Experiences Developing Socially Acceptable Interactions for a Robotic Trash Barrel

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***Abstract*— Service robots in public places need to both understand environmental cues and move in ways that people can understand and predict. We developed and tested interactions with a trash barrel robot to better understand the implicit protocols for public interaction. In eight lunch-time sessions spread across two crowded campus dining destinations, we experimented with piloting our robot in Wizard of Oz fashion, initiating and responding to requests for impromptu interactions centered on collecting people's trash. Our studies progressed from open-ended experimentation to testing specific interaction strategies that seemed to evoke clear engagement and responses, both positive and negative. Observations and interviews show that a) people most welcome the robot's presence when they need its services and it actively advertises its intent through movement; b) people create mental models of the trash barrel as having intentions and desires; c) mistakes in navigation are indicators of autonomous control, rather than a remote operator; and d) repeated mistakes and struggling behavior polarized responses as either ignoring or endearing.**

I. Introduction

At Disneyland, visitors are entertained by interactions with Push, a talking trashcan that verbally accosts passersby. A hidden operator, who discretely pilots the trashcan and voices Push's witticisms and requests for hugs, remotely controls Push. Whereas Push once represented a fantastical world where everyday objects come to life, nowadays Push represents near-term reality, where personal service robots are likely to be deployed throughout public spaces to perform simple tasks like collecting trash or distributing beverages. By and large, these real-life personal service robots have been used in specific application settings—such as robot-assisted surgery and therapy, in agriculture for milking cows, or in the defense industry for defusing bombs [1]—where they primarily interface with trained professionals. While the sensing, mapping, and navigation technologies that are needed by robots to be deployed in everyday public settings are mature, the social savvy it takes to interact implicitly with passersby—say, to know who should go through a door first, or how to speed up or slow down to keep from running into another person—is still in a state of awkward adolescence [2]. We currently lack an understanding of the casual social interactions that the robots will need to engage in to be deployed autonomously in public, social places. Even the most basic social interactions that people use to initiate engagement, or to take leave of one another, stand to be re-examined and re-visited as we consider how to design everyday robots that can work jointly with people in social spaces. Robots which are designed to carry out specific tasks are often non-humanoid in form, and yet people interpret their movements and actions in a social manner [3]. Hence, it is desirable to know more about how the basic social interaction patterns that we all use everyday should be translated for everyday robots.

Figure 1: Person uses the robot to throw away trash.

In this paper, we describe highlights and findings from two exploratory Wizard-of-Oz human-interaction field study deployments [4] where we piloted a robotic trash barrel around heavily populated public settings. The intent of these engagements is to discover more about the social interaction patterns that such a robot needs to become less socially

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awkward, in a naturalistic setting. These findings will help designers of personal service robots being deployed in everyday settings, so that the robots will be more successful in the way that they interact with people to move around a room, resolve challenges and execute their assigned tasks.

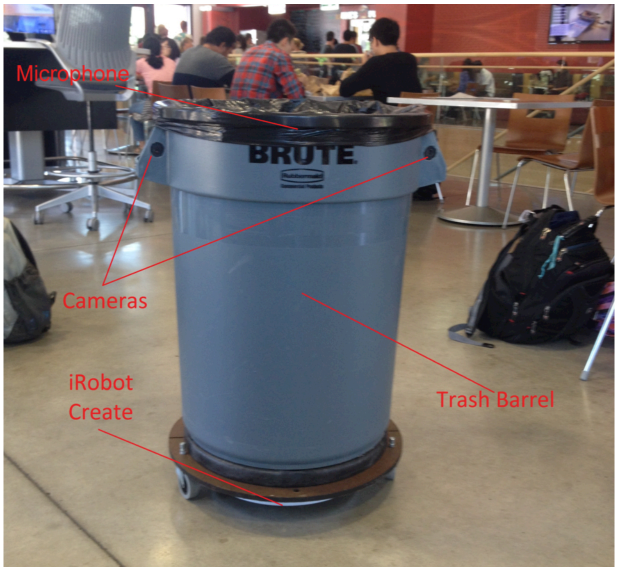

Figure 2: The robot was based on a Roomba Create mounted under a standard Rubbermaid Brute commercial trash barrel

II. BACKGROUND

Trash collection has long been used as a toy problem for robot designers. For instance, the 1994 AAAI (American Association for Artificial Intelligence) Mobile Robot competition was an Office Clean-up Event that tasked robots to clean up a messy office strewn with trash, picking up as many articles from the floor as possible in ten minutes [5]. The problem of trash collection integrates many of the key technical challenges roboticists have traditionally been interested in solving: object detection and discrimination, room navigation, obstacle avoidance, motion planning, task sequencing, and, often, multi-agent coordination.

From a social perspective, trash collection offers other, more CSCW (Computer Supported Collaborative Work) related, possibilities. For instance, remotely operated trash collection can help explore the affordances and challenges of various operator interfaces for tele-operation. Waldherr, et al. started with the AAAI office clean-up scenario, but specified that a human should guide the robot to the trash using gestures [6]. Alternatively, Kulyukin looked at how people and robots can use gesture-free spoken dialogue to come to a common understanding of what objects should be collected or not [7]. Mistry, et al's BlinkBot assumes that the operator is in the same room as the robot and the trash, and equips people with glasses that enable them to identify intentional blinks that indicate which objects should be placed in a trashbin [8].

Other research focuses less on the interaction with a trained operator, and more on cooperation with passersby. Yamaji, et al.'s Sociable Trash Box, for example, does not pick up trash on its own, but it roams around, locates trash and then uses gestural and sound-based interactions to ask children to pick up the trash [9]. A similar technique is used in Ranger [10], a robot toy-bin that asks children to pick up toys in their bedrooms. While, from a technical view, asking people to assist in picking up and disposing of trash is a clever work-around for having to distinguish trash from other items which happen to be on the floor, from a social and design perspective, these projects ask questions that are critical to designing robots that can function in the wild: how are the robot's actions and intents perceived by people? How does the robot signal engagement or disengagement with a passersby? While CSCW-related research has been performed on the human-robot teams such as those for urban search and rescue operations [11], the CSCW implications for the more ephemeral teams, formed between cooperative strangers for short-duration tasks such as tossing out a sandwich wrapper, have been largely unexplored. The public social engagement is particularly interesting, though, because it places a high bar on the robot as a sociable partner [13] and as a context for creating awareness [12]; with only passing engagement and hence little possibility for user or robot training, the robot and people involved in the joint trash collection task must rely almost exclusively on social cues to execute the desired task.

Previous research in public interaction has looked at the role that physical movement and gesture can be used to indicate intentionality and availability for engagement using automatic doors [14], kiosks [15] and room partitions [16]. These experimental studies on non-anthropomorphic technologies suggest that speed, temporal adjacency and response to contextual factors increase the sense that an automated system is interacting, rather that just acting. In the realm of humanoid robotics, Cakmak et al. found that spatial and temporal contrast in movements was critical in indicating intentionality when a robot tried to hand people drinks [17]. While all the previous research is consistent with Reeves and Nass' Social Response to Communication Technology hypothesis [18] that people engage with these automated technologies socially, and derive emotional responses much the way they would with human interactants, more recent research by Fischer [19] suggests that the nature of the social interaction is very much colored by the preconceived notions that people have about the agent they are engaging with. This suggests that although social interaction patterns between people might form a good starting place in designing a human-robot interaction, these interactions still need to be adapted to account for the differences in context and pre-conception associated with novel technologies like robots.

From a methodological perspective, much has been written about the different combinations of Wizard-ing and Oz-ing employed in different human-robot interaction team studies [20]. From an ethnographic perspective, multi-month long-term studies using fully autonomous robots such as Forlizzi and DiSalvo's study of Roombas in the home [21], Sung, Christensen and Grinter's study of Roomba adoption [22] and Kidd and Breazeal's study of weight-loss robots in the home [23] are the gold standard. From a design perspective, though, it is desirable to use quick deployments of prototypical robots into naturalistic settings early in the design process, in order to inform the designers of the context of use, to mine the real-world for naturalistic social interactions that the robot will need to generate and respond to, and to understand critical technical limitations inherent to the application [4]. In particular, for applications in which the long-term use will be based on public social engagement rather than domestic ownership and adoption, we believe that shorter field studies are both appropriate and desirable. This paper describes the first stage of iterative Wizard of Oz design approach wherein the human-operator is gradually phased out, and autonomous technologies are phased in [24].

III. Setup and Methodology

Our ethnographic inspired study is centered around a mobile, remotely operated trash barrel robot that we developed and piloted at two dining locations on Stanford University. The goal of the trash barrel was to engage bystanders and collect their trash as we observed and developed an understanding of how such interactions unfold.

A. The Trash Barrel Robot

The trash barrel robot resembles trash barrels commonly found at the university (Figures 1 and 2). Its body is a standard 32-gallon BRUTE gray trash barrel from Rubbermaid's line of commercial products and it was chosen for its ability to blend into the university surroundings and conceal electronic components. The trash barrel is mounted atop the iRobot Create platform for movement and is augmented with a laptop computer, two web-cameras, and a microphone to enable tele-operation. The computer is concealed within the trash barrel and the web cameras are mounted beneath the handles and under the lip of the trash barrel respectively. We chose tele-operation [25] rather than autonomous control to provide flexibility for real-time design improvisation and responsive behavior to unanticipated events.

1) Control of Movement

The control infrastructure for the robot consists of three components: (1) a web-based interface for the operator, (2) a remote server to host the interface and relay commands, and (3) a WiFi enabled laptop within the trash barrel to communicate with the remote server and drive the iRobot Create platform (Figure 3). The laptop uses Adobe Flash Media Encoder and FFmpeg to compress and stream the two audio/video feeds from the trash barrel's cameras to the remote server, which then forwards it to the web interface. From the web interface, the operator can view the two streams and use key presses to control the robot's movements and gestures.

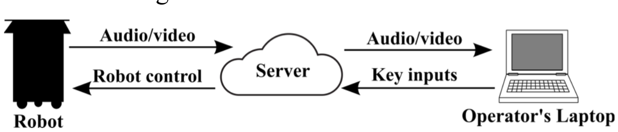

Figure 3: Robot Control System

The types of movements and gestures that the robot can reproduce are limited by the iRobot Create's differential drivetrain. It can only move forward and backward along an arc or pivot in place; it is incapable of lateral movement without first pivoting. This limitation, combined with the camera positions, creates an implicit *front* for an otherwise cylindrical trash barrel, which means that the robot must *face* a party to approach them. Aside from basic speed and direction control, the robot is also capable of reproducing two pre-programmed movements: *wiggling*, where the robot pivots left and right rapidly and *nudging*, where the robot abruptly moves back and forth rapidly. The combination of pre-programmed movements and basic drive allowed the robot operators not only to maneuver the trash barrel robot, but also to signal intent to improve legibility and predictability of robot actions [26] [13].

B. Setting

Two studies were conducted at two public campus locations: the Engineering Building and the Business Quad. These venues were chosen because they are heavily trafficked, have clean, flat ground surfaces for the robot to traverse, and have good WiFi coverage to allow for direct tele-operation.

1) The Engineering Building

The Engineering Building contains teaching, lab and office spaces for several physical engineering departments. The study sessions were performed in an indoor dining area that houses a café and popular sandwich shop. The area is bordered by a library, study area, and classroom, so foot traffic is heavy during lunch hours. Engineering students and faculty frequent the space, and the shop's popularity attracts individuals from other disciplines as well. As a result, all the tables are filled and the queue to order extends through the space to the building's entrance from noon to mid-afternoon. At this venue, the operator was hidden from sight and relied solely on the camera feeds to navigate the robot.

2) The Business Quad

The Business Quad is a rectangular outdoor area enclosed by buildings four-stories high, containing classrooms, offices and conference rooms. Business professionals and students frequent the area. We focused our study sessions in the shaded area of the Quad that is conveniently located next to a building that allowed for placement of additional overhead cameras as indicated by the orange triangles at the bottom of Figure 4. The additional cameras greatly improved our post-hoc ability to understand the interactions because of the addition of the environmental reference systems [25] to the ego-centric view offered by the on-robot cameras. Although the teleoperator did not have access to these camera views during the engagement, he was situated on the third floor of an adjacent building so that he could intermittently see the robot (The operator's location is marked with a star in Figure 4, in the bottom right corner). This helped the teleoperator to maneuver the robot through physical obstacles and to coordinate the robot's actions [26] appropriately with passersby.

C. Study Description

We conducted eight 2-hour field studies, five at the Engineering Building (phase 1) and three at the Business Quad (phase 2). At both venues, the robot was deployed between the hours of 12:00 and 14:00 with a field team consisting of 4-6 persons. The robot operator and camera operator remained constant between studies with the number of interviewers varying between 2-4. To encourage natural responses, the robot was deployed at the venues without forewarning to its inhabitants and the interviewers remained incognito.

Although there are slight variations between the two study phases, the general procedure remained similar. The primary goal of the trash barrel was to engage parties seated at the dining tables and encourage trash disposal into it. The manner in which it did so differed between the two studies and is further discussed in the next section. While the robot is engaging the group, the interviewers would be seated a few tables away, casually conversing and clandestinely observing. After a few groups of bystanders have interacted with the robot, the robot parks itself next to a pillar or column and the interviewers disperse to interview the bystander groups. The one exception to this pattern is when a bystander group begins to leave before the interviewers disperse, in which case a single interviewer would dispatch early and interview the group individually.

Initially, we attempted to use written questionnaires to collect data, but found that the bystanders were less willing to participate and provided less informative, short answers. Thus, interviews became the primary source of data collection. During the interview, the groups would be asked a series of open-ended questions such as how they felt about the interaction, how they would prefer the trash barrel to interact with them, and what they thought the robot was doing. In general, the interviewers allowed the interviewees to guide the discussion and collected notes on the interviewees' thoughts and perceptions. These would be later categorized and collated into themes. Invariably, the interview would end with one final question about whether the robot was autonomous or not and the group would be presented with a video release form for the video captured by the robot. We also tried to collect viewpoints from individuals that refrained from interacting with the robot.

After each field study session concluded for the day, all of the captured videos are linked together and segmented by interaction. For the first phase of our study, we stitched together footage from the two onboard cameras; for the second phase, we added a picture-in-picture view from the environmental cameras as well (see Fig 4 for the camera positions marked in red). The segmented video was linked with the interview data to give a complete view of each engagement. We used qualitative analysis with an open coding scheme to find notable moments and common occurrences between the interactions [27] to develop themes and crystallize key ideas observed in the interactions the trash barrel robot had with people.

1) Phase 1: Improvisation and Experimentation

The first field study site was the Engineering Building. Because this was the first phase of our explorations, the human-robot engagements were opportunistic and open-ended, with the robot operator exercising judgment in real-time about how to traverse the area and behave around parties to encourage interaction and trash collection. The operator employed wiggling, nudging, and bumping the robot to attract attention. To diversify the engagements, the robot would sometimes interrupt conversations and make excessive noise by pushing empty chairs along the concrete floor. The left side of Figure 4 shows the layout of the of the Engineering building.

Study sessions began at noon, when the venue was near capacity and the turnover rate was high. Due to the noise and

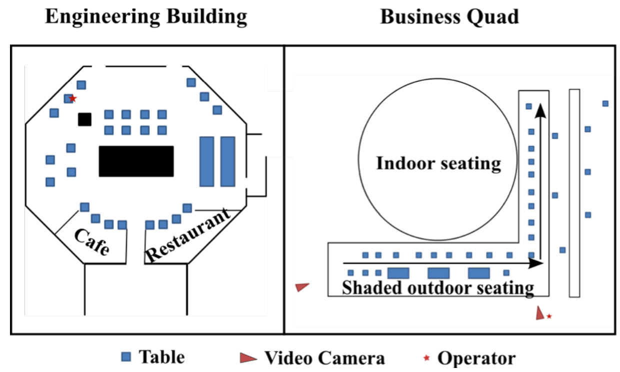

Figure 4: Map of study venues

large number of people in such a small area, individuals were rarely aware of the table-height trash barrel until it approached them within an arm's-length distance. The robot was therefore able to wander throughout the area, interacting with any nearby parties opportunistically. The image on the left panel of Figure 4 depicts the layout of the dining area, with the blue squares indicating which dining tables the trash barrel robot visited.

2) Phase 2: Directed Exploration

The second phase of the study took place across three sessions at the Business Quad. Like the setup at the Engineering Building, study sessions were deployed during the busy lunch hours just after noon. Unlike the Engineering Building, the Business Quad is used equally for meeting, studying and dining, so the turnover rate was lower. For this reason, we chose to follow a longer predetermined circuit (indicated by arrows in Figure 4) that allowed each table to turnover before the robot returned to the same spot about an hour later. These sessions were also more structured and expanded upon specific interaction strategies developed in the first phase of our study. The robot tele-operator had a different interaction protocol for each session.

In the first session, the trash barrel mimicked the basic motion pattern that an autonomous robot might follow. It moved alongside every table (occupied or not) in a circuit without turning to face its occupants, stopped within arm's length of the table for 30 seconds, and then left for the next table, ignoring any gestures and calls to remain by the group. Our intent was to construct a baseline scenario to answer whether a naive strategy of visiting every table along a path would be sufficient, in terms of social acceptability and trash collection efficiency.

In the second session, the trash barrel approached each occupied table, faced its occupants and wiggled for five seconds to announce its presence. If anyone interacted or looked confused, then the robot would wiggle again, and then depart after it had collected any trash. If nobody engaged the robot at all after thirty seconds, then it departed for the next table. Our intent here was to examine how gestures influence people's perceptions of the robot.

In the final session, the trash barrel followed the motion and interaction pattern from the second session, except that it (intentionally) appeared to struggle in its approach to each table, by either repeatedly bumping into obstacles such as chairs along the way, or by getting trapped on uneven pavements. The intent in this case was to elicit a sense of empathy and observe whether the people were more tolerant of a device whose behavior has not yet been perfected.

While it would have been ideal to perform the second study in the same setting, the atmosphere of the Engineering Building changed when the popular sandwich shop closed permanently. The Business Quad was a close a match to the Engineering Quad as we could find, but we discovered important differences between the two as we progressed with the second phase of our study. We have detailed the differences between the venues, and in the process we used at each, to aid readers in interpreting the results.

IV. General Observations

Over the course of eight two-hour sessions, we interacted with a total of 155 bystander parties (defined as a group of one or more individuals the trash barrel addresses as a whole). Eighty-seven of the parties were encountered in the first phase of our study at the Engineering Quad, and sixty-eight of the parties were encountered in the Business Quad. We estimate the median age to be in the low twenties as typical of universities.

In general, most people who interacted with the trash barrel robot found the experience enjoyable, and expressed that they liked the convenience and concept of a moving trash barrel. A few even expressed the desire to own such a robot for use in their homes. Conversely, individuals most commonly reported disliking the interaction when the robot approached them in a situation where they had no trash for the robot, or in other words, had no use for the robot. This problem was further exacerbated if the robot was persistent and wandered within arm's length of someone, which was then described as "impolite" or "intrusive." One woman in the second phase even warned the robot, "Don't come any closer, you're entering my personal space." Conversely, there were situations in which several individuals said that the robot "just left too early to be useful." They indicated they had trash and wanted an "indicator of when the robot would start moving."

In cases where the robot approached a party that preferred not to interact with it, the most common way they signaled a lack of interest in the robot's services was to pointedly ignore its presence or actions. (We call this "unteracting" and the people "unteractors"). Interestingly, when unteractors chose this route, they would continue ignoring the robot no matter how much it gestured or beeped. If someone found its close proximity particularly bothersome, they would continue to concentrate on something else while discretely nudging it away with their foot. Only in one instance did an unteractor stare at the robot and then physically kick it away; most unteractors preferred more passive strategies to encourage the robot to disengage by itself.

Some people went beyond not engaging the robot and pointedly avoided engagement. For example, one woman kept a hand by her face, as if to hold her hair back from her eyes—but always at an angle that would keep her from having to "see" the robot. Others would make a point of not looking at the robot when it was approaching them, and would then take out a camera phone and start recording the trash barrel robot as it went away and interacted with others. Still others would perform short, curt interactions and then pointedly turn away to indicate that the engagement was over. This happened roughly 1 out of 10 interactions, and occurred more often during our trials at the Engineering Quad, when we were experimenting with a wider range of maneuvers and engagement times. When the robot was sticking to a stricter 1 to 1.5 minute schedule, it was less frequently the case that the robot "outstayed its welcome."

Six of the people that we interviewed expressed privacy concerns regarding the robot's cameras. Two of these people purposely obscured the robot's cameras and then left the area in discomfort. One person expressed concern that the cameras might inadvertently capture revealing footage. Such concerns were raised when the cameras were conspicuously mounted on the exterior of the robot. When the cameras were better integrated and hidden within the robot, parties only raised concerns about privacy and personal space.

Comparing two of the sessions at the Business Quad, one where the robot physically gestured and one where the robot did not, we find that gesturing appears to be better at eliciting interactions. When the robot gestured to individuals, 21 out of the 22 parties responded by interacting with the robot. However, when the robot did not gesture, only 14 of the 20 parties interacted with the it. Furthermore, of the 21 interactions that occurred when the robot gestured, 18 parties said they had a positive interaction.

We also observed that people who were alone were less likely to engage socially with the robot. The same holds for larger groups, but only when only one person notices the robot and the others are engaged in another activity. If at least two people noticed the robot, they would engage with the robot extensively. Overall, people didn't easily interrupt their activities, whether they were watching an internet video alone or studying in a group. This finding agrees with the results by Hüttenrauch & Serinson-Eklund [28] and Fischer et al. [19], who also found that people do not attend to robots when they are already engaged other activities.

V. Discussion

From our video and interview data, we identified four common themes that we believe are informative for the design and operation of everyday robots.

A. *Ascribing Desires and Motivation*

We observed that parties often engaged in interactive behavior consistent with initiating or concluding joint actions with other people, such as waving to attract the robot or shooing to dismiss it. The most common gesture used by individuals to signal their intent to utilize the robot was by waving their trash in the line of sight of the robot. This pattern is consistent with the material signals that people use when coordinating joint action with one another, as pointed out by Clark [29]. However, we also observed behavior patterns that seemed to go beyond simply signaling for coordination. These patterns appeared to reflect a belief that the trash barrel's movements were motivated by an *attraction to*, or a *desire for,* trash. An exemplary demonstration of this belief involved a family of three with a five-year-old son. When the trash barrel first approached the family, the child appeared confused by the robot. His mother then demonstrated how to throw trash into the barrel and then repeated the throwing action with the boy, holding his hands throughout the act. As the robot interacted with other parties over the next half hour, the child re-approached the trash barrel alone on four occasions, each time waving trash directly in front of its cameras before slowly pulling the trash back, in an attempt to coax the trash barrel to follow him. It appeared as if the boy's mental model of the robot included an innate desire to collect (or consume) trash, despite his never having been informed so.

Adults also seemed to hold this mental model. A number of individuals described the experience of attracting the trash barrel and throwing away trash as "feeding" the robot. As a result, they also expressed desire for the trash barrel to acknowledge that they had thrown something away; as if giving trash to the robot were a treat or favor to the robot. A few individuals treated the trash barrel as they might a pet, such as a dog. One such person called the trash barrel over by whistling and making kissing noises while waving chopstick wrappers like a dog treat. And after he had disposed of the wrappers and the trash barrel acknowledged the trash with a wiggle, he happily noted to his colleagues, "It's wagging its tail!" At the Engineering building, some parties even inconvenienced themselves to purposely create trash for the "hungry" robot by sacrificing the sandwich wrappers that they were currently using to catch crumbs. In another demonstration, instead of ignoring or shooing the robot as it approached, one student shrunk inward submissively, raised his hands and defensively exclaimed, "I don't—I don't have any trash!" as if the trash barrel was about to attack him for trash.

It appears that people naturally attribute intrinsic motivation (or desire to fulfill some need) to the robot's behavior and that mental model encourages them to interact with the robot in a social way by "feeding" the robot or expecting a social reciprocation of a thank you. In fact, past research has shown that people respond to computers in a social way [18] and Breazeal argues that a sociable robot needs intrinsic desires to engender a "self-motivated interaction" [23]. Interestingly, the role casted upon the robot by the bystanders is reminiscent of a beggar where it prompts for collections and is expected to be thankful for donations. This contrasts sharply with human analogs such as waitstaff or cleanup janitors where they offer assistance and the receiving bystander is expected to express gratitude.

B. Mistakes Signal Autonomy

One peculiarity we discovered is that individuals appear to have a low confidence in autonomy, associating poor navigation and social mistakes with autonomy. In other words, people were more likely to think that the robot was computer controlled if they observed it getting stuck, bumping into obstacles, or ignoring people's attempts draw its attention.

We initially stumbled upon this perception when a less experienced robot driver was experimenting with the controls, actively moving the robot in strange patterns. An observer nearby asserted that the robot "has to be autonomous. It's too erratic to be controlled by a person!" When we analyzed our data from study phase 1 retrospectively, we found 28 cases where participants commented on whether the believed the robot was autonomous or not. The 16 participants who thought it was generally described the robot as "clumsy" or "unresponsive" and provided rationales such as "a human would have been able to get through the channel [of chairs] – it looked like it was programmed [when it repeatedly crashed into chairs trying to get through]." It is as if people expect human operators to be more competent than robots at navigation. We also examined the 12 interviews where people noted that the robot appeared remote controlled and they provided rationales such as "the movement seemed directed, *calculated* as it moved [through] the tables without bumping into things along the way" and "it has to be remote controlled because of the stairs. We figure any robot like a Roomba would have issues with falling down stairs." Interestingly, there were also parties that observed the robot being responsive and social, but it would also bump into things. They go farther by ascribing human qualities to the behavior in saying that the robot was human controlled because it "was messing with people" by purposely crashing into things or "it was mocking me when it followed me," implying that autonomous robots are not characteristically capable of such social functions. Taken together, these latter observations suggest that people have a very low expectation of autonomy and expect it to not be socially adaptable.

These anecdotes resonate with Kim and Hinds' findings that people attribute more blame and give less credit to robots with high autonomy [30]. Except in this incarnation, people appear to blame autonomy for accidental mishaps and credit a hidden remote operator for social grace or cleverness in orchestrating a prank. However in terms of trash collection, it appears it is also important for the participants to perceive the robot as autonomous if mishaps occur. In the scenario where the robot purposely bumps into obstacles, the 7 parties encountered with trash only gave away their trash if they thought the robot was autonomous (5 parties). The other two parties felt that the robot was radio controlled and attributed the mishaps to malice on part of the robot operator.

C. Assistance and Altruism

When the trash barrel robot exhibited struggling behavior, it had a very polarizing affect on those it attempted to interact with. About half the bystanders found the robot annoying and embarrassing while the other half found the behavior endearing.

In the final session of phase 2, the robot exhibited struggling behavior by repeatedly bumping into chairs or falling into recessed areas. Of the 18 parties who interacted with the trash barrel that session, only 10 parties reported a positive interaction. Compared to the gesturing session where 18 out of 22 parties reported positive interactions, it would appear that the struggling behavior produces more undesirable results and should be avoided. In fact, parties reported that they thought the robot was "not very smart," exhibited "erratic behavior," and "overall felt that the robot was very stupid." However, other individuals found this act of struggling to be endearing and "cute". Several parties characterized the robot as being "a puppy or a toddler." One individual recalls, “when it ran into the garbage cans, I thought, ‘silly robot!’ It was adorable.”

The struggling behavior also appears to encourage individuals to help the robot. Eight of the 10 parties that had reported positive interactions that session also provided the robot with some form of assistance such as removing chairs from its path. In one instance, the robot had recently bumped into a chair and when it turned to head toward a mother and child, the mother moved away a chair that was in the robot’s path. When asked why later, she responded, “I don’t know, it felt like it was a team effort.” Later in the study, the robot also immobilized itself three times by falling into recessed areas, and each time, the bystanders assisted the robot. One of the individuals asked the robot “Are you ok? Are you okay?” in a very sympathetic voice as they lifted the robot out. Another individual who assisted the robot, mentioned that she “noticed that the robot made people laugh and smile, and when it got stuck, I wanted to help it because I thought, ‘the show must go on.’” Even an individual who thought that the robot was slightly annoying was compelled to assist the distressed robot. So, even though a struggling robot can be polarizing, individuals tend to help the robot. It’s also worth noting that unless the robot was immobilized, none of the participants tried to move the robot itself, just the obstacles in its way. It is as if they respected the robot’s autonomy. These attitudes hint at altruism and the mental model that the trash barrel robot is a public good performing a public service. Thus, one is performing a good deed when they help the robot.

D. Unteracting

One of the axioms of communications is that one cannot not communicate [31]. With the trash barrel robot, we also noticed that people cannot not interact. Often, the people who were expending the most efforts in response to the robot’s attempts to gain attention were people who were very pointedly ignoring the robot. These actions seemed to take so much effort and to be so overt that we began to call this behavior “unteracting.”

On one occasion, there was a woman who was casually looking at the robot when it approached, but as soon as it got within arms length and bumped into another chair at her table, she very quickly looked away. When the robot tried harder to get attention by repeatedly bumping into the chair and dragging it, she picked up a newspaper and appeared to intensely concentrate on an article, feigning a lack of awareness of the commotion just an arms length away. When asked about the robot, she noted that she was aware the robot was trying to get her attention, but she chose to ignore it. She also seemed aloof and smug about the robot, “I saw the robot last week and it’s not really that unique to me” and “I don’t think I’m a good person because I’m a little jaded to these things.”

Interestingly, not all unteractors were genuinely disinterested in the robot. There were several cases whereby the person would unteract with the robot as it approached and wiggled for attention, but as soon as the trash barrel turned away and started to leave, the person would turn around to look at the robot and sometimes use their phones to take photos/videos. Even more interesting, when the robot turned around to take a new path, some of the parties would immediately snap back from looking at the robot to having a casual conversation with their friend or suddenly tilt their phone downwards as if they were just casually using it instead of recording the robot. The former form of unteraction indicates an unwillingness to interact while the latter form may indicate shyness from not knowing how to interact with the robot. A socially acceptable robot should be able to differentiate the two and respond appropriately.

VI. Conclusion

The core finding of our research is that people’s reactions to the introduction of an interactive trashcan robot range from tolerant to welcoming—they were not overtly surprised or disturbed by the phenomenon of a robotic collection bin making its way through the crowd. Most quickly surmised how to interact with it and were pleased to contribute their garbage to it. The addition of interactive gestures and actions made sense to people the robot approached, and it improved their opinions of the robots.

One interesting aspect of people’s engagement with the robots is that people ascribed intrinsic motivations for the robots behaviors. They seemed to feel that the robot wanted trash, that it was “eating” trash, and therefore they seemed to feel that they were doing the robot a favor by giving it trash as opposed to receiving a service from it. This is a departure from the model people would have about a person who was collecting trash using a mobile trash bin. People also seemed to attribute technical difficulties to the growing pains of autonomy, and are split on whether this behavior is adorable or annoying.

While this study examined how to engage people in joint action, we also discovered that design consideration also needs to be given to how best to disengage, or when to not engage in the first place. Many of the interactions which people reacted negatively to involved situations where individuals did not have any trash to throw away. Conversely, several individuals said that the robot “just left too early to be useful.” While we avoided interacting with individuals who pointedly ignored the robot, we think there is probably interesting future research to be done exploring different ways to respond appropriately.

On the whole, these studies and engagements indicate that people have social expectations for interactive robots that inform how they engage or disengaged from the robot, and those expectations color how they feel; these expectations are not exactly anthropomorphic. As the capabilities and domains for robots grow, we anticipate that these types of engagements and interactions will become more common and yet more colorful.

VII. Limitations And Future Work

There are some limitations inherent in our study methodology. First, in these field studies, we intended for people to act as if the trash barrel were an autonomous entity; however, the barrel was actually teleoperated. It is possible that a truly autonomous robot would “give off” cues that are different that those given off by a tele-operated robot, and thus evoke substantially different responses.

Nonetheless, this work is exploratory, helping lay the ground work for future studies and developments.

Additionally, people involved in the study have very little personal experience with everyday robots. Repeated exposure to everyday robots in daily life may change the norm of interaction. Thus, a longer term study involving many different types of robots and participants will help shed light on how the relationship would evolve over time.

Finally, social interactions are context-dependent. While we believe the signals people use to cue engagement have similarities that enable those who are unfamiliar with the specific context of these public eating areas, it is possible that a trash barrel wending its way across a library, or theater, or lobby, might not be welcomed as warmly. These studies were also carried out on a university campus in the San Francisco Bay Area, a technology-friendly geographical region. We expect that a similar study carried out in a non-university setting, or in a less technologically oriented geographical region would yield different findings. Future work diversifying the social environments in which the robot operates will reveal many more dimensions to the human-robot interaction.

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