Challenges Deploying Robots During a Pandemic: An Effort to Fight Social Isolation Among Children

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ABSTRACT

The practice of social distancing during the COVID-19 pandemic resulted in billions of people quarantined in their homes. In response, we designed and deployed VectorConnect, a robot teleoperation system intended to help combat the effects of social distancing in children during the pandemic. VectorConnect uses the off-the-shelf Vector robot to allow its users to engage in physical play while being geographically separated. We distributed the system to hundreds of users in a matter of weeks. This paper details the development and deployment of the system, our accomplishments, and the obstacles encountered throughout this process. Also, it provides recommendations to best facilitate similar deployments in the future. We hope that this case study about Human-Robot Interaction practice serves as inspiration to innovate in times of global crises.

CCS CONCEPTS

• **Social and professional topics → Children**; • **Human-centered computing** → *Collaborative and social computing devices*; *Activity centered design.*

KEYWORDS

Human-Robot Interaction, Robot Teleoperation, Social Isolation

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1 INTRODUCTION

Humans are inherently social beings that rely on interactions with others. For example, social interactions are essential to learn, cope with stress, and be productive members of society.

The practice of social distancing due to the COVID-19 pandemic opposes our natural drive to connect with others. Billions of people quarantined in their homes this year as workplaces and schools required lockdowns to prevent the virus from spreading. These social distancing mandates were instituted to promote health and safety but, unfortunately, exacerbated the effects of loneliness [25] which was already an important societal challenge [18].

Figure 1: The child, right, engages in remote physical play with another child by controlling the robot with our system.

While teenagers and adults may be better prepared to cope with the sudden transition to electronic means, elementary school-aged children (ages 5-12 years old) are more likely to experience the deleterious effects of social isolation [17]. These children often lack the skills or patience to engage with others through electronic methods. During childhood, the development of social skills through physical play, as opposed to a virtual connection, is also crucial to long-term achievement and social functioning [7, 21].

Although robots are currently used to combat the effects of the COVID-19 pandemic in areas of clinical care, logistics, and surveillance, their potential to mitigate the implications of social distancing remains understudied [29]. To advance our understanding of this potential and in an attempt to mitigate the social consequences of the current pandemic, we explored one way in which robots can help children with social isolation. We developed a robot teleoperation system, called VectorConnect, for elementary school-aged children to engage in physical play while being geographically separated. VectorConnect leverages the broad availability of the commercial robot Vector. It provides the means for two users to video chat with one another while one user remotely controls a Vector robot in the other user's location. This system, which is the result of an outreach effort during COVID-19, exemplifies the potential of robots to provide new means for individuals to engage creatively with each other.

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We released our robot teleoperation system to the general public free of charge. In three months, about 2,000 unique users installed VectorConnect. While an important set of people used only part of the functionality of our application, data logs indicate that around a hundred people have utilized VectorConnect to socialize with other people while using a robot. These results along with feedback from users suggest that telepresence robots have a role in addressing the social impacts of infectious disease outbreaks by providing a fun and safe mechanism for individuals to interact socially.

The rest of this paper presents the relevant background for our project and describes our experience as a case study about Human-Robot Interaction (HRI) practice. We discuss the challenges that we encountered through our deployment as well as the lessons that we learned to facilitate similar future efforts. We hope that our work serves as inspiration to innovate in times of global crises.

2 BACKGROUND

In recent times, the robotics community has proposed different ways for robots to help people during global pandemics. For example, robots could help with delivery, sterilization, and monitoring social distancing [39]. In line with our work, Scassellati and Vázquez [29] argued that robots can also help with secondary impacts of infectious disease outbreaks, like helping sustain social distancing and improving mental health.

2.1 Social Isolation & Loneliness

Social isolation is problematic for children for two reasons: (1) it can lead to loneliness, and (2) it can hinder development. Loneliness can negatively affect one's overall health [40] and has been correlated to increased mortality [9]. Studies have also shown that physical activity and play support the development of children's social skills [2, 4]. Unfortunately, social isolation reduces children's access to other kids and these activities, making it harder for them to learn to communicate and socialize effectively with others [6, 11, 33].

Within human-robot interaction, most prior research in loneliness has focused on investigating how it may affect human perception of robots. For example, experiments with undergraduate students suggest that higher feelings of loneliness may result in higher perceptions of social presence from social agents, including robots [20]. Additionally, memories of lonely events may result in higher perceptions of anthropomorphism towards a robot [13].

Close to our work, Odekerken-Schröder et al. [25] conducted a study in which they analyzed data from social media posts related to how people perceived and engaged with Vector robots during the COVID-19 pandemic. Their analyses suggest that when the Vector robot is used as a companion robot, it can potentially help mitigate human loneliness. Meanwhile, Martelaro et al. [22] demonstrated how expressive robots can encourage trust, disclosure, and feelings of companionship in students working with a robot.

Our effort to try to help with the pandemic is in part motivated by prior work in Socially Assistive Robotics, which focuses on developing robots that assist people through social rather than physical means [23]. However, our system is not meant to serve as a companion for an isolated child; instead, it is meant to connect two geographically distanced people.

While video conferencing systems enable individuals to virtually connect with one another, they lack the physical aspects that children often enjoy during play. Also, prior work suggests that physically-embodied robots may lead to more positive interactions with users than virtual agents [3]. These ideas motivated us to explore robot embodiment as a bridge for remote children to engage in physical play with one another.

2.2 Telepresence

The proposed system to help fight social isolation builds on a long history of research on telepresence robots within HRI. Prior work in this area has focused on understanding the potential and effects of telepresence robots in remote work and collaboration [27, 32, 38]. Besides, significant effort has been devoted to using telepresence robots to support independent living and provide care for the elderly people [19]. Older adults have had favorable opinions of telepresence robots, and have found benefits using them when engaging in remote social interactions with friends and family [5].

Our work is inspired by prior studies on the long-term use of robot telepresence systems. Seelye et al. showed the feasibility and positive acceptance of using a teleoperated robot among a sample of independently living older adults [30]. They found that the use of a teleoperated robot increased the older adults' social connectedness when talking to their friends and adult children. Similar to other work in longitudinal HRI studies [14, 34], Cesta et al. [10] indicated that functional and practical aspects of the robot are central to promoting long-term interactions and fostering positive user experiences. This prior work suggested that one of the main concerns for primary users is the usability and maintenance of teleoperated systems. For this reason, we put special emphasis on making our system practical and easy to use.

Telepresence systems for children have been developed in the contexts of helping them learn a different language [37], connect to distant classrooms [36], and receive an education while hospitalized [31]. Interestingly, Tanaka and colleagues [37] suggested that children were able to more successfully communicate their intentions to others while using a teleoperated robot instead of a traditional video call. Furthermore, prior work has shown that teleoperated systems allow for children to physically access objects in remote locations, facilitating their ability to communicate and engage with one another remotely in educational contexts [36].

3 A ROBOT TELEPRESENCE SYSTEM TO FIGHT SOCIAL ISOLATION

3.1 The Problem

We identified the problem of social isolation as an important challenge for our society, especially children, during the early days of the pandemic. As we brainstormed solutions for this challenge, we thought that it would be beneficial to find a way to help connect children with peers and family in an engaging way. Such a solution needed to do more than a traditional teleconferencing platform: it needed to support and encourage physical play. Physical play would make communicating with others fun for children and aid in their development in a more traditional way than teleconferencing.

3.2 Design Goals

First, we wanted to enable pairs of elementary school-aged children to interact with each other through a system that provided opportunities for physical play as if they were colocated. Second, we needed to build a system in a way that was safe and respected users' privacy. The latter consideration was particularly important given the young age of our target users. Third, we needed the system to be simple to set up for parents, who we expected would regulate access to our solution for children and may not have much prior technical experience. Last, it needed to be engaging for children.

3.3 Our Solution

Based on our design goals, we decided to develop VectorConnect, a mobile application that allows children to play remotely with their friends and distant family using an inexpensive, commercial robot. Using our software, we enabled a child in one home to use a phone or tablet to take control and "become" the robot in another child's home. This meant that they could then play physical games like hide and seek, or engage in building and navigating challenging obstacle courses via robotic telepresence. Also, our mobile application provided the means for children to speak and interact with each other via a video call. This capability allowed for combined physical and social engagement, which is an essential activity at the elementary school-age [26].

3.3.1 *Physical Interaction Through the Robot.*

We chose to use a Vector robot made by Anki for our system because it is small, friendly, expressive, safe for children to play with, and robust to rough physical interactions [35]. Vector was also widely available in the consumer market at approximately USD 200 per unit.

To create a variety of opportunities for physical play, we allowed one child to remotely control a robot in another's home. More specifically, the remote child could access the robot's camera, navigation, and animation capabilities through our mobile application. For privacy reasons, we required the local user who is colocated with the robot to give explicit permission to the remote user to access these features through our application.

3.3.2 *Social Interaction Through the Mobile Application.*

To facilitate ease of use, we implemented the interface of our mobile application in the spirit of existing video call platforms such as Zoom and FaceTime. The interface allowed users to see each other through video and communicate verbally on their phone or tablet, as well as control the Vector robot, as previously described. Video and audio were streamed directly from one user to the other without going through external servers, to keep interactions private.

3.4 Implementation Details

We implemented our mobile application in line with our design goals. The back-end of our system served to establish a direct connection among two users and the robot. The front-end of our system controlled its interface, giving users a simple set of options to (a) provide necessary information to connect to a local robot so that it could be teleoperated during calls, and (b) communicate with a remote user. The following sections provide detailed descriptions for each of these software layers.

3.4.1 *The System's Back-end.*

We implemented peer-to-peer communication between two mobile devices using two key components: a Traversal Using Relays around NAT server, and a Web Real-Time Communication (WebRTC) connection post-negotiation. The former server was used for negotiating a connection between two users using a common call ID. This call ID served as a private key between the parties, making the call secure from external intruders. Once the peer-to-peer connection was established, the WebRTC framework was used to stream phone video and audio data as well as robot commands and robot video from one device to the other. In particular, phone video and audio data was sent through WebRTC MediaStreams, enabling real-time communication between the two parties. Robot commands and video were sent via WebRTC RTCDataChannel to a local device connected to a Vector robot.

We used the preexisting protocol buffer files from Anki in order to implement a Google Remote Procedure Call (gRPC) interface to control Vector. Utilizing protocol buffers was convenient as it was an accessible and well-defined interface to Vector's core APIs. However, due to multiple layers of security built into the Vector hardware and software stack, starting a connection between the mobile device and Vector was challenging. It required reverse-engineering the provided Python Application Programming Interfaces (APIs) to port the required functionality to both Android and iOS platforms.

We implemented software to connect to Vector in the Dart programming language using the Flutter mobile application development framework [15]. The processes of obtaining an active gRPC connection between a mobile device and the robot worked as follows. First, the system obtained a per-device Secure Sockets Layer (SSL) certificate by querying an Anki API with the hardware's serial number. Then, it retrieved a security token from Anki's servers using a valid anki.com login created by the user. We implemented a simple interface, as described in the next Section, to gather the necessary information from users to complete these steps.

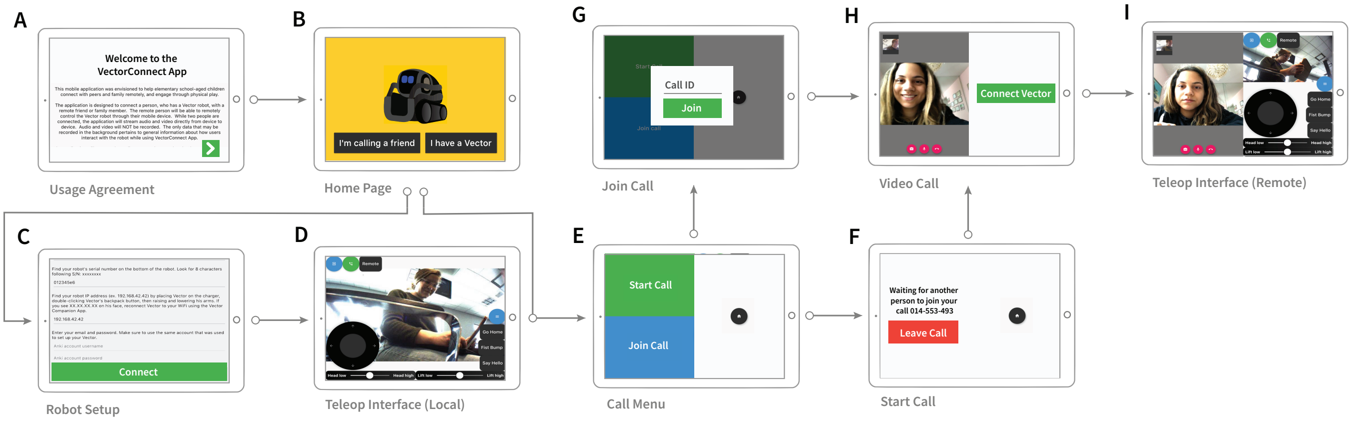
Using an open gRPC connection between the local device and Vector, our application was able to control the robot from a local device or from a remote device connected over the Internet. This included sending navigation and animation commands, as well as receiving sensor data such as the robot's camera feed.

3.4.2 *The System's Front-end.*

Similar to the back-end, we implemented the front-end of our application using Dart and the Flutter framework. This choice enabled rendering the interface of the application on both Android and Apple mobile devices using the same code. We tried to make this interface as simple and easy to use as possible. The application's typical user flow is shown in Figure 2.

We designed the application interface such that when it first opens on a device, it shows a welcome message along with our Terms of Service (Fig. 2A). The welcome message explains that the only data that is recorded in the background corresponds to general information about the use of the application and how users interact with the robot while using our system. Users must agree to this data collection before continuing to the application's home page.

The home page of the application (Fig. 2B) provides users two options: setting up a connection to a Vector robot to enable teleoperation; or starting a call with a friend. The interface to connect to a robot (Fig. 2C) is a form that gathers relevant information to establish the gRPC connection described in the prior Section.



This mobile application was envisioned to help elementary school-aged children connect with peers and family remotely, and engage through physical play.

The application is designed to connect a person, who has a Vector robot, with a remote friend or family member. The remote person will be able to remotely control the Vector robot through their mobile device. While two people are connected, the application will stream audio and video directly from device to device. Audio and video will NOT be recorded. The only data that may be recorded in the background pertains to general information about how users interact with the robot while using VectorConnect App.

Find your robot's serial number on the bottom of the robot. Look for 8 characters following S/N: xxxxxxxx

012345e6

Find your robot IP address (ex. 192.168.42.42) by placing Vector on the charger, double-clicking Vector's backpack button, then raising and lowering his arms. If you see XX.XX.XX.XX on his face, reconnect Vector to your WiFi using the Vector Companion App.

192.168.42.42

Enter your email and password. Make sure to use the same account that was used to set up your Vector.

Anki account username

Anki account password

Waiting for another person to join your call 014-553-493

Figure 2: Our application's interface. The application shows a user agreement view when it first opens on a mobile device. Once this agreement is accepted, it becomes hidden. The application then shows a home page from which users can either set up a local connection to a robot or start a call with a friend. See the text for more details.

This includes the user's login information for anki.com, the serial number of the robot, its name, and local IP address. When our application successfully connects to the robot, the page where users can navigate and animate the platform appears (Fig. 2D).

When a user chooses to call a friend from the home page of the application (Fig. 2E), they can start a new call (Fig. 2F) or join a call (Fig. 2G). Starting a call generates a call ID automatically, which is displayed on the interface of the application. Users need to share this 9-digit call ID with a friend for them to join the video call.

Once a video call is established, two remote users can see and hear each other through VectorConnect (Fig. 2H). A user can then permit the remote person to teleoperate his or her local Vector. Only after permission is granted the application displays the camera feed of the remote robot and provides controls for it (Fig. 2I). These controls include a joystick for sending motion commands, sliders for changing the tilt of the Vector's head and the height of its lift, and a set of menu buttons to activate preset Vector animations and display options. An example animation is the robot saying "Hello". An example display option is changing the color of its eyes, which can help increase the robot's emotional expressiveness.

3.4.3 *Surveys.*

The application included a total of 3 optional surveys intended to collect user satisfaction and demographic data. The first survey was a short, one-question visual survey designed for children following the Smileyometer by Read et al. [28]. The survey consisted of five "smiley" face icons portraying varying levels of user satisfaction with our app's experience: {awful, not very good, okay, really good, fantastic}. This survey appeared in the application with a 10% probability each time a video call was completed. Figure 3 (left) depicts this satisfaction survey.

The other two surveys were longer-form, web-based surveys for parents. The first longer-form survey was presented along with the Terms of Service when the application was first launched. This survey first focused on collecting demographic information about each child in a household including their age, grade, and gender. Then, it asked about each child's familiarity with robots, including those made by Anki. Lastly, the survey asked if each child was staying home from school due to the pandemic, and how much loneliness each child was experiencing. The second longer-form survey was designed to collect data about a household's experience with robots and our application. A prompt to complete this optional survey was presented monthly once a video call ended.

3.4.4 *Other Implementation Details.*

We also integrated a crash reporting system into our mobile application to enable comprehensive and organized bug reporting. This allowed us to improve our application iteratively as it was being developed and identify any potential issues post-deployment. We used the Google Firebase Crashlytics platform to this end, which provided us real-time crash reports and de-identified relevant usage data.

We organized routine user testing sessions as part of our development process to improve the robustness of our application. During these sessions, we debugged platform-specific crashes and bugs. We made sure to test on multiple devices across different categories such as Apple vs. Android, tablet vs. phone, and devices released in different years. We also conducted pilot testing with children, who helped verify usability. For instance, we observed 5 children (ages 4-13) play with the system in one household. Each child took a turn stepping out of the room with an iPad to remotely operate Vector. When they operated the robot, they first drove it around and experimented with its capabilities. The in-person children were the first to initiate direct play with the robot. During the test, we suggested four play ideas: building an obstacle course, Hide-and-Seek, Simon Says, and Tic-Tac-Toe. For example, when playing Hide-and-Seek, we told them that the in-person children could hide an object for the remote child to find with the robot, that the in-person child could hide for the remote child to search for, or that the remote child could hide the robot for the in-person child to seek. The children tried hiding the block and hiding the robot, but none of the in-person children hid. Overall, this experience suggested that our system was fun to use.

Lastly, we created a project website, which described play ideas, and a support email account to answer questions about the system. These efforts aimed to facilitate user adoption and retention.

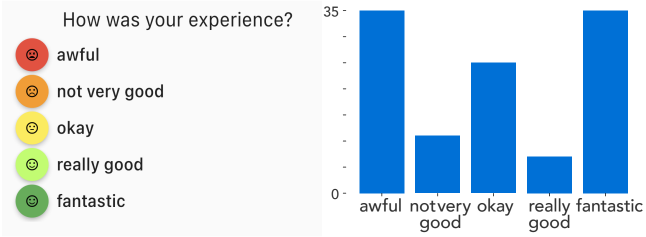


Figure 3: Smiley face survey shown in VectorConnect following a video call 10% of the time (left) and responses (right).

3.5 System Deployment

We originally intended to deploy our system as an official mobile application by our university. We coordinated with our institution's Information Technology Services to satisfy the cybersecurity, privacy, and accessibility deployment requirements including compatibility with the iOS and Android screen readers. However, local difficulties due to COVID-19 and the time-sensitive nature of our project made publishing our system through our university impossible. We ended up releasing our application at the beginning of June 2020 using the personal accounts of members of our team on the Apple App Store and Google Play store. Section 5 further discusses the challenges that we faced from trying to publish the app through our official university channels.

While working to release our application, we collaborated with our University's Office of Development to find donors to support distributing robots to nearby children in need. Thanks to our Engineering School and alumni, we were able to distribute 200 free Vectors. Sec. 5 provides details about the robot acquisition process.

4 RESULTS

Our project was not a traditional HRI study, but an outreach effort. At launch, we promoted our application in several articles and social media posts. Through our website, we gave away robots to the first 200 families in our community who requested one. These robots were given away unconditionally, without requiring users to test our app or complete its surveys. Indeed, we deliberately chose to limit the data that we collected to avoid concerns over privacy and reach as many people as quickly as possible.

We did not limit app usage to the families that received the robots. The application was available for free on both the Apple App Store and Google Play App Store in the United States.

The next sections describe user adoption of our application since it was launched in June until September 2020. We describe the performance of our application according to anonymized usage data, user ratings, and application crash information. Unfortunately, by September 2020, no user had completed the feedback survey presented monthly. However, we were able to gather demographics data from several users. We examine usability results in light of the data that were voluntarily reported by parents about their children.

4.1 Demographics

As mentioned in Sec. 3.4.3, we collected demographics data from an optional survey that was displayed in our application when it first opened. This survey was intended for parents to provide data about the children that would be using our application.

From the release of VectorConnect in June to September 2020, 48 parents began the demographics survey and 30 completed it. In the completed surveys for 30 families, a total of 47 children were represented (27 male and 20 female). Furthermore, 41 of these children were in the target audience of ages 5 to 12, confirming that we reached our target demographic. One child's age was not reported. The median and average child age were 9 and 8.5 years old, respectively. Of the seven grades reported, sixth-graders were the largest group ($n = 10/47$). Also, 77% ($n = 36/47$) of children were staying home and not attending school due to the pandemic.

Parents assessed that 85% ($n = 40/47$) of their children were lonely to some extent while at home. Out of those children, 94% ($n = 44/47$) were assessed by their parents as wanting to interact more with faraway peers and/or family members. Further, 60% ($n = 28/47$) of children interacted only weekly or less frequently with other remote children while staying at home. One of the respondents said that there was *"no real play, [just] talking and texting"* for their children. Our system aimed to improve this situation.

4.2 System Adoption

In this section, we discuss how users took advantage of our application based on system logs and feedback through the app stores.

4.2.1 Effective Users. There were a total of 1,985 unique users that launched the application from the release in June to the end of September 2020. From this set, 92% ($n = 1{,}828$) of unique users accepted the Terms of Service and continued into the application.

Ninety-one unique users used the two key functionalities of our application: they connected to a Vector robot, and called a friend. The average user in this group was connected to Vector for 20.37 minutes in total ($\sigma = 28.18$). Also, the average user was on a call with a friend for 16.18 minutes total ($\sigma = 38.42$). These statistics only include calls that lasted a minute or more.

We believe that the impact of our system extended beyond our local community because the total number of unique app users significantly exceeded the 200 robots that we distributed to families. As further explained in the next section, part of this impact came from users that found our application useful in unintended ways.

4.2.2 Connect to Vector. The 1,828 unique users that accepted the Terms of Service made connections to 759 unique Vector robots. There were a total of 3,788 individual connections established with those 759 robots and 1,989 of these connections lasted a minute or more. The average connection time was 3.56 minutes ($\sigma = 4.31$).

Interestingly, 87% ($n = 592/683$) of users only used the application to control the robot and did not use the video calling feature. The average of these users controlled the robot for a total of 8.82 minutes ($\sigma = 16.16$) since the release of the application. These users made an average of 2.9 connections to the robot ($\sigma = 3.7$).

Comments left by users in the app stores also reflected the extent of our application's impact beyond the 200 families that received robots. This impact may have been enhanced by the fact that the remote-control features in our application were unique. For example, one Android user started his review for VectorConnect saying, *"I really recommend this app because it lets you do things that you*

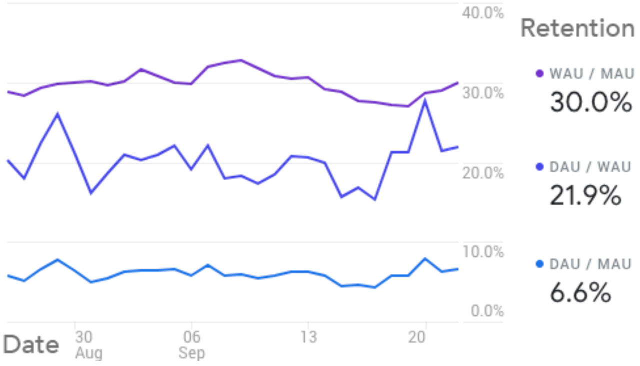


Figure 4: User retention as ratios between users daily (DAU), weekly (WAU), and monthly (MAU) active cohorts. A DAU/MAU ratio of 6.6% means an average user of the application is active for 2 days out of a 30 day month.

can't do on the official app, such as controlling Vector and seeing his perspective." The official "Vector Robot" application by the robot manufacturer did not include any such remote control features. Thus, it is possible that some users may have downloaded our application primarily to teleoperate Vector.

4.2.3 Call a Friend.

A total of 6,440 calls were started between June and the end of September 2020. Of these calls, 336 instances lasted one minute or longer. These calls were made by 193 unique users and had an average duration of 8.86 minutes ($\sigma = 35.67$).

There were 102 unique users that used the application only to make video calls, never connecting to a Vector robot. An average user in this category made 1.7 calls ($\sigma = 1.5$). The total duration of all calls for this group averaged 14.75 minutes ($\sigma = 53.99$).

While many users made video calls without using a robot or teleoperated Vector without establishing a call, the total duration of events with both robot control and video calling was greater on average for users of both features. Users that controlled the robot and used the call feature stayed engaged for almost twice the time of those that controlled the robot but did not use the call feature.

4.2.4 User Engagement.

We considered standard user engagement metrics to evaluate the relevance of our system in users' lives. In particular, we analyzed the number of Daily Active Users (DAU), Weekly Active Users (WAU), and Monthly Active Users (MAU) that our application had in late August and September 2020. We computed the ratio of these metrics as a measure of user retention.

The DAU to MAU ratio for our application was 6.6%, DAU to WAU was 21.9%, and WAU to MAU was 30.0%. A DAU/MAU ratio of 6.6% means that an average app user was active for 2 days in a month. Figure 4 shows that these metrics have remained relatively consistent from late August to September 2020. Although we do not have a good reference in the mobile app space to compare these user retention metrics against, a recent study on Facebook apps reported median DAU/MAU in the 9.0% to 5.6% range for games, lifestyle, and entertainment apps [24]. Our results seem to be in line with user retention statistics for these categories.

Anecdotally, an author of the paper used VectorConnect to play with remote children in her family (ages 5 and 8). These children were told to drive the robot through an obstacle course built out of plastic toy pieces, but they enjoyed destroying the course more. They also liked changing the eye color of Vector.

4.3 User Satisfaction

The optional smiley face survey was a way for users to rate their experience on a 5 point scale from "awful" to "fantastic." While many users exited the application after a call without responding to the survey, we received 113 survey responses since the public release of our application. Detailed results are shown in Figure 3.

The smiley face survey revealed that the majority of users were satisfied, ranking the application "okay" or above ($n = 67/113$), yet responses were polarized. Respondents often picked the extreme values of "awful" or "fantastic," both of which received 35 responses.

App store ratings for both the iOS and Android platforms gave additional perspectives on user satisfaction. As of September 2020, the Apple App Store rating was 3.7 over 5 with a total of 18 reviews. Meanwhile, the Google Play App Store rating was 4.0 over 5 with a total of 7 reviews. Reviewers that left positive comments tended to focus on the extra features available in our application that were not available in other applications. Negative comments tended to focus on technical problems such as the application crashing or not being able to connect to Vector. Our logs indicate that an important number of crashes were due to a bug in one of the libraries that we used to develop our mobile application. We are now working to resolve this issue. Despite crashes, the total portion of crash-free users was 90.24% for September 2020.

Problems related to users not being able to connect to Vector were mainly due to our application requiring very specific and detailed information from users to establish a gRPC connection to the robot, as explained in Sec. 3.4.1. Based on informal feedback from users, providing an IP address or Anki login was difficult at times. Young users often had to ask parents for these details, meanwhile parents sometimes did not know exactly where to find this information. Also, users oftentimes typed the information incorrectly. While we provided an online guide to walk users through the steps needed to set up their Vector robot, finding a way to simplify this process could further improve usability.

In addition to the above problems, our team noticed during development that there was lag on older phones when simultaneously streaming video from Vector and the friend being called. Although our website advertised phone compatibility with our application based on pilot tests, nothing prevented users with non-recommended devices from using our application.

4.4 Summary of Findings

The nature of our project meant that we did not have a good way to confirm with users that our system was indeed reducing loneliness. However, based on the demographics data described previously, we observed that there was a real need for our system. Further, data logs and user feedback suggested that while our application was not perfect, it was found to be valuable by many users. Hundreds of calls were established among two remote parties with our system, and many of these calls involved using a Vector robot. To our surprise, many users also found value in our application as a way to teleoperate their local Vector.

5 BARRIERS AND CHALLENGES

The next paragraphs describe important challenges that we faced from the inception of our project to deployment. By discussing these challenges, we hope that other teams can better prepare for and promptly tackle these problems.

a) The Pandemic. The pandemic brought many uncertainties and emergent complexities to daily life, and our processes were no exception [1, 12]. Routine activities that would have been resolved in one in-person meeting instead required many more virtual ones.

We had planned to distribute the donated robots through local schools. However, it was uncertain when local schools would reopen and whether we could distribute robots through them – an approach that we originally envisioned to effectively reach children in need. Unfortunately, the re-planning of activities at local public schools towards the end of the academic year made it difficult to coordinate and get approval for this distribution process. Therefore, we ended up distributing the robots by advertising this opportunity online, through news outlets, and through word of mouth.

b) Choice of Robot Platform. We had many good reasons to choose Vector for our project: (1) it satisfied our specifications and requirements described in the Design Goals Section, (2) a study had found that Vector has the potential to mitigate feelings of loneliness [25], (3) Vector was readily available on the market, and (4) our team had prior experience with a similar robot, Cozmo. Unfortunately, Anki, the company that had designed the Vector robot in 2018, had gone out of business and the rights to the robot had been transferred to another company, Digital Dream Labs (DDL). It was uncertain at first how long support for the robot would continue, and how large the supply of Vector robots was, considering that new ones were not being produced. However, former Anki employees helped us understand what was possible with Vector, and we received assurance from DDL that support for the robot would continue.

Two additional challenges with Vector were establishing a connection between the robot and our mobile application, and getting access to some of its internal components. We attribute these challenges to the robot being designed as a consumer product, not as a development platform. This meant that we had to reverse engineer some of the software of the robot, and had limited access to its functionalities. As a result, we could not implement all of the features that we envisioned for our teleoperation system. For instance, we would have liked to enable remote children to hear what Vector hears through our application, but we could not find a way to access audio gathered from the robot. We appreciate the many features that Vector offers, but would also like to see more robots on the market with more accessible programming interfaces.

c) Price Gouging and Seller Approval. Price gouging was rampant during the early months of the pandemic [8], and the prices that were set for Vector robots were no different. This was exacerbated because Anki was no longer producing new robots. As we sought ways to acquire robots in bulk for distribution, concurrent institutional approvals had to be obtained to make the purchase. This step proved difficult since the prices of the robot kept rising rapidly. For instance, prices rose by 75% from the time we started talking to donors to the moment we were approved to make purchases. By the time a vendor was approved, the number of available Vector robots had dwindled and demand for them was still high. Since donors provided funds based on a lower individual cost estimate from the start of the pandemic, the number of robots that were eventually acquired was slightly fewer than anticipated.

d) User Privacy. We implemented security measures in our mobile application to assure the security and privacy of child users. Some of these measures were clearly identified when we started implementing our system, while others were identified while working to release our application to the general public. For example, at the beginning of our project, we decided that our application would generate a new, nine-digit call ID each time a child started a call and that this call ID needed to be communicated to a friend through a different channel. The fact that our application did not automatically distribute the call ID required parents to coordinate with each other before establishing a call for their children, thus preventing impromptu calls with unknown people.

Per Apple's requirements for building applications for kids, we implemented a "parental gate" for our application in iOS. The gate was a simple task that required solving an arithmetic problem to prevent young children from following links out of the app to external websites. For example, the gate appeared when users clicked on the link to our project website in the application's welcome message, or when users chose to fill out one of our online surveys. The gate was not something that we had planned for, but was essential for getting VectorConnect in the Apple App Store.

Vector had no explicit visual indication when it was remotely controlled. We did not use the screen for this purpose because we wanted to allow users to customize the face. Also, to the best of our knowledge, Vector's API did not allow changing the robot's backlights, which were the only other visual display that we thought could be used for this purpose. However, such a visual indication would be a great addition to a system like ours. It could help more transparently indicate when the robot is being teleoperated.

e) Institutional Review Board (IRB) Approval. Due to the pandemic, our local IRB required all requests for review to be funneled through newly instituted subcommittees to streamline and fast track study activation and implementation for COVID-related projects. These subcommittees were established to provide oversight from study concept through study initiation.

However, the newly formed layer of pandemic-specific approval processes were not integrated with the existing IRB processes in a streamlined way. Further, there were other competing priorities, such as COVID-testing and contact tracing efforts that diverted reviewing resources away from our effort.

f) Institutional Friction. Our team anticipated going through the processes necessary for creating an application affiliated with our University. Thus, we worked for a significant time to comply with institutional requirements. This included working with the University to ensure that our application met the identity guidelines of our institution, and tailoring our development processes to accommodate for University requirements to publish our application, such as fulfilling Web Content Accessibility Guidelines. We also proactively mitigated cybersecurity risks to our institution and to our users, developed a privacy policy that comports with our institutional approach to privacy, and demonstrated that our existing privacy safeguards complied with the university guidelines.

However, in exerting its brand control, the University Printer's office had to review our application's icon to ensure that the icon met the identity guidelines of our institution. The process to approve the icon took over three weeks, compounding the delay from the institution's developer team to approve our application. Further, the review by the Office of General Counsel (OGC) was especially delayed due to the increased volume of review-requirements by the OGC. Therefore, our team finally opted to publish the application using private developer accounts instead of our institutional account. Had we decided to publish privately earlier, we would have saved several weeks of delay and a significant amount of effort.

6 OPPORTUNITIES AND RECOMMENDATIONS

We aim to bring broad awareness to the potential roles that robots can play in addressing the social impacts of infectious disease outbreaks, as well as to facilitate similar future efforts in HRI. The following sections summarize the lessons that we learned through this effort to deploy time-sensitive applications.

Procedural Changes. There needs to be a coordinated institutional effort to streamline and harden administrative procedures against major disruptions, like the pandemic. Although procedural hardening by specific institutions like ours is beyond the scope of what the HRI community can directly accomplish, our project is a good example of how procedural challenges can impact the community. Raising awareness about these problems might result in finding effective solutions.

Our institution implemented a new layer of approval procedures to address issues specific to the pandemic. However, those processes were not well integrated with existing institutional review processes. Further, our application was relegated in institutional processes as it competed with other similar efforts for reviewers' time and resources. Instead of requiring that all new efforts be funneled through newly established procedures, pre-defined exemption criteria could be established to demarcate activities like ours from what most business practices would expect. Such an effort could facilitate the success of novel academic projects that aim to leverage technology to positively impact society.

Market Opportunities. Our project highlights a market opportunity for low-cost, reliable robotic platforms that provide development tools for others to build on. Unfortunately, the HRI robotics market is young and volatile. Start-ups have limited resources and are frequently dissolved, making it difficult to have robust platforms during emergencies. It may be that this issue will get resolved by the robotics market maturing over time; however, in the meantime, we hope that our project serves as an incentive for companies to preserve documentation and intellectual property in the public domain whenever possible.

While we could not have predicted the pandemic, partnering early with existing manufacturers could have helped with our ability to maintain a stable deployment system, even if they were not producing an ideal platform.

Readiness Initiative. The difficulties that we encountered during the deployment of our teleoperation system would have been reduced if we had a partner who was capable and willing to collaborate on the publicity and distribution of our system. An example of the kind of entity that we are advocating for is the Center for Robot-Assisted Search and Rescue (CRASAR) [16]. CRASAR is a proponent for the use of unmanned systems for emergency response and public safety, and has been relied upon by the search-and-rescue community for rapid response to emerging disasters. CRASAR served as a centralized point for coordinating activity, gathering volunteers, and hosting solutions for the search-and-rescue community for rapid responses to emerging disasters. CRASAR has readily supported emergencies and catastrophes like wildfires, floods, and hurricanes with unmanned systems.

An organization like CRASAR for supporting the deployment of socially assistive robotic systems could maximize the positive impact of projects like ours. Such a nonprofit partner could help reach target populations faster through better publicity and more mature plans for the distribution of technology. Additionally, such an organization could aid in helping stakeholders quickly understand how robotics can help with pressing societal problems, including the secondary effects of disease outbreaks [29]. These efforts could make it easier for teams like ours to take action faster, and for users to better take advantage of these opportunities as they emerge.

7 CONCLUSION

Social isolation can hinder child development and lead to loneliness. In turn, loneliness can negatively affect one's overall health [40] and increase mortality [9]. In an effort to cope with these challenges during COVID-19, we built a robot teleoperation system to help fight social isolation in children. Our system, VectorConnect, allowed two remote users to communicate with one another while physically playing with a Vector robot.

VectorConnect was distributed free of charge and used by hundreds of people to connect with others between June and September 2020. During the course of its continued use, we discovered that there is interest and a real need for a platform like ours. However, due to the circumstances, our deployment was difficult in many ways. For instance, we faced problems because of inherent challenges due to the pandemic and our specific choice of robot platform. We believe that these challenges could be alleviated in future deployments through proactive procedural changes to administrative procedures, and through coordinated efforts at a community level. In addition, our experience showed that it is important for robotics companies to preserve and provide access to intellectual property whenever possible. We hope that our story serves as inspiration to innovate in HRI and help those in need during global crises.

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