Designing for Public HRI: Reflections on an Iterative Robot Sound and Motion Design Process

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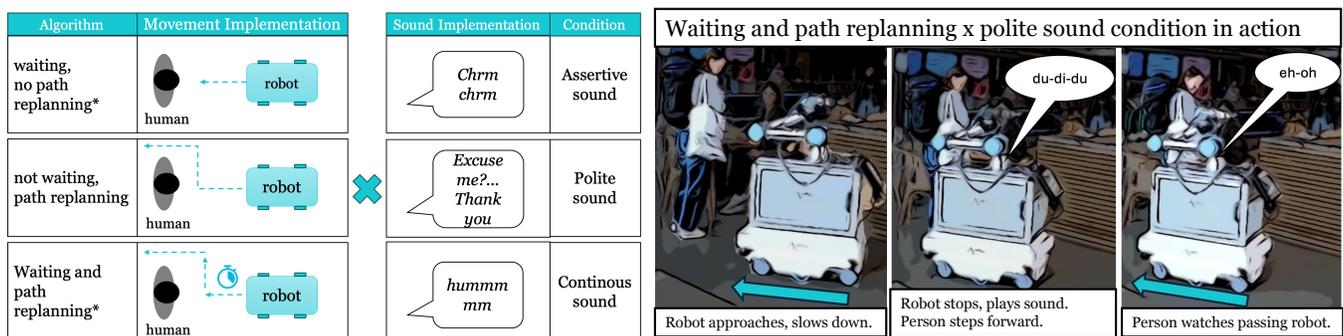Linköping University
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Figure 1: Left: Social movement planning based on three different algorithms and sound designs. Algorithms implemented by ourselves are marked with a star. Right: The robot in action: The robot approaches a person in conversation with the researcher. The person steps out of the way when the robot plays a sound.

Abstract

Mobile robots must behave intelligibly to be acceptable in public spaces. Designing social navigation algorithms for delivery robots requires different areas of expertise. The paper reports on an interdisciplinary collaboration between two ethnomethodological conversation analysts, a human factors psychologist, and two motion planning engineers. Based on video recordings of a robot moving among people, the team developed and implemented different sound and movement designs, which were iteratively tested in real-world deployments. This work contributes insights on how interdisciplinary collaboration can be facilitated in the area of social robot navigation and an iterative process for designing robot sound and movement grounded in real-world observations.

CCS Concepts

• **Human-centered computing** → **Interaction design**; *Field studies*; • **Computing methodologies** → *Motion path planning*; • **Social and professional topics** → **Project and people management**.

Keywords

1 Introduction

Designing robots for autonomous movement among people in public spaces is challenging because there are no standardized methods for designing motion and communicative behaviors. Ethnographic fieldstudies provide detailed insights on how people move around robots in natural encounters but typically do not translate into improved designs [1, 18, 20]. Motion planning literature calls for the development of social robot navigation but tends to describe general norms such as politeness [15]. Integrating knowledge about social norms and expectations into algorithmic solutions for motion planning therefore remains difficult.

We report on a 9-month feasibility study that set out to *design robot sound and motion in public spaces*. We wanted to find ways to deploy early iterations of the design into public spaces, starting

from a thorough understanding of HRI in public. Building on earlier work in sound design that developed methods for bridging the gap between analysis and design interaction in public settings [19], we (1) documented how path conflicts emerge in real world encounters, (2) designed robot sound and motion patterns for these conflict situations and (3) iteratively tested and evaluated our designs in field experiments. On a meta-level, we wanted to set up a collaboration across three different departments of our university, bringing together areas of expertise that are often delimited to one track of the HRI conference, such as *user studies*, *technical* and *design*. The project was designed to build bridges between ethnomethodologic conversation analysis, human factors and motion planning.

The contribution of this paper is twofold. First, we reflect on the interdisciplinary methods we developed for designing robots that can move around people present in public settings. Second, we discuss how our approach of moving out of the lab and into public settings during the design process can help to empower society.

2 Related Work: Designing Robots in Public

Designing robots for encounters with people in public spaces requires multi-modal, accessible communication for situations where it is necessary to interact (e.g., pathway conflicts, inattention) [1, 9]. This involves nonverbal cues, such as motion [2, 3, 8], as well as sound [14, 16] and visual cues such as eHMIs [7, 10, 25].Currently, nonverbal behavior for public robots is primarily designed to make people stop and engage with the robot [3, 11, 13, 21]. It remains less clear how robots should communicate to enable smooth coordination of movement, supporting unobtrusive co-existence.

Designing for continued flow of traffic, Pelikan and Jung [19] describe a method for sound design in ongoing interaction with a self-driving mini bus. They distinguish three phases: *describing* interaction in public with the help of video recorded interactions, *intervening* in interaction through developing sound designs through voice-overs on video recordings and wizard-of-oz triggering of sounds while the bus is driving autonomously on a public street, and *reflecting* on the designs by moment-by-moment analysis of the video recorded sound deployment.

We build on this work when developing sound and motion designs that are closely grounded in problems that surface in actual real-world interactions, and iteratively evaluated through robot deployments in public spaces.

3 Setting

Our interdisciplinary team consists of five members with backgrounds in communication and human-centered design, psychology and human factors, and autonomous systems and motion planning. Through joint workshops, we iteratively developed robot motion and sound behaviors that we tested ongoingly in our university.

3.1 The Robot

We worked with a MiR100 robot, a delivery robot platform primarily used for goods transport in manufacturing and hospital settings [24]. Our MiR100 platform is adapted with an emergency stop button, a box-like chassis with a screen, and a robotic arm for pick and place missions, which we disabled during our study (see Figure 1).

The MiR robot navigates using laser sensors to gauge the distance to nearby objects, stopping when getting too close. We mapped deployment areas during nighttime, manually driving the robot in the space. The top speed of the MiR robot is 1,5 m/s which was capped to 0,8 m/s during our deployments. The robot has an omnidirectional drive and is delivered with a general motion planner that continuously replans for smooth dynamic obstacle avoidance while on the way to a waypoint. In addition to testing the built-in algorithm, we also developed our own motion planners.

The robot was overseen by a human operator who manually set waypoints on a tablet interface during our deployments, flexibly directing the robot to locations where many people were present. Refraining from setting a next waypoint gave us an easy way to pause the robot's movement. The robot navigated fully autonomously between the waypoints, triggering sounds and planning motion as previously programmed.

3.2 The University Environment

The study was carried out at Linköping' university's main campus. To expose a broad range of students and staff to the robot, we chose the largest building on campus as a deployment site. The building is open to the general public during daytime. It houses the university library, a restaurant, a large open lecturing area, group rooms and several floors of open-plan studying areas. During the busiest hours, roughly 1000 people move through the space per hour, according to university statistics.

3.3 Ethics

We received ethical approval from the national ethics review board and did a consequence assessment for collecting video recordings and deploying a technology under development on the university campus. Posters informing passersby of the ongoing study were displayed at all points of entry to the deployment area. Cameras were clearly marked as recording devices. People who got close to the robot were approached and asked to provide their written consent to have their data stored and analysed.

4 Approach: Sound and Motion Design

Departing from a thorough understanding of the interactional troubles that occur in the setting for which we wanted to design and iteratively deploying design ideas in the setting, our approach builds on and extends earlier work by Pelikan and Jung [19].

4.1 Probing Robot Movement in the Lab

We started by testing the robot and its movements in a large lab space with the project group. Driving the robot in the lab, we improvised how interactions could look like and captured them on video recordings. We identified two categories of interactions that could be of interest during the design process: *crossing* in front of the robot and *passing by*, which we enacted either with the robot passing a stationary person or a person passing a stationary robot.

However, when reviewing our recordings, we noticed that they looked more like demonstrations of robot functionality in which the technical group members relied on their knowledge of the robot sensors. As soon as the engineers got close to the robot, they would adjust their speed and make their feet clearly visible to

trigger a robot stop (see [23] for a description of such disciplining behavior). To avoid developing algorithms that would only work for the engineers who built them, we therefore decided that we had to move into a natural space where real people are present.

4.2 Moving Among Real People: Pilot Deployment with Colleagues

To understand how the robot moves among bystanders, we arranged a pilot deployment during a departmental gathering that usually starts with a breakfast mingle. We announced the deployment via the departmental mailing list and joined the ensuing meeting to present our planned study. As people arrived for coffee and sandwiches, we drove the robot in the space. A human operator set manual waypoints to move the robot to different locations. We relied on the robot's built-in motion planning algorithm that automatically brakes and replans when encountering obstacles. In addition, a researcher was ready to press the emergency stop at any time. We captured the deployment from two camera angles, a top view of the area, and a mobile camera following behind the robot.

Reviewing the video data of the deployment, we gathered many examples of how crossing in front of the robot and passing by it looked in a naturally crowded environment. In addition, a third category emerged, which was *stationary groups*, as participants stood chatting in circles, jointly interacting with the robot. The data we captured was rich with examples that we could never have imagined: the robot got stuck for extended periods of time when attempting to cut through groups, and sometimes caught people by surprise when silently approaching from behind. Clearly, the robot lacks ways to communicate with surrounding people by making itself heard in such situations.

4.3 Sound and Motion Design Workshops

We held several design workshops based on clip collections from the pilot deployment. All workshops started with an improvisation exercise to make participants comfortable using their bodies and voices. We then watched a small selection of video clips, selected by the interaction analysts to illustrate situations in which the robot had trouble communicating with surrounding people. Playing one clip at a time on loop, we then used our voices to sketch how and when the robot could emit sound [17]. After doing a smaller session in an office where we focused on the videos, we found it more comfortable and effective to watch the videos from the pilot deployment, sketching over them and then moving to the robot immediately, re-enacting the scene that we had just observed and testing out how the robot should move and sound at the same time. We video-recorded our design sessions and at the beginning of each subsequent workshop, we looked at selected examples from the previous workshop to further refine our designs.

Working in this workshop-style manner, watching examples of actual interactions, and moving to the robot for immediate testing, we could focus on jointly designing how the robot should move and how it should sound. Working on design cases of people who were in the robot's way and stationary, for instance when chatting in a group, emerged as the most relevant design case. While we discussed different types of sounds (e.g. beeps or motor sounds), we primarily focused on exploring sound in combination with

movement, identifying *when* a sound was necessary and at which point in a robot's movement it should be triggered. We therefore used modified versions of our own vocalizations on the robot, which enabled us to adjust timing and duration of the sounds most flexibly.

4.4 Preparing Prototypes for a Field Experiment

To study whether we could use sound to instruct people to move out of the way, we combined three different algorithms with three different sounds, as shown in left-hand part of Figure 1. Low-level access to motion control enabled us to design specific movement behaviors, triggering sound immediately in response to emerging obstacles. In addition to the built-in motion planner that continuously replans its path to avoid obstacles, we implemented two additional planning algorithms, both using a pure pursuit controller [6] together with an A* planner [12] for lateral control. For our own algorithms, the longitudinal speed scales linearly with the distance to the closest obstacle in its path, resulting in the robot gradually slowing down as it approaches a person, coming to a full stop at a distance of 30 cm, and reversing if a person comes closer than that. Upper bounds were put on angular and longitudinal acceleration to prevent jerky movement.

In the **waiting, no path replanning** algorithm, the robot would remain stationary until the path was clear, enabling us to test whether people would move purely because of a sound played by the robot. We used the built-in algorithm for the **not waiting, path replanning** condition, which automatically replanned its path when objects or people were in the way, so we could use it to test whether sounds could be played as a heads-up before a close encounter. Finally, the **waiting and path replanning** algorithm we implemented included a wait time before replanning, resulting in the robot stopping in front of an obstacle before taking another path. The purpose of this was to be able to test whether playing a sound could instruct people to clear the planned path, coordinating with the robot's movement.

We picked two different sounds that should be triggered when people or objects entered predefined zones around the robot or due to the robot needing to replan: an **assertive sound**, a downpitched and abstracted recording of a person clearing their throat, and a **polite sound**, for which we used a very distorted voice saying "excuse me". In response to a person moving out of the way, an additional, distorted "thank you" would be played when the robot waited to replan (see right part of Figure 1 for an illustration). The assertive and polite sounds were played if a person stepped into the inner zone and would only be played again should the person leave the outer zone and then return to the inner zone. Finally, we also used a **continuous sound** inspired by a distorted humming voice to explore whether it could be used to announce the robot's presence in a crowded space.

4.5 Studying Bystander Reactions: Deployment in the Library

To test and iteratively improve our designs with real bystanders, we performed two robot deployments in the university library. We deployed the robot on weekdays during the academic term, for approximately five hours during the first time and four hours the second time, each occasion including the lunch hour, which tends

to be most busy. The robot operator was positioned on a platform overseeing the deployment area, dynamically setting waypoints for the robot to navigate to autonomously. The person responsible for the video data collection was also overseeing the area from this location. At all times, two researchers were present close to the robot. One was responsible for robot safety, ready to physically intervene, while the second was obtaining written informed consent from people who interacted with the robot. For the second deployment, we recruited two students to help with obtaining consent from people present in the space.

In our two deployments, we collected written consent from over 300 people. Some of these only briefly passed through the space where the robot was moving, acknowledging the robot with a glance. In such cases, the sounds were not triggered, since people did not come close enough to the robot. Other people had longer interactions, exposing typical testing behavior such as standing and front of the robot and probing whether it would stop. In these cases, we could observe how the robot sounds were triggered in real time, with people verbally interpreting the sounds in situ, for instance telling someone who was standing in the way that the robot was saying, "watch out". We learned how to better integrate our consent procedure into the environment to naturally evoke situations in which people would block the robot's path, triggering different sound and movement combinations. During the second deployment, we therefore set up a table where we guided people to sign consent forms in such a way that we created a narrow space for the robot to pass through. This often led to the robot triggering the sound, as showcased in the image sequence in Figure 1.

5 Discussion

Collaborating between three different departments, we explored how design, user studies and engineering can be combined to design sound and movement for a delivery robot in a public setting. Extending prior work on sound design [19], we developed methods to combine vocal sketching with reenactments of interactions with the robot in real time. Taking this approach, we became more aware of the relevance of our designs, developing a better understanding of how communication strategies could be used for resolving specific path conflicts.

Rather than deploying a polished design, we iteratively deployed the robot to learn about bystanders' reactions and to design for real-world navigation problems. By testing the robot in different contexts, we gained insights into how designs from one context translate to another, in our case when the spatial organization changes. In the mingling setting in the pilot study, participants were mainly standing still, in circular formations, while the robot drove around them. People in the university library in contrast mainly used the space to go somewhere else and only spent a short time in the area where the robot was deployed. This stresses the value of on-site testing and prototyping to create interaction designs that fit the specific robot, space and people.

5.1 Methods for Interdisciplinary Collaboration

We provide insights on how to bridge different competencies within the social robot navigation community to design robots for public spaces. The designerly, hands-on approach was crucial for bringing the different perspectives together. Referring to successful prior work [19] helped to legitimize the design methods in the team. We quickly learned to appreciate how the workshops enabled us to work on eye level, combining our different competencies in practical work. Prototyping with the robot from the beginning helped to explore the design space by playfully probing what could be done with the robot's movement [26]. The deployments were important milestones to drive the project forward and to work towards joint goals without spending too much time in separation.

In summary, iterating between the stages proposed by Pelikan and Jung [19], observing interaction, intervening in design workshops and deployments, as well as reflecting by analysing video recordings as a basis for the next design iteration proved a valuable method even for designing sound in combination with movement.

5.2 Involving Bystanders in the Design Process

Our work adds to an emerging body of work in the area of public robot deployments by HRI researchers, such as [1, 5, 22]. Rather than actively seeking engagement [11, 13] or discouraging people from engaging [4], we aimed to design for smooth coordination of movement in fleeting encounters. As people are typically on the way to somewhere, they cannot be easily recruited for formal experiments. Instead, researchers have to come to these spaces as guests. We described a method that allows members of the local community to contribute to the ongoing design process by exposing sound and movement prototypes iteratively in a public location.

To enable this exploratory form of research [3, 26], we had to navigate discussions with ethics reviewers and local lawyers, who had little experience in how to handle and support our work. Deploying the robot in the library while developing the design proved more challenging than we had first anticipated. We had to overcome several practical questions related to robot transport, storage and charging in the space. Most importantly though, obtaining consent from everyone who passes through the open plan deployment site was not trivial. While we found a way to make the consent procedure suggested by the ethics review board work in our favor by using it to evoke path conflicts, we would not recommend it unless one has access to a team of researchers who can facilitate the procedure. It may be more feasible to ask for permission to do such studies without written consent, using explicit opt-out instead.

Reporting on our process, we hope to stimulate discussion on how design processes that involve bystander participation can be accomplished in a safe, ethical and effective way.

6 Conclusion

We reported on an iterative, interdisciplinary study to design sound and movement for a delivery robot in a public setting. Future work will report on detailed interaction analysis of the video data and evaluate which sound and movement combinations were most effective in preventing or resolving pathway conflicts.

Acknowledgments

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