. Boliche's memory so that it could record past experiences with different users and react to them based on that. For example, if this user has previously treated it aggressively, Sr. Boliche would not greet him; and on the contrary, if the user always plays with it, Sr. Boliche will go greet the user showing happiness. Detecting emotion intensity is another interesting future work, the intensity of each detected emotion, could affect the intensity of the movements of Sr. Boliche.

The emotion detection part can also be improved. The used library has not given the expected results despite being the best of those tested. With better motion recognition, the interaction with Sr. Boliche would be more dynamic and responsive. We could gather some biosignals from the user in a contactless way to improve emotion recognition for example heart rate can be detected in a contactless way with infrared cameras. Along these lines, we can use behaviour analysis to infer how the user is feeling, e.g., amount if time that the user plays with Sr. Boliche, how long it takes between actions, or the time that the user spends observing the pet.

Another feature would be the possibility of using voice commands. The user could give some commands to Sr. Boliche and it would be able to detect the user's emotions through the voice, and react to those emotions as usual. The commands could be: go home, fetch the ball, or do a trick like running around the house.

Regarding the levitation properties of Sr. Boliche, it would be interesting if it could levitate higher. We could add a z-axis for controlling the height, enabling new ways of expressing emotion through changes on levitation height, for example to simulate breathing or sadness by levitating at a low level from the ground. A larger distance from the ground, would also enable Sr. Boliche to perform eye-catching tricks such as passing through hops at different locations.

Interactive functionalities such as playing mini games with the user would enhance the bonding that is created with the pet. Also, the possibility of adding more interactive items for Sr. Boliche is another line, such as putting a zen garden in the playground and making it able to draw in it.

We have not performed structured user studies, yet two type of potential studies were identified during the preliminary tests of LevPet. Firstly, we could test how effective the different movements of Sr. Boliche convey its affective status, we designed these animations following the existing literature, but an elicitation study with more participants and an identification test would be more adequate. The other user study would be to study on how the levitation and affective characteristics improve the LevPet potential in learning or therapy applications. That is, to determine if the learning activities done with LevPet are more effective dues to its unique capabilities of levitation and empathy.

We hope that this first realization of a levitating pet, inspires and motivates other researchers or artists to explore the kind of affective connections that can be established with tangible pets that are categorically different from the usual ones.

ACKNOWLEDGMENTS

This research was funded by the EU Horizon 2020 research and innovation programme under grant agreement No 101017746 TOUCHLESS.

REFERENCES

[1] Bexy Alfonso, Joaquin Taverner, Emilio Vivancos, and Vicente Botti. 2021. From Affect Theoretical Foundations to Computational Models of Intelligent Affective Agents. *Applied Sciences* 11, 22 (2021). https://doi.org/10.3390/app112210874

[2] Minoru Asada. 2015. Development of artificial empathy. *Neuroscience Research* 90 (2015), 41–50. https://doi.org/10.1016/j.neures.2014.12.002 Social Neuroscience.

[3] Tadas Baltrusaitis, Amir Zadeh, Yao Chong Lim, and Louis-Philippe Morency. 2018. OpenFace 2.0: Facial Behavior Analysis Toolkit. In *PROCEEDINGS 2018 13TH IEEE INTERNATIONAL CONFERENCE ON AUTOMATIC FACE & GESTURE RECOGNITION (FG 2018)*. IEEE Comp Soc; IEEE Biometr Council, 59–66. https://doi.org/10.1109/FG.2018.00019 13th IEEE International Conference on Automatic Face & Gesture Recognition (FG), Xi an, PEOPLES R CHINA, MAY 15-19, 2018.

[4] İrem Şahin Berk Sudan. 2020. *8 emotions detected in real-time with 77% accuracy. Used: OpenCV, Python 3, Keras, Data Preprocessing, Deep Learning & Machine learning Techniques*. https://github.com/berksudan/Real-time-Emotion-Detection

[5] Sandra Cano, Carina S. González, Rosa María Gil-Iranzo, and Sergio Albiol-Pérez. 2021. Affective Communication for Socially Assistive Robots (SARs) for Children with Autism Spectrum Disorder: A Systematic Review. *Sensors* 21, 15 (2021). https://doi.org/10.3390/s21155166

[6] Randolph R Cornelius. 1996. *The science of emotion: Research and tradition in the psychology of emotions*. Prentice-Hall, Inc.

[7] Paul Ekman. 1992. An argument for basic emotions. *Cognition and Emotion* 6, 3-4 (1992), 169–200. https://doi.org/10.1080/02699939208411068 arXiv:https://doi.org/10.1080/02699939208411068

[8] P. Ekman and W.V. Friesen. 1978. *Facial action coding system: A technique for the measurement of facial movement*. Consulting Psychologists Press, Palo Alto, CA.

[9] Flyte. 2020. *Buda Ball*. https://flytestore.com/products/levitating-sphere-buda-ball-by-flyte

[10] M Fujita. 2001. AIBO: Toward the era of digital creatures. *INTERNATIONAL JOURNAL OF ROBOTICS RESEARCH* 20, 10 (OCT 2001), 781–794. https://doi.org/10.1177/02783640122068092 9th International Symposium of Robotics Research (ISRR 99), SNOWBIRD, UT, OCT 09-12, 1999.

[11] M Fujita. 2004. On activating human communications with pet-type robot AIBO. *PROCEEDINGS OF THE IEEE* 92, 11 (NOV 2004), 1804–1813. https://doi.org/10.1109/JPROC.2004.835364

[12] Carolina Herrando and Efthymios Constantinides. 2021. Emotional Contagion: A Brief Overview and Future Directions. *Frontiers in Psychology* 12 (2021). https://doi.org/10.3389/fpsyg.2021.712606

[13] Toru Higuchi and Marvin D Troutt. 2004. Dynamic simulation of the supply chain for a short life cycle product—Lessons from the Tamagotchi case. *Computers & Operations Research* 31, 7 (2004), 1097–1114.

[14] Isabelle Hupont, Sandra Baldassarri, and Eva Cerezo. 2013. Facial emotional classification: from a discrete perspective to a continuous emotional space. *Pattern Analysis and Applications* 16, 1 (2013), 41–54.

[15] Pirita Ihamaki and Katriina Heljakka. 2021. Robot Pets as Serious Toys - Activating Social and Emotional Experiences of Elderly People. *INFORMATION SYSTEMS FRONTIERS* (2021). https://doi.org/10.1007/s10796-021-10175-z

[16] Vanguard Industries Inc. 2021. *MOFLIN | An AI Pet Robot with Emotional Capabilities*. https://www.ces.tech/Innovation-Awards/Honorees/2021/Best-Of/M/MOFLIN-An-AI-Pet-Robot-with-Emotional-Capabiliti.aspx

[17] Ravinder Jerath and Connor Beveridge. 2020. Respiratory Rhythm, Autonomic Modulation, and the Spectrum of Emotions: The Future of Emotion Recognition and Modulation. *Frontiers in Psychology* 11 (2020). https://doi.org/10.3389/fpsyg.2020.01980

[18] Jinha Lee, Rehmi Post, and Hiroshi Ishii. 2011. ZeroN: mid-air tangible interaction enabled by computer controlled magnetic levitation. In *Proceedings of the 24th annual ACM symposium on User interface software and technology*. 327–336.

[19] Wei Li, Zhen Zhang, and Aiguo Song. 2021. Physiological-signal-based emotion recognition: An odyssey from methodology to philosophy. *MEASUREMENT* 172 (FEB 2021). https://doi.org/10.1016/j.measurement.2020.108747

[20] Egger Maria, Ley Matthias, and Hanke Sten. 2019. Emotion Recognition from Physiological Signal Analysis: A Review. *ELECTRONIC NOTES IN THEORETICAL COMPUTER SCIENCE* 343 (MAY 4 2019), 35–55. https://doi.org/10.1016/j.entcs.2019.04.009 European Conference on Ambient Intelligence (AmI), Larnaca, CYPRUS, DEC 31, 2018.

[21] Nahal Norouzi. 2020. Augmented Reality Animals: Are They Our Future Companions?. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*. 563–564. https://doi.org/10.1109/VRW50115.2020.00133

[22] Nataša Obradović, Émilie Lagueux, Karine Latulippe, and Véronique Provencher. 2021. Understanding the Benefits, Challenges, and the Role of Pet Ownership in the Daily Lives of Community-Dwelling Older Adults: A Case Study. *Animals* 11, 9 (2021). https://doi.org/10.3390/ani11092628

[23] Andrew Ortony, Gerald L Clore, and Allan Collins. 1990. *The cognitive structure of emotions*. Cambridge university press.

[24] Ana Paiva, Iolanda Leite, Hana Boukricha, and Ipke Wachsmuth. 2017. Empathy in Virtual Agents and Robots: A Survey. *ACM Trans. Interact. Intell. Syst.* 7, 3, Article 11 (sep 2017), 40 pages. https://doi.org/10.1145/2912150

[25] Sandra Petersen, Susan Houston, Huanying Qin, Corey Tague, and Jill Studley. 2017. The Utilization of Robotic Pets in Dementia Care. *JOURNAL OF ALZHEIMERS DISEASE* 55, 2 (2017), 569–574. https://doi.org/10.3233/JAD-160703

[26] Rosalind W. Picard. 1997. *Affective Computing*. MIT Press, Cambridge, MA.

[27] Rosalind W. Picard. 2003. Affective computing: Challenges. *International Journal of HumanComputer Studies* 59 (2003), 2003.

[28] Tony J. Prescott, Ben Mitchinson, Sebastian Conran, Tom Power, and George Bridges. 2018. MiRo: Social Interaction and Cognition in an Animal-like Companion Robot. In *Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction* (Chicago, IL, USA) *(HRI '18)*. Association for Computing Machinery, New York, NY, USA, 41. https://doi.org/10.1145/3173386.3177844

[29] Gisela Pujol-Vázquez, Alessandro N. Vargas, Saleh Mobayen, and Leonardo Acho. 2021. Semi-Active Magnetic Levitation System for Education. *Applied Sciences* 11, 12 (2021). https://doi.org/10.3390/app11125330

[30] Ira J Roseman. 1996. Appraisal determinants of emotions: Constructing a more accurate and comprehensive theory. *Cognition & Emotion* 10, 3 (1996), 241–278.

[31] James Russell. 1980. A Circumplex Model of Affect. *Journal of Personality and Social Psychology* 39 (12 1980), 1161–1178. https://doi.org/10.1037/h0077714

[32] Kristel J Scoresby, Elizabeth B Strand, Zenithson Ng, Kathleen C Brown, Charles Robert Stilz, Kristen Strobel, Cristina S Barroso, and Marcy Souza. 2021. Pet Ownership and Quality of Life: A Systematic Review of the Literature. *Veterinary Sciences* 8, 12 (2021), 332.

[33] Lin Shu, Yang Yu, Wenzhuo Chen, Haoqiang Hua, Qin Li, Jianxiu Jin, and Xiangmin Xu. 2020. Wearable Emotion Recognition Using Heart Rate Data from a Smart Bracelet. *Sensors* 20, 3 (2020). https://doi.org/10.3390/s20030718

[34] Divyanshu Kumar Singh, Sumita Sharma, Jainendra Shukla, and Grace Eden. 2020. Toy, Tutor, Peer, or Pet?: Preliminary Findings from Child-Robot Interactions in a Community School. In *HRI'20: COMPANION OF THE 2020 ACM/IEEE INTERNATIONAL CONFERENCE ON HUMAN-ROBOT INTERACTION*. 325–327. https://doi.org/10.1145/3371382.3378315 15th Annual ACM/IEEE International Conference on Human-Robot Interaction (HRI), Cambridge, ENGLAND, MAR 23-26, 2020.

[35] Yanet Sánchez, Teresa Coma, Antonio Aguelo, and Eva Cerezo. 2019. ABC-EBDI: An affective framework for BDI agents. *Cognitive Systems Research* 58 (2019), 195–216. https://doi.org/10.1016/j.cogsys.2019.07.002

[36] Özge Nilay Yalçın. 2019. *Modeling Empathy in Embodied Conversational Agents*. Ph. D. Dissertation. SIMON FRASER UNIVERSITY, School of Interactive Arts and Technology Faculty of Communication, Art and Technology.

[37] Özge Nilay Yalçın. 2020. Empathy framework for embodied conversational agents. *Cognitive Systems Research* 59 (2020), 123–132. https://doi.org/10.1016/j.cogsys.2019.09.016