Using AI-Enhanced Social Robots to Improve Children's Healthcare Experiences

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Abstract. This paper describes a new research project that aims to develop an autonomous and responsive social robot designed to help children cope with painful procedures in hospital emergency departments. While this is an application domain where psychological interventions have been previously demonstrated to be effective at reducing pain and distress using a variety of devices and techniques, in recent years, social robots have been trialled in this area with promising initial results. However, until now, the social robots that have been tested have generally been teleoperated, which has limited their flexibility and robustness, as well as the potential to offer personalized, adaptive procedural support. Using co-design techniques, this project plans to define and validate the necessary robot behaviour together with participant groups that include children, parents and caregivers, and healthcare professionals. Identified behaviours will be deployed on a robot platform, incorporating AI reasoning techniques that will enable the robot to adapt autonomously to the child's behaviour. The final robot system will be evaluated through a two-site clinical trial. Throughout the project, we will also monitor and analyse the ethical and social implications of robotics and AI in paediatric healthcare.

Keywords: Socially assistive robotics · Child-robot interaction.

1 Introduction

Children experience pain and distress in clinical settings every day, with the negative consequences of unaddressed pain producing both short-term (e.g., fear, distress, inability to perform procedures) and long-term (e.g., needle phobia, anxiety) effects [15, 24]. A range of psychological interventions have been clinically demonstrated to be effective for managing procedural pain, including

breathing exercises, child-directed distraction, nurse-led distraction, and combined cognitive-behavioural interactions [5], with these interventions successfully delivered through a variety of mechanisms including bubble machines, distraction cards, kaleidoscopes, music therapy, and virtual reality games [29].

Recently, several studies have explored the use of social robots in this context, specifically providing psychological interventions during needle-based procedures [2, 12, 27]. The results of these studies have generally been positive, showing high acceptance among the target population as well as promising initial clinical results. However, these studies have all been hindered by a critical technical limitation: in all cases, the robots were remotely operated and employed purely scripted behaviour with very limited autonomy and responsiveness, diminishing the flexibility and robustness of its behaviour as well as its potential to offer personalized, adaptive procedural support to children.

This paper describes a new project aimed at addressing this limitation by developing and evaluating a clinically relevant and responsive AI-enhanced social robot. We believe that interaction with this sort of adaptive and socially-intelligent robot can effectively distract children during painful clinical procedures, thereby reducing pain and distress. The added autonomy of the system has the potential to increase the effectiveness of robot interventions while also making them more practical and robust for clinical applications. We also plan to explore the social context in which such robots are deployed, ensuring that the robot's role is ethically appropriate.

2 Background

This project builds on previous work in several areas: the use of socially assistive robots in healthcare, the use of artificial intelligence for decision making in social robots, and the general study of the role of AI and robotics in paediatric healthcare contexts.

2.1 Socially Assistive Robotics in healthcare

This work falls into the area of Socially Assistive Robotics (SAR) [8], the specific area of social robotics where the goal is for the robot to create a close and effective interaction with a human partner for the purpose of providing assistance and achieving measurable progress in a defined domain. SAR have been used successfully in a wide range of healthcare contexts. In adults, robots have been used to improve the cognitive abilities of Alzheimer's patients [26], to alleviate feelings of loneliness and depression in the elderly [30], and to help adults with autism to improve work-related social skills [14]. For children, a significant application of SAR has been in the context of autism, where robots have been used for diagnosis, intervention, and therapy, and have been shown to improve clinical outcomes including verbalisation, socialisation, and emotional expression [4]; the fact that children often perceive social robots as something between a

companion animal and a pet has meant that they have also been used for play therapy and social learning [3].

In a recent medical scoping review, Dawe et al. [6] surveyed the potential uses of social robotics in children's healthcare contexts and found potential benefits of using social robots to help children who require short- and long-term hospitalisation, as well as intensive care. This review also identified several important gaps in this research area, which we plan, in part, to address. First, most studies have used relatively small sample sizes, non-clinical trial designs, and had acceptability as the main outcome; larger sample sizes and more robust, patient-oriented healthcare outcomes are needed. Also, while it appears that human facilitators play a key role in influencing the outcome of the interaction, the role of these humans has not been extensively studied. Finally, they identified an urgent need to increase the autonomy of the robots to improve robustness and adaptability.

The specific goal of our project is to investigate the use of SAR to reduce children's acute distress and pain in the clinical setting. Trost et al. [28] recently examined eight studies where a robot was used to reduce children's pain and distress: overall, while the results seem promising and several studies suggest that the robots succeeded in reducing pain, there is also a need for improved methodology and measures to draw conclusions. In particular, the authors suggest more effective interventions could be created by ensuring that healthcare experts and engineers collaborate from the start, and that user and family partners contribute to a user-centred design process. Our proposed work includes input from all such groups as part of the research team collaboration.

2.2 Using AI for Action Selection in Social Robotics

A fundamental component in any social robot is the action selection system: the robot must monitor the social situation and make high-level decisions as to which spoken, non-verbal, and task-based actions should be taken next by the system as a whole. It is also crucial not only to choose the appropriate action, but also to monitor the state of the world as detected by the sensors: particularly in the context of an embodied interaction with a robot, it is likely that the predicted state will often differ from the sensed world state, due to both the unexpected behaviour of the human interaction partners as well as the inherent uncertainty involved in sensing and acting in the physical world.

The majority of social robotics systems generally use either scripted behaviour for action selection, or else use machine learning approaches to learn the correct responses to user actions given sample inputs. We instead adopt a third approach and plan to use automated planning techniques [10] as the basis for high-level action selection and monitoring. One current social robot which incorporates aspects of automated planning is the MuMMER social robot [16], which combines planning for action selection with a more traditional dialogue manager. The most similar approach to ours is the JAMES social robot bartender [17, 18], which directly used an AI planner to choose all of the robot actions. Recent work on explainable planning [9] has also highlighted the links between planning and user interaction.

2.3 Ethical Aspects of AI in Paediatric Healthcare

As AI systems such as robots grow more pervasive in daily life, understanding the impact of such systems on society has become ever more crucial. For social robots, in particular, an important consideration is determining the social role that the robot should play [23], as well as an ethical and appropriate means of making the capabilities of the robot clear. Most existing literature on ethical aspects of AI in the healthcare setting often focuses on AI diagnosis tools [21].

With the increased awareness of AI and other related topics, such as autonomous systems, robotics, or surveillance, the need and desire for more information on the end-user side has also increased. However, as in other studies involving media literacy, topics like data privacy are not often addressed in a user-focused manner. Livingstone [13] and colleagues [25] have researched media literacy regarding children's needs and perceptions when it comes to their data and online behaviour and found, for example, that (a) children's concepts and perceptions of AI and data privacy often differs from adults' understandings, (b) children consequently might have different questions, and (c) children will respond differently when provided with information about such topics.

3 Overview of this project

Building on previous work in this area, we are developing and evaluating an autonomous, AI-enabled social robot designed to help children deal with procedural pain in emergency rooms. The behaviour of the robot will be based on psychological interventions that have been demonstrated to be effective in this context, with the details refined through a co-design process with all relevant stakeholders. The system will be tested in the target environment throughout the project period, culminating in a two-site randomised clinical trial at the end of the project. The target robot platform is the Nao robot from SoftBank Robotics (Figure 1), which has been widely used in child-robot interaction studies, including several in the identical clinical context we are targeting [2, 12]. Concretely, this project is addressing the following research questions:

1. When developing an autonomous, socially intelligent robot designed to alleviate children's distress and pain in a clinical context, what behaviours are desirable and feasible to implement with the current robot technology?
2. Can an autonomous, socially intelligent robot alleviate children's distress and pain in a clinical setting, compared to standard techniques?
3. What is the appropriate and ethical way to communicate the role and capabilities of a social robot to children and their caregivers?

To explore these questions we are employing a range of interdisciplinary techniques: the robot behaviours will be defined and developed through a co-design approach that includes children, family members, and healthcare providers; the robot software will be implemented using state-of-the-art AI techniques, and will be evaluated using approaches from usability testing; the clinical trial will be carried out using standard tools and techniques; while the investigation of ethical and social implications will rely on techniques from content analysis.

Fig. 1. A child interacting with the Nao robot

4 Co-design and usability studies

At a high level, the robot will be designed to deliver psychological interventions that have been proven effective for children undergoing clinical procedures. The details of the exact behaviours and features to be included will be developed through a co-design approach involving a number of relevant groups—children, parents/caregivers, as well as healthcare providers (HCPs)—utilising the principles and stages of user-centred interaction design [1, 19]. Co-design participants will be involved throughout the project from an initial co-design phase to determine the needs of all participants, to a usability study phase where the system prototypes will be tested, and a final clinical trial and evaluation phase.

4.1 Co-design

The overall objective of the co-design study is to determine the desired behaviours and features for the social robot from the perspectives of children, parents/caregivers, and HCPs in the emergency department. In particular, the co-design process will attempt to answer the following questions:

1. What are the perceived distraction needs of children undergoing painful procedures in a clinical setting?
2. What are children's perceptions on the use of an AI-enhanced social robot to help them reduce pain and distress when undergoing a painful clinical procedure? What features, functionality, content, and other usability-related aspects would they like in such a robot?
3. What are the perceptions of parents/caregivers of children undergoing painful procedures with respect to social robots?
4. What are the perceptions of HCPs with respect to such robots?
5. What essential features, functionality, and content do HCPs believe should be included in a robot designed for children undergoing painful procedures?
6. How do the views of children, parents/caregivers, and HCPs compare?

Using a prospective descriptive qualitative design, the research team will conduct semi-structured focus groups and individual interviews with children, parents/caregivers, as well as HCPs recruited from two Canadian children's hospitals, with different groups at each site (e.g., 5–7 year olds, 8–11 year olds, parents/caregivers, and HCPs). Children will be included in the study if they are in the appropriate range and require intravenous insertion (IVI), and also meet other medical and practical criteria; parents/caregivers will be included if they have a child who meets the inclusion criteria; while HCPs will include any clinical staff (e.g., nurse, physician, child life specialist) at either site. Each focus group session will be video- and audio-recorded, with a trained researcher taking detailed notes and a second researcher moderating the session via focused open-ended questions. Questions will be based on our previous experience of acute pain management and of conducting focus group needs assessments related to robotic technologies. The interviews will explore core aspects of design, interaction features, and potential direct and indirect impacts of the whole system.

4.2 Usability

The initial co-design studies will be used to inform the behaviour and features incorporated into the robot system. As the system prototypes become available, usability studies will be conducted to evaluate and refine the robot system until it is deemed acceptable and safe for children in a hospital setting undergoing painful procedures. Children and their parents/caregivers at our partner hospitals will take part in usability testing.

Once a child has interacted with the robot for 5-10 minutes (the typical time required for a painful procedure such as IVI), a separate interview with both the child and the caregiver will be conducted. The child will be asked a series of standardised open-ended questions regarding acceptability of the AI-enhanced social robot, any adverse events, and recommendations for improvement. The procedure will be video recorded in order to analyse interactions between the child and the robot at a later time.

This procedure will be repeated until data saturation, or the point where no new information is gleaned from interviewing (expected to occur after 2-3 testing cycles). Information collected in early interviews will be used to inform later interviews using a constant comparative method. Any problematic issues with the robot system intervention that arise during testing will be communicated to the technical team. All interactions with the system will also be logged to help the robot system developers improve the system.

5 Technical development

Informed by the findings from the co-design and usability studies, the robot system will be developed to flexibly and autonomously adapt its behaviour to the needs of the children, incorporating components for social signal processing, goal-directed action selection, and execution monitoring and recovery. In particular,

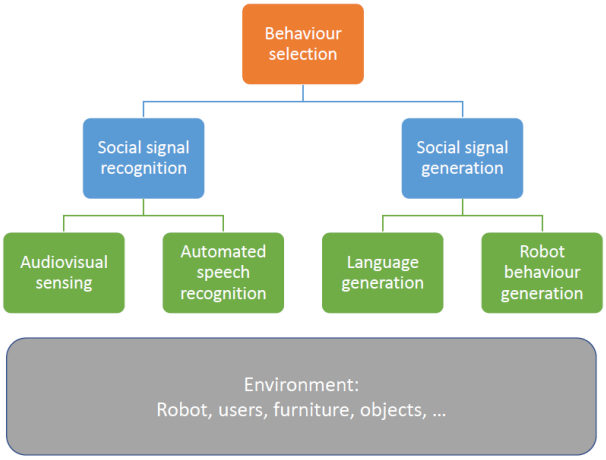

Fig. 2. Software architecture for the robot system.

the following components are being developed as part of the software architecture for the robot as shown in Figure 2:

Social signal recognition A fundamental task in the system is to use the information from the robot's built-in audio-visual sensors—potentialy combined with environmental sensors if necessary—to determine the state of the child, as well as any adults in the area. The particular states to be detected will be determined through a combination of the capabilities of the sensors, as well as the states determined to be relevant from the co-design studies. Based on the detected verbal and non-verbal cues employed by all humans in the vicinity of the robot, we will estimate the socially and psychologically relevant information about their states, such as attitudes, emotions, and intention. In particular, we plan to use a neural-network approach to detect the states, similar to the approach of [22] to automatically detect children's attachment status.

Behaviour selection Based on the interaction strategies identified in the co-design studies, as well as the detected social user actions and social states arising from the social signal recognition process, the system will choose appropriate high-level actions to be performed by the robot. Actions will be selected by a high-level automated planning component that combines theory-of-mind reasoning with efficient action selection techniques [17]. Building on a previously successful epistemic planning framework [18], generated plans will support both task-based robot action and human-robot interaction, with robot actions that include asking questions, giving information, and performing engaging behaviours such as dancing, among other possibilities.

Social signal generation The output of the behaviour selection process is a high-level behaviour specification, represented by a set of high-level actions.

The role of social signal generation is to convert these high-level actions into concrete robot-level actions that can be executed on the robot platform. As output, this component will produce fully-specified multimodal behaviour plans, including verbal and non-verbal actions. The output will be coordinated temporally and spatially for execution on the robot.

Execution monitoring and recovery The system will monitor the changes to the world state (as detected by the social signal recogniser) while the actions selected by the behaviour selection component and elaborated by the social signal generator are executed by the robot. Due to the inherent uncertainty of the robot sensors, as well as the unpredictable behaviour of humans, it is likely that the predicted world state will often differ from the actual world state. The monitoring system will detect such mismatches and will determine whether the execution of the current high-level plan should continue or whether a new plan is needed, invoking the behaviour selection mechanism as necessary to identify new actions to execute.

All software components will be developed and integrated into a single system that will run on the target Nao robot platform. For integration, we will use the Robot Operating System (ROS) [20], a standard, open source robotics platform that provides the necessary technical interfaces and middleware to allow independently developed components to be combined into novel integrated robot systems. The use of ROS will allow existing open-source components to be easily integrated into the system and will also permit the software developed during the project to be released and reused by others.

6 Clinical trial

In the final phase of the project, we will carry out a clinical trial of the developed robot system. The goal of this clinical trial is to test the primary hypothesis of the project: that interaction with a robust, adaptive, socially intelligent robot can effectively distract children during IVI, thereby reducing their distress and pain. The two-armed, randomised controlled superiority trial will be conducted at the same two Canadian paediatric emergency departments where the co-design and usability studies are being carried out, and will be preregistered with clinicaltrials.gov.

Each participant will be randomly assigned to the control or intervention group. The control group will receive departmental standard of care which will include topical anesthetic cream (mandatory) and may include parent/caregiver support, child life services, nursing support, etc. At present, there is no single established distraction therapy or routine that is consistently employed for IV procedures within the target emergency departments. Thus, for pragmatic and ethical considerations, the new study intervention will be compared to what is currently already in practice (i.e., standard of care). Details of the planned clinical trial are as follows.

Eligibility Criteria These will be the same as for the co-design and usability studies, with the addition that children who participated in one of those studies must be excluded.

Objectives Our primary objective is to pragmatically compare patient-reported distress and pain with the use of distraction (via the robot developed in this project) to standard care in children.

Primary Research Questions This trial will address two main research questions: Does interaction with a socially intelligent, autonomous humanoid robot reduce the reported distress associated with IVI, as measured by the Observational Scale of Behavioural Distress-Revised (OSBD-R [7])?, and Does interaction with a robot reduce the reported pain of IVI, as measured by the Faces Pain Scale – Revised (FPS-R [11])?

Outcomes The primary outcomes will be observed distress, as measured by the Observational Scale of Behavioural Distress-Revised (OSBD-R) and self-reported pain, as measured by the Faces Pain Scale-Revised (FPS-R). Secondary outcomes will include measuring parental anxiety, and examining the association between parental anxiety and child outcomes.

Randomisation will be determined using a secure online randomisation tool. We plan to collect a range of data including demographic information, video of the intervention; pre- and post-procedure ratings of child pain (FPS-R) and parental anxiety; plus satisfaction ratings from the clinical personnel and the family. Overall, we aim to recruit 80 patients with usable data, which will provide sufficient power to potentially find a difference in both primary outcomes, using appropriate statistical tests to evaluate the research questions.

7 Ethical and social implications

In parallel to the co-design, software implementation, and clinical trial tasks of the project, we will also examine the role of social robots in children's healthcare settings, employing a user-centric approach that acknowledges the needs of patients and caretakers to understand more about AI and how it affects them directly and indirectly. This work will be divided into three main tasks.

First, we will conduct an exhaustive, multi-disciplinary literature review on AI, ethics, and healthcare, focusing on the literature/research from social sciences, humanities, human-robot interaction, and healthcare.

Next, we will extract from the literature review questions and design input for the co-design and usability design studies in the project, a code-book for a content analysis of existing information material (knowledge translation content) regarding AI in healthcare to conduct a content analysis on such material, asking how far the different (communication) needs and perceptions of both children and caretakers have been acknowledged in the information material design.

Finally, we will include the results from the content analysis in the final design of the clinical trial and will also triangulate the outcomes with the results from the clinical trial, in order to discuss how AI and robotics can be employed responsibly and with a user-centric design.

8 Summary and conclusions

This project plans to extend research on the use of socially assistive robots into the paediatric clinical context, going beyond previous studies in this area by incorporating co-design and ethical considerations throughout, by adding autonomy and responsiveness to the robot system, as well as including adequately powered clinical trial with patient-relevant outcomes. It will also extend existing work on social robotics into a relatively unexplored domain, demonstrating new application possibilities in real-world settings with the potential for real impact on people's lives. In addition to producing a new state-of-the-art technical deployment for the Nao robot platform, we plan to engage continuously with end users to ensure that the research findings have the chance to be translated into clinical practice. As well, the impact of the ethics work will provide recommendations and guidelines for any future user-centric research in AI and robotics, particularly involving children. At present, we have begun the planning stages of our co-design process and technical development on the robot system. However, it is hoped that the outcomes throughout the project will reach healthcare institutions, policy-makers, HCPs, as well as children and families both in Canada and beyond.

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