When Can I Get a Robot for my Home?: A Constrained Design Approach to Feasible, Deployable Companion Robots

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Abstract— **Research in personal care and companion robotics has successfully demonstrated potential for social robots to support people and improve general wellness. Despite this, we still have not reached even modest adoption and deployment of actual robots in use, in people's homes or in care centers. We posit that this problem – that research successes have not translated to domestic robots – results from a predominant design approach in social human-robot interaction: research often studies idealized social interaction with near-perfect simulated robot behaviors (e.g., via Wizard of Oz). However, without the sophisticated teams and infrastructure needed for this research, the behaviors are often not feasible in dynamic home environments. We propose an alternate design approach that works within the practical constraints of currently feasible and deployable robotic technology and present a set of design strategies that can be helpful in creating these robots.**

I. Introduction

Companion robots are being increasingly explored as a means of helping improve people's wellbeing. Social care robots can serve as aids to help alleviate a range of challenges including loneliness and anxiety [1], [2]. Likewise, they can provide benefits for people with dementia or cognitive impairments [3]. Although sparse, some early results have shown how robots may successfully serve as people's companions [4], [5]. However, despite ongoing success in research, we still do not see mass adoption or deployment of successful social companion robots. This is highlighted by several commercial robots that have not been successful, perhaps due to their design, the unrealistic expectations of their functionality (e.g., as discussed in [6]), or a lack of understanding of what these social robots can offer to people [7]. We offer a brief discussion on this problem and present a design approach for building feasible, deployable domestic robots.

One source of this problem is that we see is that much of social robotics research happens in laboratory settings with sessions lasting typically one hour, or in highly supervised environments, such as short interaction sessions in care homes. This focus has emerged in-part due to the highly complex nature of many social interactions being researched and the experimental nature of the robots being used, often requiring a team of specialists to manage the robot in real time (e.g., [8], [9]). In many cases, this involves the "Wizard of Oz" technique [10], where a researcher secretly remotely-controls a robot that participants believe is autonomous (e.g., [11], [12]). In reality, participants are interacting with another person through the robot proxy, and not with a social robot; this introduces fundamental changes in the interaction such as the number and nature of robot errors [11]. With this approach stand-alone technical implementation is typically left as future work; however, the complex social behavior being studied may not be feasible in the near future, or indeed, perhaps ever. However, if our goal is to deploy these companion robots unsupervised into dynamic environments, we need to consider stepping away from these complex studies, and instead develop robot prototypes and behaviors that can be easily deployed for in-situ research of adoption and use in domestic environments.

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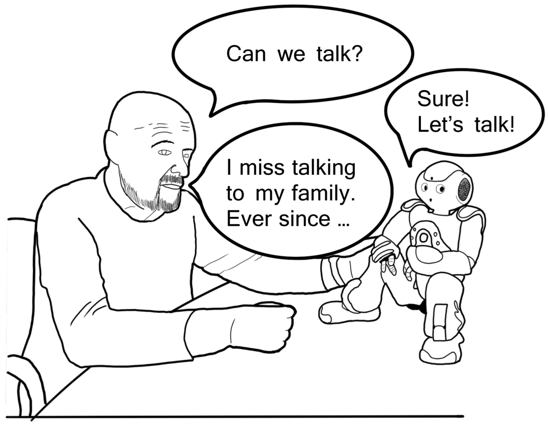

Figure 1. We followed our constrained design approach to create a companion robot that a person can talk to and it will listen to them. This may promote self-reflection and provide an analog to companionship, which we expect to decrease feelings of loneliness.

We advocate for a constrained design approach to creating domestic companion robots, where we limit ourselves to considering behaviors that are currently feasible to implement. Instead of asking big-picture questions of what might someday be possible with social robots, we instead ask "what can we create, right now, with current technology?". Designing within this constraint will lead to robots that are deployable and robust for domestic environments, enabling us to focus more on effective and supportive designs for people, and less on solving difficult technical problems.

This paper presents a set of strategies to create companion robots that can be both feasible and deployable while still being capable of supporting the user. These techniques and methods are then used to analyze currently available robots as well as our robots currently in development.

II. Related Work

Most research on social robot design approaches explores social mechanics – how a robot communicates with a person using different techniques (e.g., explained in [13]) – and proposes frameworks or guidelines for how to use them. For example, one such framework focuses on how to design the physical form of the robot, its ability to have human-like dialog and manage failures, and development of consistent behavior that follows social norms [14]. A more recent review of social robotics literature presented a set of guidelines for social robots to partake in successful long-term interaction [15]. Researchers highlighted several aspects of robot design that should be considered, such as matching the appearance of the robot to its purpose, giving the robot basic and incremental behaviors, having the robot understand and respond to emotions, and providing it with social memory [15]. However, many of these guidelines can only be implemented in controlled laboratory settings, due to their complexity and unfeasibility without researcher supervision. For example, any guidelines requiring social abilities (e.g., [14], [16]) are not yet possible with current technology [17].

We therefore propose an approach in which robots are designed considering currently-possible capabilities. This approach is supported by research on transparent design – highlighting what a robot can and cannot do – which provides many benefits in social robot-interaction [18]. Companion robots such as Maah [19] – which looks like a piece of furniture to not encourage unrealistic expectations – showcase the value of this approach, setting appropriate expectations to increase acceptance [20]. we advocate for designing robot behaviors that are currently possible in the real world (e.g., homes), without the need of supervision or intervention. In this paper we propose our constrained-design approach strategies, which can guide the design of successful robots for real-world use.

III. Constrained Design Strategies for Feasible Deployable Robots

We present a novel human-robot interaction design approach, focusing on simple robot behaviors that are feasible and deployable with current technologies, with the hope of more successful in-home adoption. In this section, we provide several strategies aimed at creating feasible social and companion robot behaviors. The ultimate goal is to aid researchers in creating companion robots that can be deployed into homes, without supervision, and still be able to benefit the individuals.

A. Aim for low expectations of robotic ability

When people are introduced to advanced-looking social robots that promise a wide variety of complex functionalities, we can expect them to develop unrealistically high expectations that might lead to disappointment or abandonment if these expectations are not fulfilled [21]. We advocate for avoiding the common situation where a companion robot overpromises and underdelivers [4], [22]. Instead, users should be purposely led to believe that robots can do things actually feasible with current technology. We propose doing this by setting end-users expectations low and have robotic physical designs that match the robot's capabilities.

Research has shown that expectations impact user's acceptance of a robot [22], [23]. If these expectations are too high, it can lead to disappointment when the robot fails to fulfill them, on the other hand, if expectations are low and the robot overdelivers, people may think of the robot more positively [23]. Since the robot's physical design impacts expectations, designers and programmers alike should consider avoiding formfactors that might suggest abilities or interaction capabilities that are not possible with the robot. These simple designs and the act of setting low expectations could lead to people more widely accepting and adopting companion robots.

B. Focus on simple social interactions

Robots often do not require complex social behaviors to achieve their interaction goals. Although humans have tremendous social ability, mimicking or understanding human behavior tends to be difficult and error prone for robots. This is due to small social nuances, that are hard to replicate, such as the ability to understand social context, conversational timing, and reading facial expressions. To avoid issues with complex nuances, we propose focusing on simple robotic social interactions. By simplifying the robot's social abilities to the bare necessities for the desired outcome (e.g., simply smiling to appear friendly), we can create feasible interactions between the robot and the person without the need for intervention, supervision or faking the behaviors. These behaviors need to be transparent and be able to still convey the robot's intentions and emotions. Research shows that people are able to understand these intentions even if they are conveyed in a simple fashion (e.g., basic movements of seal-like PARO robot [24] or simple body language from humanoids Pepper and NAO [25], [26]). We therefore encourage researchers to consider what social interaction features are actually necessary for the task at hand, and use simple interactions instead of attempting to create a robot that behaves as a human.

C. Use static, pre-programmed behaviors

The more sophisticated a behavior is in how it is required to react to the interaction, the more it may be required to interpret human input, including speech, facial expressions, touch, or context. We propose to employ static, pre-programmed behaviors whenever possible to minimize the potential for robot errors. These errors can lower trust and acceptance towards the robot [27]–[29]. To avoid this, we advocate for reducing or eliminating the need for the robot to interpret and adapt by steering away from generating behaviors based on varying input that can yield a vast amount of variable behaviors. Instead, by using simple, pre-programmed, static behaviors that have the same output regardless of the subtle changes in the input, we can fully test our behaviors. This can enable us to have more successful companion robots outside of controlled environments as we reduce the likelihood of inappropriate or unexpected behaviors.

D. Consider error impact in robotic behaviors

When choosing robotic behaviors that have potential for errors, we propose to carefully select them based on the impact of their errors. Just as with any technical interaction, errors will occur, and some errors have more negative impacts than others. However, given the complexity of social interaction (and the context it happens in), the impact of an error by a social robot may not be as obvious to the designer. Further, some failures can be highly frustrating and can impact trust and acceptance

[27]–[29] (such as misunderstanding a food order) while others are innocuous (vacuuming the same spot twice).

We advocate for designers to carefully consider the potential social scenarios that may result from a robot error, and use this analysis in selecting which behaviors to employ: robots perhaps should use behaviors that fail in a safer and less harmful fashion. If we have good transparent design, people should be able to understand the intention of the robot through different cues even if not properly executed, and therefore, help the robot recover from small failures. Focusing on simple robots that have either errors that the user might not notice or have safer errors that avoid inappropriate responses, confusing behaviors, or damaging the user or its surroundings, might lead to a decrease in negative attitudes towards robots as well as creation of more useful and accepted companion robots.

E. Reduce reliance on robotic abilities

Many interactions with a robot, even complex ones, do not necessarily require complex involvement from the robot. This can include putting the robot to sleep, making it warm, talking to it or feeding it, which are complex and meaningful human actions that do not require complex technological solutions. These rely more on the complex behavior of the person than the abilities of the robot, while still increasing engagement with a reduced need for complex interactions and behaviors from the robot. We propose designing for this type of interactions, complex interactions that do not require complex robotic behaviors. Research suggests that by engaging the user as an active participant of the interaction, they might be more inclined to interact with the [30]. When the responsibility is placed on the person, it helps by reducing reliance on the robot, and engaging them in interaction. Engaging the user with the robot in these ways will hopefully help people accept the robot more, create stronger bonds and simplify the design of the robot's behaviors which will hopefully lead to less abandonment problems.

IV. Case Studies

We explore our proposed design approach by considering three existing research and commercial robots from the perspective of our design considerations. For this, we selected three currently common social robots used in the real world or for research: Pepper, the humanoid robot from Softbank; PARO, the baby robotic seal; and AIBO, Sony's pet like robot dog.

A. Softbank's Pepper

The Pepper robot is a commercially available humanoid that has arms for gesturing, can move its body and it is tall enough that a person can interact with it and its integrated tablet. Pepper is designed and marketed as a kiosk that people can use to get information from it. It has been deployed as a service kiosk-like robot in different places such as museums, restaurants, or airports. The way Pepper understands and replies in conversation is simple, its conversational model relies on saying pre-selected sentences and finding single keywords in the person's replies and again, say a pre-programmed answer and do a pre-selected gesture.

Aim for low expectations of robotic ability – Pepper's tall physical design with a humanoid shape, arms, and an ability to move around a space makes it look complex and might create expectations of similarly complex behavior such as fluid, natural conversation with it. When these natural interactions are not feasible, due to current technological constraints, the user might be disappointed and abandon the use of the robot.

Focus on simple social interactions – Pepper has simple interaction capabilities like simple conversations and gestures. Pepper also has a tablet computer attached to its chest for touch-screen interaction. Given Pepper's simple conversation model as explained above, we expect its simple approach to result in fewer errors in comparison to more complex conversational behaviors. Further, hand gestures need to be kept generic if they are to be successful, as adapting them to the conversation can be quite challenging, reducing the potential for their impact and utility. Finally, Pepper's use of gaze is simple and might increase engagement as it is capable of doing what people expect from their conversational partner.

Use static, pre-programmed behaviors – Pepper's default API for creating behaviors focuses on pre-programmed behaviors that follow simple logic. Pepper's limited ability to understand single keywords as explained before lends itself to only use simple behaviors that reduce testing time. One of the advantages of this is that even if it reduces the type of possible interactions, it prevents the robot from saying or doing something inappropriate. Pepper's gestures when moving can also be pre-programmed to be general enough to function in the majority of scenarios.

Consider error impact in robotic behaviors – As noted previously, Pepper's programming is generally created to listen for specific, single keywords or short phrases. If the user is aware of this, then perhaps errors when a reply is not correct will not be as impactful for the user, yet if they are a new user that is not aware, they might be disappointed. Due to its formfactor, and how it portrays that is has the ability to move around the space it is in, in case of failure it might frustrate the user. Things like gaze detection, if it can properly recover from it (i.e., look around until the person is found), might not have a big impact in people's acceptance since it is not harmful in any way.

Reduce reliance on robotic abilities – One of Pepper's main interaction capabilities is through social engagement. It relies on the person engaging with the robot for a specific purpose that causes the robot to be programmed to only understand and be able to reply to a simple subset of requests which simplifies the robot capabilities. Designers can also leverage its built-in tablet to have people interact with it to decrease the complexity of the programming. When used as a kiosk, in the case of failure or inability to answer the person's request, Pepper can direct people to a store associate to help them with their request.

B. PARO Seal Robot

PARO is a commonly deployed companion social robot shaped like a baby seal. PARO has limited interaction: it can move its body, react to touch, and make sounds. Despite this, PARO has shown promising results from helping people with dementia [24] as well as reducing pain perception in people [31].

Aim for low expectations of robotic ability – PARO has a simple physical designed created after a baby harp seal. Since people generally tend to not have prior knowledge of a baby seal, they usually do not compare PARO to a real baby seal [32]. Based on the simple shape and the way it is introduced to people, as a robot to be cared for and petted, users will likely not have high expectations on its abilities.

Focus on simple social interactions – PARO is designed to react to human input, be it touch or voice by moving its body and making noises. This design steered away from human-like behavior and avoids nuances that come with it. PARO has simple behavior designs that are still capable to engage the user positively.

Use static, pre-programmed behaviors – PARO has both static behaviors and generated behaviors [33]. However, they are simple enough and very primitive, since it is made to mimic a seal, it only changes speed of the movement and amount of times to do a movement [33]. Because the parameters limits movements to be slow and small enough, the auto-generated behaviors have almost no risk of harming the user or the environment when compared with more complex interactions such as speech generation or walking. movements will possibly not harm the user.

Consider error impact in robotic behaviors – The creators exploited the benefits of using an animal that many have never interacted with; people likely have no previous knowledge of its abilities [32] and do not know what to expect from it. Even then, users are able to understand PARO's intention[24]. The robot's simple abilities can at most, lead to trivial errors such as moving quicker, making a noise when it should not have or repeating a behavior. These errors might not even be perceived as errors by the user if they do not know what to expect from a seal robot.

Reduce reliance on robotic abilities – PARO relies on the person for various complex behaviors. It leverages the user's ability to carry out complex tasks for the robot, like petting and carrying it, that does not require complex technological solutions, while still increasing engagement with it.

C. Sony's AIBO dog

AIBO is a dog-like robot that has been around since 1999 and has been updated more than 5 times. It is a consumer ready product that has been successful in not only research but also in homes of people as a companion robot. AIBOs have a growing community of people who treat them and play with them like real dogs.

Aim for low expectations of robotic ability – AIBO is shaped as a real puppy, based on this, people might have the same expectations they have with AIBO's real counterpart. Although high expectations can lead to disappointment, in the case of AIBO it might not affect the user since it is actually capable of imitating many of a puppy's behavior properly.

Focus on simple social interactions – AIBO is a dog like shape robot that conveys emotion by leveraging dog behavior that people might be familiar with. It can wag its tail to show emotion or bark to get attention. The interaction capabilities it has are just enough to possibly make people think of it as a real dog which explains why if it fails to understand something, people might think it is just normal dog behavior.

Use static, pre-programmed behaviors – Some of AIBO's behavior is preprogrammed, like its tricks, songs, or its reaction to different input. Some of AIBO's behaviors, like how he moves around a room and walks, is not preprogrammed. Things like lighting conditions can affect its ability to explore a room, however, it is safe enough and lightweight that it will possibly not harm anyone or the robot's surroundings. Other things, like its tricks, songs, or reaction to different input is preprogrammed. AIBO's reaction to voice commands, if it registers them, will always be the same, and that can avoid unexpected errors as the robot does not need to interpret or adapt to new situations.

Consider error impact in robotic behaviors – AIBO has a vast array of features, from playing with people to being able to map around a room and move around it. Some of its complex abilities (e.g., mapping a room or recognizing a person's face) could not work and a person might not even notice since they are not part of its main functionality of acting like a dog. Due to its similarity to a real puppy, AIBO's errors could include not replying to a command or getting stuck somewhere. We expect that people will attribute that to puppy-like behaviors and not as a robot error which makes them not highly impactful or frustrating. This shows how properly considering the type of errors can lead to successful robots.

Reduce reliance on robotic abilities – AIBO has a variety of interactions that do not require complex technological solutions. It can go to people and bark so they can interact with it by playing or petting it. By using behaviors like needing to be played with or asking the user to give something to it (toys), it relies on the person for some of the complex behaviors. People might be more likely to give into the fiction of the robot as a real puppy if they have to do something for it.

V. Sample Robot Prototypes

We applied our design strategy in our own design and development of social companion robots. We present two new interactive robot designs: a conversational humanoid robot and a physical comfort plushie robot. Both have the same goal in mind, to provide emotional comfort to people through the use of simple and feasible interactions, without promising more sophisticated capabilities.

A. Conversational robot for loneliness

Research suggests that humanoids can leverage simple conversation to engage with people and increase their overall wellness [34]. Using Softbank Robotics' humanoid robot Nao, we are designing a conversational companion robot for people living alone (Fig. 2, left), to be able to share their feelings and experiences, and hopefully decrease feelings of loneliness. By following the design strategies proposed and described in section III, we are developing robot behaviors that should be possible to test it in homes, without researcher supervision. Below we analyze the programmed behaviors of this robot within our design approach.

This robot will be able to engage in conversation with the person after they click a button. The robot's main goal is to ask questions to the person to have them talk and self-reflect. The robot behavior will be simple as it will only wait for the person to finish talking but will have no information of what the person said. The robot will ask generic follow-up questions to prompt the person to talk more.

Aim for low expectations of robotic ability – To offset high initial expectations of the robot's capabilities due to the robot's humanoid shape, the robot will be introduced to users fully explaining its simple capabilities, and the possibility of errors occurring. The goal is to prevent a drop in trust or perceived efficacy by setting low initial expectations, and for individuals to have higher and continued acceptance of the robot.

Focus on simple social interactions – The robot is designed to not attempt to understand speech or timing, instead, it converses by waiting for the individual to finish talking (i.e., waiting for silence for a specific amount of time), or by a simple touch of one of its sensors. Hand and head movements are only used to provide acknowledgement while a person speaks, and the robot does not produce any other body language or facial expressions, therefore simplifying the interaction. We expect its basic social behaviors to encourage higher acceptance of the robot, allowing it to help individuals.

Use static, pre-programmed behaviors – This design utilizes only pre-programmed speech in order to converse with people, without the need for context. For example, the robot can ask "What are you grateful for today?" and without context, it could reply "Why is that?" or "Where do these feelings come from?" which are simple generalized replies. This enables the robot to be fully tested, easily deployable, and hopefully prevents the robot from saying an inappropriate answer.

Consider error impact in robotic behaviors – By choosing pre-programmed follow-up questions that are generic enough to fit to the main question regardless of what the person is saying, even a reply that might be incorrect or out of place (e.g., asking "why?" when the person explained it already)will be generic enough to hopefully not make the user uncomfortable. By also letting the user know from the beginning that the robot can make errors, we expect them to be less likely to abandon the technology. In addition, introducing the robot as a listener and prompt creator provides some leeway if it makes some conversational errors, as it is not meant to understand the conversational context.

Reduce reliance on robotic abilities – Most of the interaction designed for this behavior is done by the person. The robot will mainly provide prompts for the individual to talk about and reflect on. The length and depth of interaction is therefore defined by how long the person would like to talk to the robot.

We believe that using this design approach to generate and design the conversational robot's behaviors we can have a more immediate deployment of simple robots that still fulfill their goal. Even though the shape of the robot might make people believe it is capable of doing more, we expect that by introducing the robot as being only a conversational robot that will not understand the user's self-reflection and overall having limited capabilities, it will help us reduce problems with expectations and real capabilities.

B. Stuffed narwhal robot

We are currently developing a modified plush toy narwhal (Fig. 2, right). We added lights and motors to it to be able to communicate with the user and move to create a simple and affordable companion robot. This robot is intended to be affordable and easily obtainable, using a widely available plush toy and simple electronic components. This robot will be tests in people's homes as a resource to help those with feelings of sadness, loneliness, and isolation.

Figure 2. Robotic prototypes. Conversational robot on the left and soft toy on the right. Pictures used with permision.

This robot is designed to be cuddled. It will require the user to hug it several times a day and keep it warm with a heated bag, or else, it will display several cues to indicate that it gets lonely. It will be able to communicate through lights, noises and movement of its flippers. Here we analyzed this robot under the design approaches we defined.

Aim for low expectations of robotic ability – We exploit the simple design of this toy to lower expectations of participants, since users should not expect a stuffed animal to be capable of moving much or making sounds. This might increase their positive perception of it, making it more likely to be accepted into people's lives.

Focus on simple social interactions – This robot responds to a small amount of input like changes in its temperature or to hugs. This robot has a non-human zoomorphic shape, and yet is not shaped like a traditional pet. By using a stuffed toy with simple interactions, we hope to avoid trying to understand different social behavior from the users. This should enable the robot to be easily and quickly built, and encourage people to use it.

Use static, pre-programmed behaviors – The robot's behaviors are all pre-programmed. The robot's horn lights up depending on the temperature of the robot, or to show that it needs to be interacted with. Tail movement are also pre-programmed in a slow fashion, to avoid potential harming to the user. All of these static behaviors are able to be fully tested before deployment to avoid harming the user.

Consider error impact in robotic behaviors – People will possibly have no prior expectation of what a stuffed animal with advanced capabilities can do. The robot only has simple movements, light cues and noises. One of the errors that could appear is that the robot registered a hug when there was none, this will only make the robot happy and move, if it does not register, people might need to hug it again. These simple errors might not even be noticed by the user due to their simplicity, and if they notice it, it will possibly be harmless. We anticipate these simple errors to not decrease people's acceptance of the robot.

Reduce reliance on robotic abilities –Leveraging the capacity of the person to do complex interactions such as keeping the robot warm or giving it a hug, do not require the robot to do much but it can increase the engagement of the person. These interactions do not require complex technological solutions since most of the interaction is conducted by the individual, with the robot mainly prompting specific responses.

This prototype follows our proposed design strategies, and by simplifying the robots' design and behaviors we hope to create an affordable alternative to existing robots that can be more widely deployed to help people. This robot is a great example of how a robot does not need to be highly complex to be able to interact with people, but we can rather use currently available technologies to create companion robots.

VI. CONCLUSION

There is a variety of factors that affect the success of care and companion robots for people. In this paper we proposed different design strategies for successful deployable robots. By reversing our design approach for robots and proposing to work with current technological advances that are ready and tested, we argue that this will lead to successful domestic robots quicker. The main focus of this is to simplify design and interactions to create engaging robots that are less likely to fail when deployed outside of labs and that people will accept and hopefully adopt. We are currently designing robotic prototypes to test these approaches on acceptance of companion type care robots. These prototypes are meant to be tested directly in longer term interactions with people, so they are ready to be deployed after initial studies.

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