A Novel Online Robot Design Research Platform to Determine Robot Mind Perception

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***Abstract*—A common issue in Human-Robot Interaction is a gap in understanding how robot designs are perceived by the user. A common issue encountered by practitioners of Machine Learning (ML) is a lack of salient data to use in training. The "Build-A-Bot" project is developing a novel research platform implemented as web-accessible 3D game that affords data collection of many user-provided robot designs. The designs are used to train ML models to better evaluate robot designs, predict how a design will be perceived using Convolutional Neural Networks (CNNs), and create new robot designs using Generative Adversarial Networks (GANs). This paper outlines the current and future work accomplished by an interdisciplinary undergraduate student team at the University of XXX across Computer Science, Music, Psychology, and other related STEM fields that have created Build-A-Bot.**

***Index Terms*—robot design, machine learning, fNIRS**

I. Introduction

Traditionally, robots were built for use in industrial settings [1]. However, the roles of robots are rapidly evolving thanks to recent advances that allow them to act socially [2], [3]. The applications of social robots range from healthcare to education to domestic assistance [4]–[7]. Facing this new category of social agents raises significant questions about the prospective relationship between human and machine. One leading question that will highly influence our interactions with robots is how a human interprets and perceives a robot in a given context. It is known that humans attribute mental states to others to interpret their behavior, referred to as the Theory of Mind (ToM). However, key elements of social features that humans assign to robots are not well understood. For instance - to what extent do people perceive a mind in robots? How would a robot need to be designed to decrease or increase mind perception?

To answer these questions, it is necessary to explore the full range of design characteristics of robots. These characteristics entail higher order cognition (e.g., rationality and logic) and emotion (e.g., feelings and experience) [8], [9], two core capacities that map onto the dimensions of mind perception, agency and experience [10] that we seek to explore. It has been demonstrated that people automatically evaluate a target's mind along these dimensions [10], and such targets can either be living entities, such as humans and animals [11], or non-living entities, such as robots [9], [12].

Fig. 1. The Build-A-Bot Logo as designed by students on the project.

Historically, robots are attributed with mainly higher order cognition but not emotions [1], [13], [14]. However with the recent deployment of social robots, robots display emotions and socially engage with humans. They are designed using form factor, a hardware design aspect addressing performance-based characteristics (e.g. the robot being able to move) and aesthetic dimensions of the robot (e.g. appearance, how it moves). Form factor design has been shown to generally influence human expectations of the robot [15], perceived trust [16]–[18], intelligence [19], [20], and warmth and competence [21], [22].

When a form factor is chosen, the designer chooses factors for robot functionality as well as for what they think is the best choice to enable desired robot social functions. However, research so far has been inconclusive about the causal relationships between robot design and perceived social functions in the robot [23]–[25]. In the worst case, the design can lead to misconceptions and rejections of the robot [15]. One major challenge facing both research and industry applications is the wide range of design dimensions. This makes it nearly impossible for humans to predict how a new design, or a change in an existing design might impact how that robot is being perceived. Simply put, the challenges facing robot design include:

1) Current design choices are heavily influenced by the robot's functionality
2) The field of robotics suffers from under-representation, which limits the kinds of designs that we can explore
3) Too many possible designs exist to manually test which mind perception attributes a user identifies in each

In order to address the first two challenges, the Build-A-Bot project creates a novel research platform for rapidly creating new robotic designs. Through this platform, we engage with the community to solicit new robot designs that are tied to a specific item of mind perception. This reverses the traditional evaluation approach of robot mind perception. Often, the robot design is fixed and we ask users a number of questions in regards to how they perceive the given robot. In our new platform users can create any robot they desire by piecing together parts in an interactive application. When the user creates a new robot, we present them with a targeted mind perception attribute and ask to create a robot that is most closely associated to that target.

The Build-A-Bot platform seeks to maximize possible robot design choices by enabling designs independently of robot functionality (e.g. the designed robot does not actually have to be functional given physical constraints). To counteract under-representation in the robotic design field, the platform is deployed online and usable by anyone with internet access and a display of the size of a tablet or larger. It is anticipated that the design of the interface enables users from ages 6 and up to design robots, broadening the participation of children as well as the elderly in robot design.

To address the last challenge, we will be using Machine Learning (ML) to assess how mind perception is tied to robotic design. One strength of ML is its ability to extract salient feature information from a given training corpus. In order to be effective at feature extraction it is necessary for the training corpus to have a large number of diverse examples. By addressing the first two challenges, the Build-A-Bot platform is expected to create a diverse set of designs provided by our users and will serve as an ideal training dataset to use in ML.

II. Technical Approach

In order to allow users the greatest degree of freedom while enabling the collection of research data for each created robot design, we need a platform that meets the following criteria:

- Allows for robot designs to be created intuitively (e.g. drag and drop of building blocks to create a design)
- Is available online to be accessed from multiple locations
- Is cross-platform to be accessed from almost any computing device
- Enables 3D representation of the designs to display robots similar to how they might be interacted with
- Allows for usage data to be collected as users interact with the system

After exploring multiple options, we decided to utilize the game engine Unity [26] for creating the Build-A-Bot robot design platform due to its flexibility, extensive documentation, and existing implementations of character creation interfaces [27] from which we wanted to base our new robot design interface.

We originally chose Unity Multipurpose Avatar (UMA) [28] from the Unity Asset Store as a pre-made base character customization setup. However, we realized this would not suffice as it relied on humanoid models, preventing the user from creating more biomimetic or non-biomimetic robots and the implementation if a crucial feature: the ability to pick and choose different body parts and replace them at will. For our 3D model creation we compared two popular tools: Autodesk Maya and Blender. Autodesk Maya provides a better integration with Unity than Blender [29], [30], has faster rendering times [31], and offers more detailed modeling options [32] – a key feature for our objective of maximizing robot design choices. In order to maximize the possibilities of what a user can do with each 3D model, parts are designed to be as generic as possible (e.g. the same model could be used as torso, leg, arm, or nose). Models are also designed to load quickly inside the web-based application. Polygon counts are kept as low as possible when building a new model, and we avoid using overly complicated mesh structures.

Once a user submits their robot and marks it as complete, the design and its associated metadata are stored for analysis. We store a tree structure capturing the user's actions as they create a design, as well as usage statistics associated with the user's session. The 2D screenshots and 3D model definition for the user's submission are also stored. This data provides a detailed look into how the user incrementally created their robot, including points where they changed their mind about a given design choice. The screenshots and model definition are also crucial, as they give us data that can be used to train machine learning models capable of predicting if the look of a given robot is likely to perceived a certain way.

III. Research Approach

Our initial research question was to explore how people create a Theory of Mind (ToM) while interacting with a robot [33], [34]. However, we realized that using only existing robot designs is not suitable to fully answer this question. Currently, the largest database that looks at how existing human-like robot designs are perceived [35] contains around 250 different robots. Even if we had access to each robot in this collection, evaluating theory of mind for each design would be a costly undertaking and would only produce results pertaining to the relatively small subset of possible robot designs. This reactive evaluation of existing designs would have little predictive power when generalizing findings to new robot designs. Because of this, we have decided to reverse the design process and allow users to generate novel robotic designs without being constrained by current manufacturing limitations. Once we have created our own dataset of user-submitted robot designs, we can then perform ML-facilitated analysis of those designs with the goal of extracting knowledge about mind perception in robots. We are working along three aims to answer these questions and employ hypothesis testing to verify our approach.

A. Creating the Build-A-Bot Game Platform

Our first research question is if we can create a game that serves as a research platform where users are given a specific attribute inspired by traditional ToM research and then design a robot accordingly. Our online research platform uses gamification, the application of typical elements of game playing, to engage with users and explore how users create robot designs to given mind perception attributes.

With our platform we flip current evaluation approaches and create a system that provides a participant up front with the attributes (stimuli) along the dimensions of mind perception. Participants are asked to design a robot that best exemplifies the given mind perception attributes. We then study the participant's designs to discover which robotic features are most strongly correlated to those attributes. To date, robot mind perception has only been studied sparsely [12]–[14], and no study has flipped the robot design process. The platform allows users to design robots that are, in their opinion, most capable of expressing various attributes linked to mind perception. We have developed a prototype of the research platform (see Figure 6) that uses building blocks to assemble the robot. As the building blocks can be assembled in random order and places, it is expected that with the combination of approximately 100 buildings blocks and the assumption that a robot has a minimum of three parts, the resulting combinations are at least around 150,000 ($\binom{100}{3} = \frac{100!}{3!(100-3)!} = 161,700$) not accounting for the full RGB coloring option for each part.

1) 3D Modeling: 3D modeling is one of the most labor intensive parts of the platform creation due to the volume of 3D parts that are required to maximize robot design possibilities and enable users to be fully express their creative ideas. With Autodesk Maya, 3D designers can begin by manipulating basic shapes, such as a square, and transform them into far more complex robot parts (e.g. a hand). The initial approach to creating 3D parts is to design pieces that have a notional use case as envisioned by its designer, but once in the design platform users are free to use the 3D parts at any place and at any scale that they wish when designing a robot. For example, the part shown in Figure 2 was originally inspired by a cat-like ear, but could be used in many other ways within the platform (e.g. as a nose).

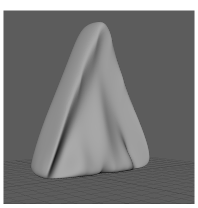

Fig. 2. Model of a potential ear

Fig. 3. Model of a potential torso

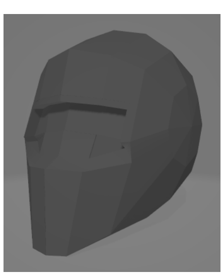

Fig. 4. Model of a potential head

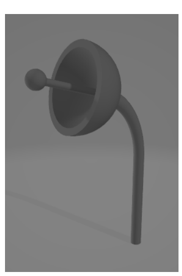

Fig. 5. Model of a potential antenna

2) Unity and the Web: The interface that users will interact with when creating a robot design is our Unity-based 3D game. The Unity-based application will be hosted within our website URL where users can manage their account, view their robot designs, and create new robot designs (see Figure 6). Each user's work is incrementally saved as they create a new robot design, allowing users to come back to designs that they have not yet finished and complete them later. Once a design has been submitted, it can no longer be modified. However, users are allowed to use their existing designs as a basis for new designs.

3) Sound: In order to create an immersive experience as we created a soundtrack that will play as users design a robot. The music was composed with the intent to be engaging, but kept in the background to not heavily influence design choices. We also created a set of sound effects to provide feedback when a user interacts with a button, or drags a part onto the current scene. The user is able to turn the music and sound effects on or off at any time. The application used to create our soundtrack and sound effects was Logic Pro. As sound or the absence of sound could have an impact on the user, the user's choice for music is collected as a datapoint.

B. Creating a Machine Learning Model

Our second research question is if we can use the targeted ToM attributes and their associated robot designs created in RQ1 to train a set of Machine Learning models focused on feature extraction, validation of desired robot ToM attributes in proposed robotic designs, and eventually as a tool to generate new robot designs targeting a given ToM attribute. Deep Neural Networks (DNNs) such as Convolutional Neural Networks (CNNs) have been shown to be highly effective at classifying images across multiple domains [36]–[39], however there has not been any work to date that focuses on associating robot design features to categories of robot mind perception. Our goal for the Build-A-Bot platform is to create a large database (>10,000) of robot designs and associated mind perception features sourced from a broad range of users with regards to age, race, and country of origin. This data will be used to train a set of DNNs that can extract salient features from the submitted design data, which will enable us to better understand which aspects of robotic design are most important in regards to mind perception targets. There are multiple uses we envision for these trained DNNs. First, we can use our network to validate whether existing robot designs correlate to a targeted mind perception attribute. Second, we can assess which aspects of a robot's design are most important to invoking a targeted mind perception attribute. Finally, we can use our trained network to generate completely new designs for a given a mind perception target.

C. Evaluating Robot Mind Perception

Lastly, we employ neuroscientific measures as proof of concept to verify our models. Current measurements of Human-Robot Interactions often use explicit [40], [41] (e.g. surveys, interviews) or implicit and behavioral [42] (e.g. how robots influence human behaviors) measures. While these kinds of measurements can give significant insights into how people

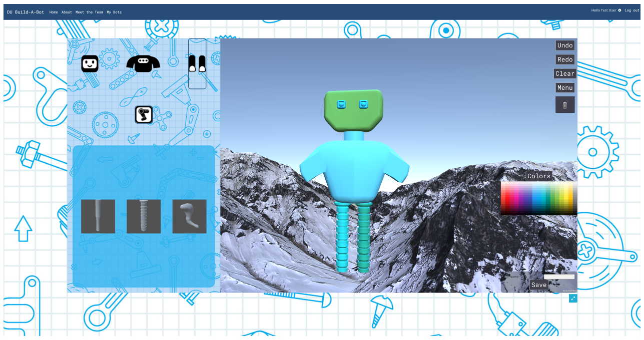

Fig. 6. Screenshot of the user interface

perceive robots, they also are subject to participant biases [43], [44], and are often not temporal in nature (e.g. the survey is administered right after the stimuli, not during). We will use Functional Near-Infrared Spectroscopy (fNIRS), in conjunction with robotic designs collected via the Build-A-Bot platform and other existing design databases, to gain new insight into a robot theory of mind. We hypothesize that participants will exhibit increased neural activation in the associated Theory of Mind (ToM) brain regions such as medial prefrontal cortex and dorsolateral prefrontal cortex [45] in response to robot designs that are developed to elicit mind perception when compared to a control design. To date, robot mind perception research has no models based on a large dataset. Additionally, no prior research attempted to link implicit mind attribution measures to robot design features. This novel approach is used as a method of verification and refinement for the results of our first two research questions.

IV. Results

One crucial aspect of our early platform development efforts was for users to interact with 3D robot parts while building their design. This included actions such as the ability to move, rotate, and scale individual robot parts. Creating a system where users can interact with parts while building their robot is key to increasing user engagement. The interface to manipulate parts needs to be intuitive, easy to interact with, and seamless in its implementation. Implementing these core platform mechanisms early in the development process allowed us to have a strong foundation to work and test from. In addition, we provided a system in which our 3D modeling team could test their robot part designs as they built them.

As we finished the initial development of our core functionality, we moved into developing the underlying structure for the platform. This included the User Interface (UI), the integration with the website hosting the platform, and data collection mechanics. We went through several iterations of the user interface (UI), with each iteration improving one or more aspects of the User Experience (UX). The design of the UI was prototyped in the Figma [46] platform, allowing increased collaboration and iteration for the developers.

When integrating the platform with the website hosting it, we needed to be able to communicate effectively between the different technologies in use. We initially used a browser feature to send messages with data between the platform and our site. It was discovered that this was inefficient for some use cases, particularly when uploading files such as the 2D screenshots and 3D model files used in our data collection. This led us to change our design to be a combination of browser communication and a feature included in Unity that allows us to send HTTP requests directly to the server that our site is hosted on. This hybrid design allowed for a cleaner integration between the platform and the site.

When collecting data about a user's submitted robotic design it is imperative that we collect as much data as possible about the choices the user makes while designing a robot. By having detailed information about each submission we can then analyze the data from multiple perspectives, and try to identify common patterns in how users interact with the system. However, it is also important to have data that is well structured. We want to be able to store the data as efficiently as possible. To achieve this, three main methods of data collection were chosen: 2D screenshots of submitted robotic designs, a 3D representation of the robot in the form of an STL file, and a running history of each interaction performed by the user in the form of an action tree. These three data collection methods are combined with other datapoints associated with the user's submission (such as whether the user has marked the robot design as complete, and the target mind perception attribute for the robot design) to create a holistic representation of the user's interaction with the Build-A-Bot platform.

V. Conclusion

In this paper we have introduced the "D U Want to Build A Bot" (Build-A-Bot) project, a novel platform for creating and evaluating robotic designs with regards to mind perception and Theory of Mind (ToM). This platform was created to address three core challenges facing researchers in this area: a small number of existing designs to evaluate, biases present in existing designs caused by focusing on a robot's functionality, and the cost associated with manually testing mind perception for a given robotic design. Our platform utilizes gamification to create a system where users can create unique robotic designs associated to mind perception targets without being influenced by the biases present in existing designs. Once these new designs are created we then use machine learning and neuroscientific approaches to explore what aspects of these designs are most tied to a given mind perception target. We discussed the current implementation of Build-A-Bot, including challenges that we faced and planned future work for the platform as we continue with our research.

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