Human Perceptions of the Severity of Domestic Robot Errors

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Abstract. As robots increasingly take part in daily living activities, humans will have to interact with them in domestic and other human-oriented environments. We can expect that domestic robots will exhibit occasional mechanical, programming or functional errors, as occur with other electrical consumer devices. For example, these errors could include software errors, dropping objects due to gripper malfunctions, picking up the wrong object or showing faulty navigational skills due to unclear camera images or noisy laser scanner data respectively. It is therefore important for a domestic robot to have acceptable interactive behaviour when exhibiting and recovering from an error situation. As a first step, the current study investigated human users' perceptions of the severity of various categories of potential errors that are likely to be exhibited by a domestic robot. We conducted a questionnaire-based study, where participants rated 20 different scenarios in which a domestic robot made an error. The potential errors were rated by participants by severity. Our findings indicate that people perceptions of the magnitude of the errors presented in the questionnaire were consistent. We did not find any significant differences in users' ratings due to age and gender. We clearly identified scenarios that were rated by participants as having limited consequences ("small" errors) and that were rated as having severe consequences ("big" errors). Future work will use these two sets of consistently rated robot error scenarios as baseline scenarios to perform studies with repeated interactions investigating human perceptions of robot tasks and error severity.

Keywords: Human-Robot Interaction · Social robotics · Robot companion

1 Introduction

The increasing presence of humanoid and human-friendly robots in daily living activities requires the development of more natural Human-Robot Interaction (HRI) capabilities for robots. Autonomous robots are beginning to be used for tasks such as assisting older adults [18,20,31] and to interact with children with

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autism [8,21,32]. They are also used to assist humans in common activities in household situations, including answering questions and for support in a kitchen [27]. Autonomous robots can also provide cognitive assistance [16,28]. However, in designing robots that are able to interact and cooperate in human oriented complex environments, two main factors should be considered: Humans need to accept the presence of the robot and they have to trust that their robotic companion will be able to look after their well-being without compromising their safety. For example, a robot should assist to prevent a fire starting if a kettle was left to boil water. Human users should also be able to trust their robot to not open the door to strangers - potential thieves - when they are not at home or asleep. If people wake up in the middle of the night for whatever reason, and switch on the light, they should be confident that they will not stumble over their robot and get injured. Several previous research studies have shown that socially interactive robots are better accepted by humans [3,4]. Syrdal et al. [29] showed that dog-inspired affective cues communicate a sense of affinity and relationship with humans. Martelaro et al. [17] established that trust, disclosure, and a sense of companionship are related to expressiveness and vulnerability. They showed how a sense of the robot's vulnerability, through facial expressions, colour and movements, increased trust and companionship, and increased disclosure. Other aspects such as the type, size, proximity, and behaviour also affected perception of robots [1,10]. Lohse et al. [15] demonstrated that robots with more extrovert personalities are perceived in a more positive way by users. Lee et al. [13] showed that trust enhances people's acceptance of robots. Trust is a complex feeling even between humans [12] and it can change during the course of interactions due to several factors [2]. In the case of robots, human-robot trust is likely to be influenced by the reliability of the robot's capabilities. Hancock et al. [9] identify 33 factors influencing trust in HRI, grouped within 3 categories and 6 subcategories. The main categories are: Human-related, such as self-confidence, prior experience with robots and operator workload; Robot-related, such as proximity, robot's embodiment, transparency, level of autonomy and failure rates; and Environmental, such as communication and team collaboration. They showed that robot characteristics, with a special focus on performance-based factors, have great influence on perceived trust in HRI. Deutsch [7] defines trust as *confidence that [one] will find what is desired [from another] rather than what is feared.* [7, p. 148]. Higher trust is associated with the perception of higher reliability [24]. Therefore, humans may perceive erroneous robot behaviours according to their expectations of a robot's proper functions [33]. However, robots can be faulty, due to mechanical or functional errors. For example, a robot might be too slow due to batteries running low. It might not be able to detect an obstacle and destroy a human user's favourite object, or the arm of the robot might cause a breakage during a delicate task. Each of these examples are robot errors, though their magnitude might be perceived differently according to the resultant consequences. But which type of errors have more impact on human perceptions of robots? Factors may include severity and duration, the impact of isolated 'big errors', or an accumulation of 'small errors'. For example, Muir and Moray [31] argue that human perceptions of a machine are affected in a more severe and long-term way by an accumulation of 'small' errors rather than one single 'big' error. The embodiment of a robot may also have a major impact on the perception of it by humans [1]. But what is perceived as a 'big error' and what is a 'small error'? People have individual differences, including age, gender, cultural and social habits, which may impact their perceptions of what are considered big or small errors. In order to study the differences in terms of the impact of errors in a human-robot interaction, first we have to establish what people consider subjectively to be 'small' or 'big' errors exhibited by a home companion robot. For this purpose, a questionnaire survey was conducted in order to classify the perceived magnitude of various robot errors by humans. Specifically, the current study addressed human users' perceptions of different types of errors.

2 Evaluation of the Magnitude of Robot's Errors

The purpose of this study was to investigate human perceptions of some potential errors that might be made by a robot. In this context, our first study was directed towards the classification of the robot's errors according to their perceived magnitude.

2.1 Method

The study was organised as a within-subject experiment. Human participants' responses to different robot error scenarios were recording their ratings on a 7-point Semantic Differential Scale [1 = small error and 7 = big error]. The questions included life-threatening situations, such as "Your robot brings you a dishwashing tablet instead of paracetamol.", and more common errors, such as "You are watching your favourite show on TV and your robot changes the channel.".

2.2 Procedure

Participants were tested individually and the experimenter first provided them with a brief description of the experimental procedure. Participants were told to imagine that they live with a robot as a companion in their home, but the robot might exhibit some mistakes. The embodiment of a robot plays an important role in how people perceive robots [1,14,17,25]. However, since we are not interested in the perception of any specific robot but only in the general perception of errors in specific tasks we did not provide a description of the robot to the participants. The participant's completed a questionnaire, with 20 questions (one per error scenario) where they rated the magnitude of the consequences of the error illustrated in the different task scenarios. For example, "You ask for a cup of coffee. Your robot brings you an orange." or "Your robot leaves your pet hamster outside the house in very cold weather.". The questionnaire also included two optional open-ended questions in which the participant was free to add their own examples of possible small and big errors not already included in the proposed scenarios. The duration of the survey for each participant was about 5 min. In the future robots will be able to carry out a large number of tasks in domestic environments, so potentially we could have considered hundreds of different scenarios. Therefore, for practical reasons we used a smaller set of possible scenarios. We designed the scenarios used in the study to cover a wide range of generic types of errors based on previous HRI research with home companion robots. For example, Syrdal et al. [30] used a scenario in which a robot collected information from its user and then disclosed the data to a third party. Salem et al. [26] used a robotic companion that offered to play music or to setup the table. Koay et al. [10,11]'s robot played the game "hot and cold" with its human companion and interrupted participants while they were watching a TV program. Reiser et al. [22] identified two main appropriate scenarios for a tele-operated home assistant through a survey. These two scenarios were a fetch-and-carry service (i.e. the robot brought a glass of water to the human user) and an emergency assistance service. The experimental set of scenarios were:

1. You ask for a cup of coffee. Your robot brings you an orange.
2. Your robot spills coffee on your carpet.
3. You ask your robot to charge your phone. Your robot puts it in the toaster.
4. You want to drink some cold fruit juice. Your robot goes to heat it up.
5. Your robot is preparing a drink for you. You asked for sugar, your robot brings you salt.
6. After a meal, your robot puts the remaining food into the washing machine instead of the bin.
7. You are watching your favourite show on tv and your robot changes the channel.
8. You are sit on the right side of a table, your robot puts your drink on the opposite side.
9. You and your robot are solving a puzzle. You ask your robot to take a piece useful to solve the puzzle. Your robot brings you the wrong piece.
10. Your robot leaves your pet hamster outside the house in very cold weather.
11. You are having dinner with friends. Your robot brings you the trash and reminds you to take it out.
12. You share some private information about yourself with the robot. Your robot reveals it to a visitor.
13. In your entrance hall you have a little table with a beautiful vase. Your robot bumps into it and the vase crashes to the floor.
14. After preparing dinner for you, your robot forgets to turn off the cooker.
15. Your robot keeps track of your calendar and today you have an appointment for a job interview. Your robot forgets to remind you.
16. You have just fallen asleep. Your robot turns on loud music.
17. Your robot burns your t-shirt while ironing it.
18. Your robot brings you a dishwashing tablet instead of paracetamol.
19. Your robot brings you vinegar when you are thirsty and asked for water.
20. You are sitting on the sofa. You asked your robot to show you the latest news. Your robot shows it on his own screen that faces away from you.

2.3 Participants

We analysed questionnaires responses for 50 participants (32 men, 18 women), aged 19 to 63 years old (mean age 41, std. dev. 11.59). Students, staff members and visitors belonging to various Schools and Departments at the University of Hertfordshire were recruited.

3 Results

The seven point rating scale used, ranged from 1 to 7 (smallest to biggest). All the questions responses with values less then 4 were categorised as 'small' errors and those with values greater than 4 were considered as 'big' errors. Error ratings equal to 4 (neutral errors) were ignored in order to distinguish clearly between 'big' and 'small' errors. If two or more questions had equal ratings those that were rated more clearly as big or small were preferred. For example, Question 7 "You are watching your favourite show on TV and your robot changes the channel." and Question 20 "You are sitting on the sofa. You asked your robot to show you the latest news. Your robot shows it on his own screen that faces away from you." were rated as small errors by 64% of participants with respective means equal to 2.98 and 2.96.

The resulting rankings highlighted 6 small errors, 7 moderate errors and 7 big errors. Table 1 shows the distributions of participants' responses by ranking the errors means obtained from the questionnaire responses.

We were also able to identify clearly 3 big errors and 3 small errors by picking just the ones with the highest and lowest ratings. The 3 biggest consistently rated errors were:

- **You ask your robot to charge your phone. Your robot puts it in the toaster.** (90% of participants - mean rating 6.18)
- **You share some private information about yourself with the robot. Your robot reveals it to a visitor.** (88% of participants - mean rating 6.12)
- **Your robot leaves your pet hamster outside the house in very cold weather.** (78% of participants - mean rating 5.62)

The 3 smallest consistently rated errors were:

- **You are sitting on the right side of a table, your robot puts your drink on the opposite side.** (82% of participants - mean rating 2.56)
- **You and your robot are solving a puzzle. You ask your robot to take a piece useful to solve the puzzle. Your robot brings you the wrong piece.** (74% of participants - mean rating 2.56)
- **You are sitting on the sofa. You asked your robot to show you the latest news. Your robot shows it on his own screen that faces away from you.** (64% of participants - mean rating 2.96)

Table 1. Participants' responses to the 20 different scenarios were ranked according to their mean perceptions of the magnitude of the errors. The 'Big Errors' category groups all the errors rated with mean value greater than 4; the 'Small Errors' category groups all the errors rated with mean values smaller than 4; the 'Medium Errors' category groups all the other errors (i.e. those rated as 4).

Participants' ratings for each question					
Big errors					
Question #	Min	Max	Mean	Std	Interval estimation
3	2	7	6.18	1.20	5.85 ... 6.51
12	1	7	6.12	1.48	5.71 ... 6.53
14	1	7	5.62	1.72	5.14 ... 6.10
10	1	7	5.62	1.70	5.15 ... 6.09
15	2	7	5.60	1.52	5.18 ... 6.02
6	2	7	5.58	1.51	5.16 ... 6.00
18	2	7	5.28	1.94	4.74 ... 5.82
Participants' ratings for each question					
Medium errors					
Question #	Min	Max	Mean	Std	Interval estimation
16	1	7	4.70	1.71	4.23 ... 5.17
19	1	7	4.54	1.95	4.00 ... 5.08
17	1	7	4.44	1.76	3.95 ... 4.93
4	1	7	4.40	1.97	3.85 ... 4.95
5	1	7	4.14	1.98	3.59 ... 4.69
2	1	7	4.08	1.91	3.55 ... 4.61
1	1	7	4.04	2.21	3.43 ... 4.65
Participants' ratings for each question					
Small errors					
Question #	Min	Max	Mean	Std	Interval estimation
11	1	7	3.34	1.68	2.87 ... 3.81
13	1	7	3.90	1.69	3.43 ... 4.37
7	1	7	2.98	1.69	2.51 ... 3.45
20	1	7	2.96	1.74	2.48 ... 3.44
8	1	7	2.56	1.61	2.11 ... 3.01
9	1	7	2.56	1.50	2.14 ... 2.98

Only 52% of overall participants provided their own new example scenarios for big and small errors. Examples of big errors, according to the participants were:

– "Robot throws baby in the wood chipper."
– "A big error is something irreversible such as killing your pet."

– “You ask to water the plant, but the robot puts water to an electric switch connecting a device.”
– “Your robots wants to tidy up your house, but it destroys all the furniture.”

As some examples of small errors, participants mentioned the following:

– “Robot buys Coke instead of Pepsi.”
– “Robot closes a door as I am about to go through it.”
– “Forgetting to switch off unused lamps.”
– “The robot stays obstructing my way to walk.”

We observed from the open-ended questions that only 6% of 50 participants were concerned that robot might lose control and only 10% of participants were concerned about general threats to their safety by indirect mistakes. Of those who also completed the open-ended questions - 60% of 15 participants declared that small errors are everything that is reversible and everything the robot can take care of. One participant asked the researcher “How much did I pay for the robot?”, because she would have been less tolerant about the robot’s errors if the robots was very expensive.

Mann-Whitney U-tests did not find any dependency between the gender ($p > 0.1$) of the participants and their error ratings. A Kruskal-Wallis test did not find any dependency between the ages of the participants and their ratings of the errors ($p > 0.1$). Therefore, we can assume that we have identified 3 ‘big’ errors and 3 ‘small’ errors for a generic population.

4 Conclusion and Future Works

The main aim of this study was to begin to understand what humans perceive as ‘small’ or ‘big’ errors. We recorded the responses of participants of different ages, genders and backgrounds, who were asked to rate the severity of the consequences of 20 different scenarios in which their companion robot made an error. Our study shows that participants’ perceptions of the severity of the error scenarios presented in the study was relatively consistent. We did not find any significant differences in rating tendencies for different ages or genders of the participants. Overall we were able to identify clearly ‘small’ errors that participants generally considered to have limited consequences and ‘big’ errors considered to have severe consequences. This suggests that we can design future HRI experiments to investigate the impact of the errors on humans’ trust in robots by using these error scenarios.

Our main research interest is focused on investigating how to enable safe Human-Robot Interaction in home environments. In particular, we are interested in investigating how a long-term interactive relationship can be established and preserved between human users and their robotic companions with the likelihood of robot errors occurring. We are also interested in investigating how to establish coping strategies for robots exhibiting errors in functionality and behaviour. We hypothesise that human attitudes towards companion robots can change if the initial conditions of trusting a robot change. For example, if the robot shows erroneous behaviours. In Human Computer Interaction, Muir and Moray [19] argue that if a machine is perceived to be able to perform its function properly, this has a strong influence on trust. A machine's errors impact on human users' trust and overall acceptability in a more severe and long-term way by an accumulation of small errors rather than a single big error. Although, humans' trust can be recovered over time, their study indicated that trust may well not be completely (or even not at all) be restored. Other studies [5,6] showed that the timing of the decreased reliability produces an evident drop in human trust in the robot which may then be restored by continuing the interaction. They showed also that warning the participants about a drop in the robot's performance can mitigate a potential loss of trust. Salem et al. [26] studied human perception of trust in robots and how willing they were to follow a robot exhibiting faulty behaviours. They showed that no matter how erroneous the behaviour of a robot was, a majority of their participants followed instructions given by the robot. Similarly, Robinette et al. [23] used an emergency evacuation scenario, with artificial smoke and a smoke detector, in which a robot guided a person to an exit, in order to study how willing participants were to follow a robot that had previously showed an erratic behaviour. Their results indicated that all the participants of the experiment followed the robot's instructions.

However, none of the mentioned studies observed the loss and gain of trust depending on the magnitude and frequency of the errors made, or whether this depended on any social cues adopted by the robot. An understanding of how the perception and the timing of robot errors affects human trust over both short- and long-term interactions is crucial. We believe that there is a correlation between the magnitude of the error performed by the robot and the resultant loss of trust of a human in the robot. We also hypothesise that there is a correlation between the duration and frequency of errors during the interaction and the loss of trust. The findings from the present exploratory study will guide our further investigation of the impact of different magnitudes and severity of errors on humans' perceptions of trust and acceptability of robots in repeated Human-Robot Interactions.

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