

Designing Robots for Well-being: Theoretical Background and Visual Scenes of Affectionate Play with a Small Humanoid Robot

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Abstract

Social well-being, referring to a subjectively perceived long-term state of happiness, life satisfaction, health, and other prosperity afforded by social interactions, is increasingly being employed to rate the success of human social systems. Although short-term changes in well-being can be difficult to measure directly, two important determinants can be assessed: perceived enjoyment and affection from relationships. The current article chronicles our work over several years toward achieving enjoyable and affectionate interactions with robots, with the aim of contributing to the perception of social well-being in interacting persons. Emphasis has been placed on both describing in detail the theoretical basis underlying our work, and relating the story of each of several designs from idea to evaluation in a visual fashion. For the latter, we trace the course of designing four different robotic artifacts intended to further our understanding of how to provide enjoyment, elicit affection, and realize one specific scenario for affectionate play. As a result, by describing (a) how perceived enjoyment and affection contribute to social well-being, and (b) how a small humanoid robot can proactively engage in enjoyable and affectionate play—recognizing people's behavior and leveraging this knowledge—the current article informs the design of companion robots intended to facilitate a perception of social well-being in interacting persons during affectionate play.

Keywords: Human-robot interaction; Well-being; Enjoyment; Affection; Recognizing typical behavior; Small humanoid robot

Introduction

The current article briefly presents, with an emphasis on underlying theory and visual depictions of interactions, some of our work over the course of recent years in designing robotic artifacts intended to facilitate the perception of social well-being in interacting persons [1-5]. Well-being is “far from a unitary concept, and its definition and measurement can vary greatly across research studies” [6]. We use this term in the sense of Diener [7] and Steel et al. [6] to mean a subjectively perceived [7] long-term [6] state of existence characterized by happiness, life satisfaction, health, and other prosperity [8,9]; we use the term “social well-being” to refer to well-being afforded by social experiences [6].

Toward contributing to people's social well-being, we targeted two important factors linked to causing well-being, with the following logic. Because work related to social well-being in robotics is relatively new, we wished to start with small steps, by verifying changes to a short-term variable via simplified experiments. This would be difficult to accomplish by directly measuring well-being, which is perceived over the long term as a result of numerous events and causes [6]; starting with a long-term study would also have been risky due to our lack of knowledge in this area and results would have been slow to obtain; and, in light of the complexity of the phenomenon, the current typical method of measuring well-being by directly asking respondents has been described as “clunky” [10]. For example, if a person interacting with a robot is asked about their well-being, their answer may mainly reflect any pleasant or unpleasant experiences they have had recently and not the interaction with the robot. Therefore, we turned our attention to some important factors associated with causing well-being. The results of a survey conducted by AARP (American Association of Retired Persons) Research & Strategic Analysis with Heart and Mind

Strategies¹ indicated that enjoyment and affection, along with health, were considered by respondents to be the most important dimensions associated with well-being; experiences considered to contribute most highly to well-being included perceiving something funny or unexpected but positive, kissing or hugging a loved one, as well as spending time with and receiving affection from friends or pets [11].

We define our usage of the terms enjoyment and affection. We use the term “enjoyment” as it is used by Vorderer, Klimmt, and Ritterfeld to mean an agreeable response to a stimulus [12] involving pleasure, satisfaction, or gratification [13]. This broad definition encompasses the pleasurable or gratifying experiences distinguished by Seligman [14]. Examples of enjoyable experiences could include playing or spending time on one's hobby, eating a favorite food, or taking a warm shower. Unenjoyable experiences could include wasting time on a boring task, drinking an ill-tasting beverage, or being scalded by hot water. We use the term “affection” as it is used by Floyd [15] to refer to “fond attachment, devotion, or love” [16], whose communication is principally

¹AARP (American Association of Retired Persons) is a large nonprofit organization in the U.S.A. which provides information intended for seniors. Heart + Mind Strategies is a research consultancy which also conducts surveys.

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important in humans. Examples of affectionate experiences could include receiving a hug, seeing someone smile, or being complimented by someone. Unaffectionate experiences could include being struck, seeing someone frown, or being reprimanded. In one sense, enjoyment and affection are not necessarily exclusive. Enjoyable events such as finding a book one wishes to read may not involve affection; but, affectionate behavior such as a back-rub can be enjoyable. The primary distinction here is one of focus: typically enjoyment is derived from an activity or event, whereas affection comes from another person. For example, feeling pleasure from a massage does not mean we necessarily love the masseuse; and, we can feel love toward a family member even when not receiving pleasure from interacting. Therefore we separate these two concepts in the current work. When we propose to seek to elicit enjoyment in a person, this refers to a pleasurable feeling; when we seek to elicit affection, this means we wish a person to like a robot. To further clarify our terminology, we summarize our definitions of well-being, enjoyment, and affection in Table 1.

Our work is based on the premise that well-being is related to enjoyment and affection, but above we have only presented evidence from one survey; therefore we present some additional evidence to support this key conjecture. In psychology Seligman has linked these three constructs, along with engagement, meaning, and accomplishments [17]. Well-being, enjoyment and affection may also be related from a neurochemical perspective. Oxytocin, which contributes to well-being via improved health and wound-healing [18], appears to be related to affection: it can be released during social interactions as a result of affectionate stimuli such as touches [19] and has been called the “love hormone” [20]. Another nonapeptide which contributes similarly to well-being, vasopressin, has also been linked with enjoyment (satisfaction) and affection [21]. Serotonin, thought to contribute to well-being and happiness [22], has been observed to be released, albeit in non-humans, after an enjoyable discovery of food [23] or the experiencing of affection [24]. The World Health Organization also states that well-being can be perceived as a result of addictive drugs such as cocaine [25] which act by heightening the effects of dopamine [26]; the latter neurotransmitter may also be released by enjoyable and affectionate experiences such as food and sex [27]. Endorphins which contribute to perceived well-being by mitigating pain [28] could be produced by stimulating enjoyable experiences such as exercise and music [29] and play a role in affectionate bonding [30]. Thus, various sources of evidence appear to link well-being with enjoyment and affection, suggesting that if the latter can be provided, a positive influence may be expected toward well-being.

Our motivation for seeking to contribute to social well-being stems from reports of important concomitant benefits such as longer life [31] and better health [32]. The importance of well-being as a criterion to maximize has also been pointed out by Helliwell and Putnam, who described this quality as arguably “the ultimate ‘dependent variable’ in

social science” [9], and Seligman and Csikszentmihályi, who referred to it as an important indicator toward making life more fulfilling [33]. Perceived enjoyment has been also linked as an important indicator of intent to use for technological systems, especially those which seek to provide self-fulfilling value and achieve prolonged use [34]. Perceived affection likewise is fundamentally involved in the formation, maintenance, and quality of human relationships [16]. Benefits can also be understood from the neurochemical perspective: for example, oxytocin lowers blood pressure, expedites healing, facilitates bonding, reduces stress effects and anxiety, and improves sleep [19]; serotonin can be used to treat depression, and regulates mood, appetite, and sleep [22]. For these reasons, we wished to contribute to social well-being via enjoyment and affection.

As a focus of our work we selected a scenario of affectionate play in which a small humanoid robot recognizes how people seek to interact and reacts appropriately. Play is useful to investigate because people of all ages engage in such behavior [35]. A humanoid robot was chosen because it offers an interface which is familiar to people. A small robot was selected because a childlike appearance may elicit affection [36], and because we expect such a size will invite people to pick up a robot and play with it from an intimate distance [37]. The capability to recognize people’s behavior was desired because such social intelligence can contribute to enjoyment [38].

Thus, our goal was to allow a small humanoid robot to identify, recognize, and react to playful and affectionate behavior to elicit enjoyment and affection, on the premise that this would contribute to well-being. Challenge resulted from the high complexity of human behavior. Our approach involved deriving knowledge from observing people’s interactions with a number of new prototypes and asking people to evaluate and comment on the interactions. Medium to low-fidelity prototypes were used to allow people to actually interact with a functioning artifact, while avoiding tunnel vision which can result if a high-fidelity platform is selected which may not be appropriate for the requirements of an interaction [39].

This approach allowed us to fulfill a portion of our goal to identify behavior, how to recognize it, and how such results may be used. With this knowledge, designers can construct robots which can engage in affectionate play, toward contributing to people’s well-being. Subsequent sections are structured as follows. The next sections compare our work to some related studies and detail our objectives. Then we describe providing enjoyment and affection through touch-based play with small humanoid robots, along with one novel scenario for affectionate play. We conclude by briefly describing limitations and some future work.

Related Work

The scenario addressed in the current article is mostly novel; previous work in robotics related to well-being has focused mostly on preliminary conceptualization, and health care, and less on eliciting enjoyment and affection. In the former case, although robots capable of recognizing behavior and responding in a way conducive to well-being were foreseen decades ago in popular media (e.g., Astro Boy, Doraemon, Star Wars, and Short Circuit), Picard seems to have first articulated the intuition that it could be beneficial if artifacts were capable of recognizing and expressing emotional cues [40]. McGee felt this should also apply to haptic devices [41]. Fong and Nourbakhsh asserted that intelligent robots will be required to reduce human workload and fatigue [42]. And, Reddy stated that robotic applications

Term	Definition	Sources
Social well-being	a subjectively perceived long-term state of happiness, life satisfaction, health, and other prosperity afforded by social interactions, which may result from perceived enjoyment and affection	[6-9,11]
Enjoyment	an agreeable response to a stimulus involving pleasure, satisfaction, or gratification	[12-13]
Affection	fond attachment, devotion, or love, whose communication is principally important in humans	[15-16]

Table 1: Some important definitions in regard to providing social well-being via affectionate play with a robot.

could “profoundly impact the well being (sic) of our society” [43]. These studies indicated a demand for robots which can contribute to various facets of well-being, which concurs with our objective, but did not investigate how to provide well-being through its principal determinants. Many other studies have sought to provide well-being through health care. For example, Graf and colleagues constructed in Care-O-bot 3 a capability to offer drinks to prevent dehydration [44]. Kawamoto et al. also described a robotic suit, HAL, built to allow disabled individuals to regain mobility [45]. RIBA was designed to lift and move patients, a task which can be difficult for health care workers [46]. Such studies focused on the important aspect of facilitating people’s physical health toward providing well-being, but did not address how to provide social well-being through enjoyment and affection.

Some work has also addressed providing well-being through enjoyment. Fasola and Matarić described enjoyable motion-based interactions involving a person exercising with an autonomous humanoid robot [47]. Takeda, Kosuge and Hirata created an interaction incorporating movement and touch in which a humanoid robot can engage in ballroom dancing with people [48]. Hansen, Bak and Risager designed an enjoyable interaction in which persons moved to chase and touch a humanoid robot [49]. Müller, Lupashin and D’Andrea furthermore showed how flying robots with excellent mobility could provide enjoyment in ball games [50]. These studies described several enjoyable motion-based haptic scenarios, but did not indicate how we could provide enjoyment in a playful interaction with a small humanoid robot when a person is free to choose how they wish to play.

Toward providing well-being through affection, some work has focused on how to design devices which can convey affection to loved ones over long distances, as has also been described in an overview by Saadatian and colleagues [51]. DiSalvo et al. first designed a tele-operated robot to transmit affectionate hugs to a remote person [52]. Teh et al. also built a hug conveying system for the case of parents communicating with a child [53]. Samani et al. constructed a device to transmit not only hugs but also kisses [54,55]. In addition to examining possibilities for affectionate tele-communication, Samani et al. also proposed some important principles for an affectionate interaction with an autonomous robot based on the literature in human-human interaction [56]. These related works, while investigating how affection can be transferred through artifacts and suggesting a model for a robot’s artificial intelligence in affectionate interactions, did not reveal, for example, how people would seek to show affection to a small humanoid robot.

Thus, related studies provided some intuitive knowledge, but did not indicate how a person would seek to interact with a robot, how such behavior could be recognized, or how the results could be used to provide enjoyment and affection toward contributing to well-being.

Target Scenario

Here we discuss the target scenario and the overall context in more detail. It should be emphasized that these are our own ideas and not derived from previous work. We consider there to be four important factors involved in seeking to provide well-being through an interaction with a robot: the basic topic of an undertaking, the quality or qualities being evaluated, the type of interaction, and the nature of the robot(s) and person(s) interacting. Work can involve increasing a robot’s capability to be useful by performing specific tasks; reducing inconvenience (e.g., improving a robot’s power sources to allow

human-robot interaction to occur more easily); or serve a self-fulfilling purpose such as play. Qualities which can be evaluated include well-being directly, health, enjoyment, and affection. Basic properties of an interaction include the number of interactants (multiple or dyadic), the naturalness of the surroundings (a controlled environment or field experiment), and the provision or absence of objects. The robot or robots used may be of various sizes (small, medium, or large) and shapes (humanoid or non-humanoid), possess various sensory-behavioral capabilities (touch, sound, or vision), and feature various degrees of lifelikeness (a person must seek out the robot; or the robot has some capability to approach or accompany humans). Interacting persons may vary in age (children, adults, or elderly), nationality (Japanese or other), motivation (interact for one or more reasons), and posture (sitting or standing). In our target scenario, we focus on realizing a self-fulfilling purpose, affectionate play; enjoyment and affection as qualities to measure; a dyadic interaction in a controlled environment with no objects provided; a small humanoid robot with touch recognition capability and some lifelike mobility; and adult Japanese interacting to play or for other reasons while sitting or standing. To clarify, we also present as an example a narrative involving a persona, or fictional user.

At first, after moving far from her family and friends, Cleo found she wasn’t feeling too well; she was sighing more than usual, gained weight, and had trouble sleeping. For fun, she decided to buy a companion robot, which she had always wanted to try. Cleo didn’t need a large robot to perform physical tasks and her room was filled with various belongings, so she ordered a small flying robot which she thought would best fit her lifestyle. As soon as she took it out of its box, her new buddy began to bounce excitedly up and down like a ball, which made her laugh. She decided then that the robot would be known as Golfball, although it didn’t so much look like one; its wide eyes, cute large face, and small arms reminded her of a small child, or maybe a little on the huldufólk or elves in the stories her Grandma used to tell her when she was young. That’s maybe why Cleo doesn’t expect Golfball to do anything in particular; she just likes having it around. Sometimes she’s surprised to realize that she has been playing with Golfball without even thinking about it. Like the other day, Golfball came over and it really took her mind off some little problem she had been worrying about. Cleo likes to play with Golfball when she’s sitting on the couch sometimes in the evenings and on the weekends. Sometimes for fun she picks up Golfball and suddenly raises it up high, which Golfball seems to like because it laughs and begs her to do it again. Other times, Cleo likes to just hold Golfball on her lap and stroke it, which makes her feel relaxed and drowsy because Golfball is soft and can even become warm. Another thing that’s fun is that Golfball can recognize some simple gestures and words; Cleo can wave the robot over, and tell it stop, although Golfball sometimes ignores the latter command when it’s excited. In the sense that Cleo can talk about her robot with other people, she imagines it must be like owning a pet. But she’s glad her little friend does not get lonely like an animal might, when she’s not at home or too busy to play. At the end of the day, Cleo now feels better because of her little robot companion.

This scenario suggests some important problems which required solutions:

- 1) A small robot should be able to recognize when its body is moved by a person during play (“motion-based play”) and itself behave in an enjoyable way
- 2) A robot should be able to recognize affectionate touches and also elicit a person’s liking through its own affectionate behavior, which could include thermal responses like becoming warm

3) A robot should be able to recognize some visual and aural cues and behave appropriately

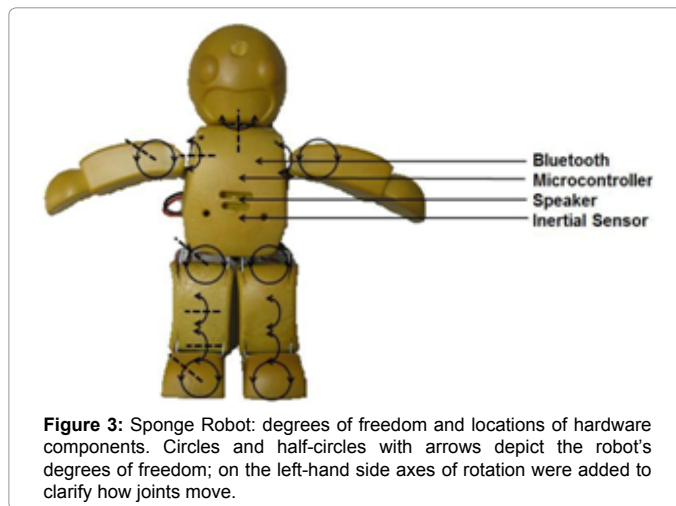
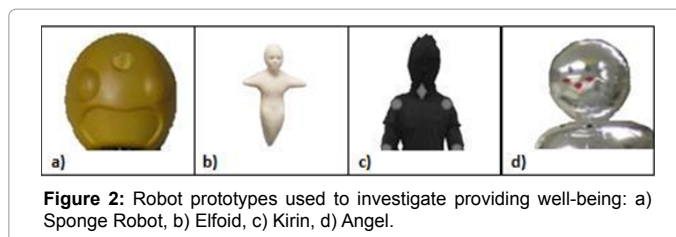
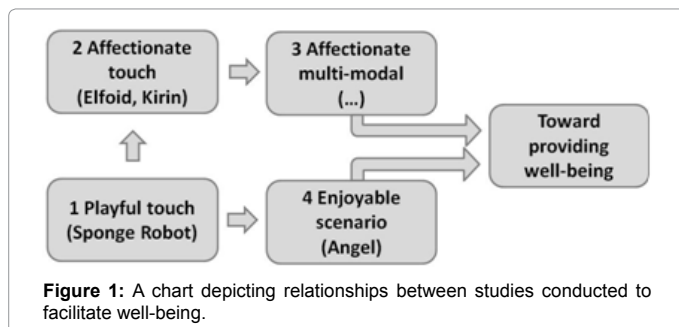
4) A robot which uses flight capability to be able to approach a person in a difficult real environment should be able to fly safely and appropriately

Problem 1 is dealt with in the next section and Problem 2 is partially addressed in the section after that. Part of Problem 2 and Problem 3 have been addressed in work which we have completed but not yet published; this will not be discussed in the current article. Problem 4 is addressed in the second-to-last section.

We describe our approach to solve these problems in detail as follows. To develop the capability to recognize motion-based play, we observed people interacting with a robot prototype, acquired data, and built a recognition system. To identify how a robot can behave in an enjoyable way we again observed interactions, interviewed people to find out why some interactions were unenjoyable, proposed guidelines, and verified that the guidelines provide enjoyment. By providing enjoyment, we expect a robot can contribute to well-being, because these qualities are linked. To recognize affectionate touches, we observed how people touch two different humanoid robot forms for various reasons including but not restricted to play and asked them to describe the meaning of their behavior; then as before, we acquired data and built a recognition system. This knowledge enabled us to investigate how to elicit affection, toward contributing to people's well-being; however we do not discuss here the work we have completed toward eliciting affection, and recognizing affectionate cues in touch, vision, and sound, which has not yet been published.

To study how flight can be used by a companion robot around humans, we built a prototype, proposed theory in proxemics and kinesics, and verified our proposals using the Think Aloud Method and animation sequences depicting human-robot interaction; the Think Aloud Method was used because we did not know categories to check and animations were used because our prototype could not perform a direct up-down motion. This project, by describing how a companion robot could approach and accompany people with flight, helps to enable a scenario for an affectionate play in which a robot is not merely a toy on a shelf but can appear to have a life of its own; by facilitating the eliciting of enjoyment and affection, we expect also a positive effect on well-being, which is linked to enjoyment and affection.

As noted above, overcoming these problems represents only a first step within one specific scenario toward realizing interactions which provide well-being. Many other problems exist and we also expect new ones to emerge. Figures 1-2 depict the studies we conducted and introduce our robot prototypes.



Providing Enjoyment Through Motion-based Play (Sponge Robot)

The work we conducted on the first topic has been described previously in several papers [1-2,5]. The concept for this first stage of our work involved combining several ideas:

- Enjoyment can be provided via play.
- Play often involves moving an artifact and obtaining feedback from its motion.
- People will move a small held humanoid robot.
- Such gestures can be detected by an inertial sensor inside the robot.

The first point is intuitive and supported by the literature (e.g., [35]). The second point is suggested by the large number of toys which involve motion-based play, including balls, dolls, swings, stuffed animals, teeter-totters, ropes, yo-yos, discs, building bricks, hoops, tops, puzzle pieces, and sculpting clay. The third point can be expected from how people interact with babies and small humanoid toys such as dolls. The fourth point is our conjecture, which we validated in the steps described below. This project was necessary because as described in the preceding sections, enjoyment is an important determinant of well-being, and previous research did not indicate how it could be provided by a robot; in terms of the user case example, this knowledge will allow a robot such as Golfball to provide enjoyment to a person such as Cleo when she tries to play with it.

This logic motivated the preparation of the robot shown in Figure 3. Sponge Robot is a small light humanoid robot which possesses 13 degrees of freedom (four in each leg, two in each arm, and one in its head), a speaker located in its abdomen, an inertial sensor (three-axis accelerometer, two-axis gyro), a Bluetooth module for sending data to and receiving commands from an external computer, a battery (the robot is completely wireless), and a soft outer covering made



Figure 4: Typical “full-body” gestures performed by a person during play: a) inspecting a robot, b) moving a robot up or down, c) laying a robot down, d) raising a robot upright.

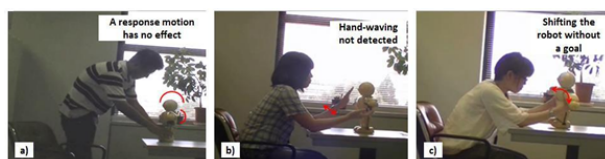


Figure 5: Failures in interactions: a) the robot’s motions are perceived as meaningless, b) the robot does not recognize a person’s behavior, c) a person’s behavior is without a goal.

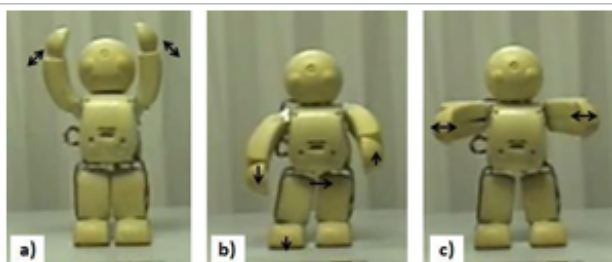


Figure 6: Some suggestions performed by our robot: a) “Raise me up in the air!” b) “I want to walk!”, c) “How about a hug?”.



Figure 7: Some moments participants reported to have enjoyed: a) raising the robot high in the air like an infant, b) watching the robot perform push-ups in an attempt to stand, c) helping the robot to walk across a desk.

of urethane. During play, the soft molded urethane covering entices motion-based play, which is measured at 12Hz by the inertial sensor and sent wirelessly to the external computer. There, the raw data are processed to recognize a person’s behavior and plan how the robot should behave. Then instructions are sent back to Sponge Robot to perform motions and also play back Adaptive Delta Pulse Code Modulation (ADPCM) sounds. We expected Sponge Robot to be well-suited to the designated motion-based play scenario due to its small humanoid form (people are familiar with playing with small children), its soft covering, its typical number of degrees of freedom for a small humanoid robot allowing various movements, and its inertial sensor which can detect how its body is moved.

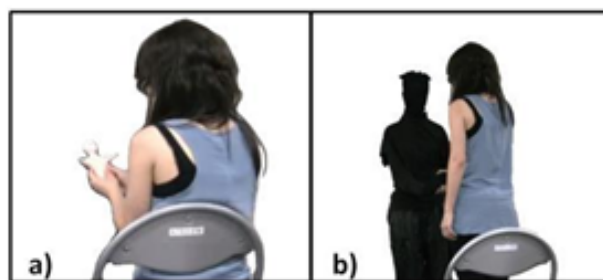


Figure 8: Participants touched two humanoid robot forms for various typical reasons such as greeting or thanking and assessed how much affection a robot should feel for each touch: (a) sitting to touch Elfoid and (b) standing to touch Kirin.

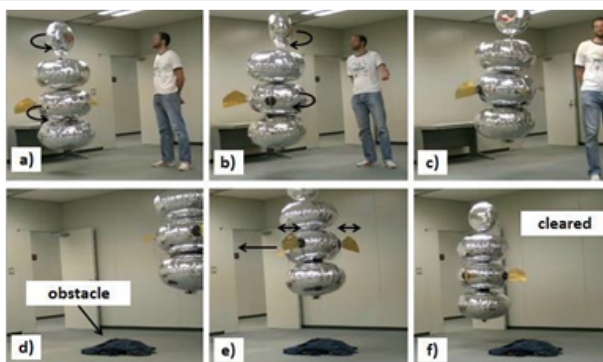


Figure 9: Angel demonstrates some capabilities: a-c) communicating, d-f) flying over an obstacle. In detail: a) Angel turns its head and body to face a person at the start of an interaction, indicating its awareness of the person, b) a person rotates his body forward and points forward and the robot again rotates its head and body forward, indicating its awareness of the indicated direction, c) the human’s intent and the robot’s recognition have been successfully communicated and the pair is ready to move forward. d) Angel moves forward toward an obstacle lying on the floor, e) Angel’s wings flap, driving the robot forward over the obstacle, f) Angel has successfully cleared the obstacle.

To identify how people seek to play, we employed an observational approach, handing the robot to 17 young adult Japanese. The play environment was set up such that each participant was seated in a chair in front of a desk, but could stand and move about as desired. We focused on the fundamental scenario in which the robot did not move, allowing participants to themselves decide how to play, and no objects or toys were provided. As a result, we observed 13 typical gestures which were performed by more than one participant, some of which are depicted in Figure 4: inspecting the robot from various angles was most frequent, followed by vertical movements including picking up the robot, laying it in a horizontal position, and restoring it to a standing orientation. We found we could classify these gestures with an average accuracy of 77% by first calculating 19 statistical features (including means, standard deviations, and changes from first to last value for individual inertial data axes) using short windows of several seconds of inertial data, and then inputting the features to a set of Support Vector Machines (SVMs) for recognition. Empirically determined thresholds were used to ensure reliable online output; to detect interaction, we also used some codebook vectors representing orientations, along with thresholds representing noise due to the robot’s own motions.

In the spirit of a case-based approach [57], we created an initial

design by adapting intuitive knowledge from existing products: we incorporated a simple turn-based strategy and behavior appropriate for the robot's infant-like appearance. To revise the design, we observed some initial interactions and sought to find common failing points. During the initial interactions, participants sat at a desk but could stand, walk, or lie down as they desired. As a result, three failure categories were revealed, as shown in Figure 5: (a) a participant disregarded a motion whose meaning was not understood, (b) the robot could not recognize a person's behavior (hand-waving), and (c), a person tilted the robot without an objective. We queried participants regarding the causes of failures and, based on this, compiled a list of heuristic guidelines relating to meaningful motions, rewarding responses, inspiring suggestions, and fulfilling instructions. Figure 6 shows some suggestion motions: (a) our robot raises and wiggles its arms to imply that a person should lift it high; (b) the robot shifts its weight, peddles its arms, and shuffles forward slightly as if walking; and (c) the robot exhibits a desire to be hugged.

Some guidelines for our robot's responses and suggestions were not clear. Therefore, a user study with 20 participants (age: $M = 20.3$ years, $SD = 2.1$) was conducted. As before, participants sat at a desk with the robot in front of them, but were free to stand, walk, lie down, and play as they wished. Each participant played with and evaluated four different versions of the robot using maximal or progressively larger responses and quickly shifting suggestions or suggestions which were repeated several times. As a result, it was revealed that, within the designated context, suggestions from a robot should be repeated several times to convey clear goals for interacting and provide enjoyment; progressive responses could be used to increase perceived variety but were not perceived as more enjoyable than maximal responses. This latter result appears to be in-line with a Bates' proposal that exaggeration is beneficial when an agent's output information is restricted [58]. Participants also reported to have felt enjoyment from playing in various ways, and causing the robot to be "happy". Figure 7 depicts some moments which participants described as enjoyable: raising the robot high, watching the robot do pushups, and helping the robot to walk.

The first study allowed us to complete the guidelines; a second user study was required to confirm that using these guidelines allowed for more enjoyment to be elicited. Therefore, we conducted a second user study with 21 participants (age: $M = 21.8$ years, $SD = 3.0$). As before, users sat at a desk with the robot in front of them, but were free to move about as they wished. Each user played with two versions of our robot: our initial version and revised version. As a result, we confirmed that the completed design was perceived as more enjoyable than our initial one. In summary, as a result of this project, we identified some typical motion-based play behavior, how to recognize it, and a number of guidelines (described both above and in the papers referred to above) which can help to provide enjoyment to people; because enjoyment is linked with well-being, we expect these guidelines will also contribute to the well-being of interacting persons.

Eliciting Affection during Play (Elfoid and Kirin)

Touches do not always involve moving a robot's full body. Robots should be capable of recognizing various touches and using this knowledge to also elicit affection in a person. In the current article, we only discuss our work on this problem dealing with the recognition aspect, which has been previously published [3]. The concept for the second stage of our work also involved combining several ideas:

- People will perform a number of typical touches toward a small humanoid robot.
- A person's attitude can be inferred by recognizing touches.
- Because touches are both felt and seen, they can be recognized by touch and vision sensors.

The first and second points are our conjectures, based on our expectation that human behavior is not random; we describe below how we verified these expectations. The third point we feel is evident by virtue of the phenomenon: any person capable of feeling and seeing knows that touches can be felt and seen. This project was necessary because as described in the preceding sections, affection is an important determinant of well-being, and previous research did not indicate how a humanoid robot could engage in an affectionate interaction with a human; in terms of the user case example, this will allow a robot such as Golfball to react to affectionate touches by a person such as Cleo when she tries to play with it.

Based on this logic, we prepared two humanoid robot "forms" (mock-ups), Elfoid and Kirin. Elfoid is a small (20cm long) hollow plastic doll with arms and a face. Kirin is a large (168cm, between average male and female human height) mannequin-like form with articulated limbs (eight joints in its head, arms and body, six of which can be rotated in any direction). Elfoid and Kirin were selected for this study due to the following logic. By using two forms instead of one, we intended to identify behavior not dependent on any one robot appearance to select as our recognition target. By using highly robust minimal prototypes, we intended to allow participants to perform any behavior without feeling apprehension that they might break a robot.

Thus, we again utilized an observational approach to determine how people seek to convey affection via touch. We asked 21 participants (age: $M = 24.1$ years, $SD = 4.4$) to interact with the two humanoid forms for typical reasons, such as greeting, thanking, or seeking to play. Participants sat to touch Elfoid and stood to touch Kirin, as is shown in Figure 8. After each touch, participants described how much affection the robot should feel using a seven-point scale (one conveying dislike, seven conveying liking). As a result, we identified 20 typical touches performed by more than one person toward the two humanoid robot forms. Kissing and hugging were perceived as highly affectionate by participants; patting, checking and controlling as not conveying much affection; and rough and minimal touching (slapping or pushing vs. touching very lightly and quickly) as unaffectionate.

We found we could identify these touches with an accuracy of 91% using a system which used both touch and vision sensors to acquire raw data, statistical features calculated from a short window of this raw data (pre-processing some vision features for translation invariance), and SVMs to classify each set of features. Such an approach of first calculating features from raw data is common when using SVMs. The resulting knowledge—what to recognize and how to recognize it—allows humanoid robots to engage in affectionate touch-based interactions with people toward eliciting affection and providing well-being, because affection has been linked with well-being.

A Scenario for Affectionate Play (Angel)

In order to seem "alive" and worthy of participating in affectionate interactions, we felt that a companion robot should not be confined to waiting for a human to come and touch it; instead, a robot should be capable of approaching and accompanying people even in environments featuring stairs, fences, or objects lying on the ground.

Toward this, we conducted work which has been presented previously [4]. Our logic was as follows:

- One possible solution for achieving both excellent communication capability and mobility involves combining a humanoid form with flight capability.
- Some related challenges involve how to create a suitable embodiment, how such a robot should move around people, and how people will perceive the significance of a robot's motion.

The first point is obvious because (1) people are familiar with communicating with humanoid forms (other people), which means they do not have to waste time learning how to use a new interface, and (2) obstacles such as magazines, clothing, or tables which may present a problem for legged or wheeled robots can be flown over. The second point represents our conjecture. This project was conducted because robots are currently restricted in terms of communication and mobility, which should be improved to facilitate affectionate play; in terms of the user case example, this will allow a robot such as Golfball to approach a person such as Cleo and show emotions such as excitement via its flight.

We determined that a safe proof-of-concept platform, Angel, could be constructed using a lighter-than-air approach; helium balloons were combined, situating heavy components near the robot's base for stability, and a pair of flapping wings afforded flight. Figure 9 shows some interactive and mobile capabilities we anticipate for robots such as Angel; in the top half of the figure, Angel turns first its head and then its body to interact, then rotates back to accompany a user; in the bottom half, Angel flies over a simple obstacle, a pile of shirts lying on the ground. We chose this lighter-than-air implementation for Angel to avoid erratic fast flight which could be dangerous; the wings make it clear where Angel is moving and also were intended to appear new and enjoyable, while reminding of the metaphor of an affectionate angelic being.

To gain insight into how people will perceive a humanoid robot's flight, we conducted a user study with 10 young adult participants (age: $M = 29.4$ years, $SD = 7.8$). We used the Think Aloud Method to avoid having to make assumptions about how participants will perceive a humanoid robot flying, and several animated clips, which presented a generic robot-like appearance and allowed us to test all types of motion (Angel has a distinctive appearance and could not ascend/descend in place due to our implementation). The animations were structured around our predictions and shown on a computer screen. During sessions, participants sat at a desk to watch the animations and freely spoke their thoughts, which were transcribed and coded. Participants' comments suggested a humanoid robot should fly near head height when interacting but not too near to a person's head or feet; that rotations could indicate agreement and playfulness; that a standing posture was perceived as neutral; and that high velocity and acceleration could convey arousal. We expect the resulting knowledge—how a humanoid robot could proactively approach a person using flight—will help to facilitate affectionate play and thus contribute to people's social well-being.

Discussion

This article chronicled our published work in recent years toward designing robots capable of supporting people's perceived social well-being, emphasizing underlying theoretical background and visual depiction of the interactions. Through the studies described, we found:

- Typical playful touches performed during motion-based play, how to recognize them, and a set of guidelines for structuring a robot's behavior in an enjoyable way based on recognition input, which emphasizes persistent suggestions.
- Typical affectionate touches and how to recognize them.
- That flight offers one way to facilitate affectionate play by providing a robot with excellent mobility to proactively seek interactions; a robot should avoid flying near a person's head or feet and can express emotions in a new way using its flight motions.

In our studies, we used a number of different types of robotic prototypes: Sponge Robot, which was capable of performing many motions and recognizing how its body was moved; Elfoid and Kirin which were highly robust and different in appearance so as to be conducive to eliciting various touches; and Angel which was designed to fly slowly and safely in proximity to people toward approaching people to proactively initiate affectionate play interactions. We plan to integrate these findings to produce a robot which can respond in an enjoyable and affectionate way to people's typical proprioceptive gestures, touches, and visual and aural signals; and also proactively seek to interact. Although we feel this will bring us a step closer to realizing some interactions which can provide well-being, there is still much knowledge missing in relation to the general problem.

Limitations : First, restrictions must be noted with regard to our platforms, target demographic (young adult Japanese), and approach. Using robots of different sizes and shapes, and other modalities, will expose new problems. Also, some facets of people's behavior are culturally specific, such as so-called "emblem" gestures which represent words. Frequent use was made of subjective measures; results for the animation clips depend on the appearances of the interactants; and, we focused on investigating a dyadic interaction between willing and capable partners, which will not always be the case encountered outside the laboratory.

Future Work : Also, we must note that a vast amount of work remains to be done on this broad but important topic. Progress must be made on a number of fronts toward reducing practical difficulties posed by incorporating robots in everyday environments; this includes not only more convenient power sources (currently batteries may require frequent recharging by a human, lose their charge over time, and can be expensive), but also increased safety, dexterity, mobility, and awareness of when a robot is "in someone's way". Likewise, a capability to reliably perform useful tasks which people do not wish to do or which robots are best suited to accomplish will be important; a number of crucial tasks will involve providing health and care toward individuals including, but not confined to, the elderly and disabled. Within the larger context of our own work, providing enjoyment and affection, we should investigate recognizing signs of elicited enjoyment or affection in people toward adapting a robot's behavior instead of relying on subjective measurements; visual, aural, or other signs such as smiling, laughter, or certain patterns of brain activity could be useful to detect. The capability for a robot to reciprocate touches such as hugs or stroking in a human-like fashion will be a challenging goal but worthwhile for providing affection. Future work will also entail investigating behavior directed toward non-humanoid robots including animal-like or abstractly shaped robots. Revealing how people will seek to typically play with a robot, or express and receive affection, using objects will further expand the range of possible interactions. Another crucial aspect will involve tackling the difficult challenge of realizing long-term interactions which contribute to well-

being. With these goals accomplished, we believe companion robots will be able to make a strong and highly meaningful contribution to people's perceived social well-being.

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