Designing a Connect 4 Robot

Societal Implications of Consumer Robotics

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By
Kellan Delaney

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Technical Team Members:
Roman Kaker
Jared Tyranski

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

ADVISORS

Adarsh Ramakrishnan, Department of Engineering and Society

Harry C. Powell Jr., Department of Electrical and Computer Engineering

Introduction:

The consumer robotics market is growing rapidly, with revenues of 4.122 billion USD in 2019 to an expected 32.8 billion USD in 2027 (GMI Research, 2021). Especially during the COVID-19 pandemic, spending has shifted more towards inside the home expenses than outside the home, including on consumer robots, leading to a 4.3% increase in revenues from pre-pandemic expectations (Edwards, 2021). These machines help people in their daily lives in many ways including cleaning and household care, healthcare, entertainment, education, or just keeping company (Maynard, 2019). With this upshift in prevalence, it is also important to take note of this technology's potential impacts on society. The world is no stranger to connected devices and the Internet of Things (IoT), but with many robotics, a physical interface is being put on the computing power of the internet, creating the Internet of Robotic Things (Matthews, 2019). This could introduce many new ways to collect data on people, which has historically been a very controversial topic. It also means people could become physically harmed by their devices. Even if unintentional, the fact that there are moving parts that are meant to interact with a human means that something could go wrong and cause the robot to hurt its user. To understand the process of developing a safe consumer robot, the capstone team is building a consumer robot in the form of a semi-autonomous robot that can play Connect 4 against a human player. In order to better understand how the advancement of consumer robotics affects society, the thesis will explore research on the potential privacy and safety concerns associated with consumer robotics.

Technical Topic:

In this paper, a "consumer robot" is defined as a device that helps people with their daily routine tasks by interacting with the world around it in some physical manner. For example, one

of the most successful of these robots, in terms of name recognizability and revenue, is the Roomba by iRobot. In the first quarter of 2021, iRobot's revenues were $303.3 million, with an increase of 58% from $192.5 million in the first quarter of 2019 (Kramer, 2021). iRobot's first and most iconic product is the Roomba robot vacuum, but it has other robotic products as well, including the Braava robot mop and an educational robot for teaching coding. Given the success of the Roomba, most people think of household care and chore automation when considering consumer robots, but other tasks are being supported by consumer robots as well. The following examples demonstrate the wide-reaching applications of consumer robotics.

In healthcare, the Pria robot by Black and Decker is a device which allows a user to load medication and set a schedule through a mobile app for it to be dispensed (Barack, 2020). At the scheduled times, it notifies the user through a noise on the device and through a mobile app, reminding them to go take their medication. It also allows users to connect with caregivers and loved ones through a messaging system and video calls. This single device illustrates how consumer robots can be used to solve or make easier many potential problem areas in home healthcare.

In education, many consumer robots are emerging into the market. Tega from Personal Robots Group acts as an educational assistant to make learning more fun for kids (Gottsegen, 2021). Children with autism have been found to be more comfortable communicating with robots from International Robotics Inc. than with adults. Education robots could be considered a subset of social robots because they primarily will be interacting with humans in a similar manner that another human would. General social robots, like robotic AI assistants, are still a long way from commercial viability but developments are being made to bring the world closer to that reality (Daily, 2017).

Entertainment robots are simply robots designed to entertain humans. This can be in the form of toys, games, some method of displaying media, or really anything. The Furby robot serves no functional purpose and only exists to entertain whoever is using it by making facial expressions and sounds (IEEE Spectrum, 2018). Another example, the robot dog Aibo, is designed essentially as a replacement for a real dog (Tarantola, 2019). It learns its name, recognizes people it sees regularly, and can play games with its owners. It is considered an entertainment/social robot hybrid. There can be a lot of overlap between entertainment, social, and educational robots because these types often have similar behaviors, verbally or tactilely interacting with their user instead of simply performing a task as is the case with many cleaning or healthcare robots.

The technical project for the capstone team is to design and build a robot that can semi-autonomously play Connect 4 against a human player. The proposed robot serves as a fun application to combine the team members' skills in hardware, software, and firmware; also, it aligns well with the thesis topic of consumer robotics. The Connect 4 robot classifies as a consumer robot similar to those described above, to be used primarily for entertainment and education. It provides entertainment through the novelty it has implicitly by physically playing the game with a person, and it could be used for educational purposes by providing an example of how robotics can be used to automate simple tasks and illustrate how software and hardware interact in the real world.

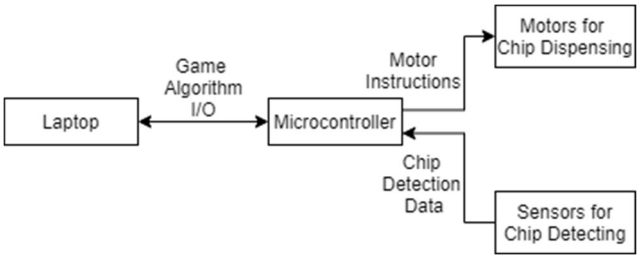

Figure 1. Simplified Block Diagram of Technical Project

STS Topic:

The introduction of any novel technology also introduces a variety of potential risks. The InfoSec Institute lists five primary types of security and safety risks associated with household robots, which in this paper are considered to be synonymous with consumer robots (Dimov, 2015):

1. Risks related to the interconnection of household robots with other devices.
2. Risks related to the data collection and disclosure abilities of household robots.
3. Risks related to the physical interactions of household robots.
4. Risks related to the infection of household robots with malware.
5. Risks of psychological attacks conducted by household robots.

If during the design process of a consumer robot, engineers only strive to achieve their desired functionality, then these risks are turned into explicit vulnerabilities which could cause harm to the user. These risks boil down to the fact that bad things could happen if a malicious individual gets control of a consumer robot. These individuals could collect sensitive data or force the robot to behave in ways that could physically or mentally harm a user.

Physical safety is the most critical of the safety criteria in the design of robots. Electronics and moving parts have the potential to physically harm a user if they are not designed with safety in mind. Preventing mental harm caused by robots on the other hand is something much more abstract. When people use robots, they may form an emotional bond with their device. This is especially true in the case of social robots; the actions of the robot have the potential to psychologically manipulate or harm the user if controlled by someone with malicious intent.

The ever-growing Internet of Things is an easy entryway for consumer robotics to enter many households (Petrara, 2019). If a robot can utilize smart home devices that are already in a home, consumers will be incentivized to use it. While this is a great way to take advantage of existing technology, it also presents the first risk described above. If everything is connected to a single network, it is much easier for a hacker to hijack the system and collect data or control a device. The simplest solution to this problem is to have the robot completely isolated from any networks. However, then the robot can't utilize any data from other devices or processing power on the Internet. There are likely solutions that allow the robot to have a more secure connection through things like encryption and firewalls, but that is beyond the scope of this paper.

The issue of privacy is also a concern for many people, especially in the United States (Auxier et al., 2019). With consumer robots, another opportunity to have personal information collected and tracked is introduced. Many current internet based products and services track user data in order to improve user experience. This is likely to occur in consumer robotics where it could offer the same potential user experience benefits. A common solution to this ethical dilemma is to offload the decision making to the user by allowing them to opt-in to the data tracking service. Then it is up to the user to decide whether or not they want their information tracked and shared.

In the design of the Connect 4 robot, these risks will need to be addressed. Its primary users are children given the device's nature as a game. For this reason, physical safety for use by people of all ages is a primary goal of the project. It will be utilizing motors, which are inherently dangerous, to dispense chips into the board's columns. These motors and the electronics required to power them are the biggest safety issue of the project. It will not be connected to the internet or collect any information, so privacy is not a concern. It will not have

any kind of social interaction with a user, so unintentional psychological attacks are also not a risk.

Research Question and Methods:

Most standards regarding the design of robotics are specifically for physical safety of industrial robots, which are not considered consumer robots; this is concerning given the rising number of daily interactions with such machines. In addition, current standards do not resolve the risks that were presented earlier beyond the physical, including mental health and cybersecurity issues, a discrepancy that should be addressed before consumer robots become any more widespread (Martinetti, Chemweno, Nizamis, & Fosch-Villaronga, 2021). The thesis will seek to create general guidelines which engineers can employ to create consumer robots that minimize risks to their users.

Unlike the existing standards, the thesis will utilize practices similar to anticipatory governance to allow these guidelines to be adaptable to future technological developments. Current practices for safety, privacy, and security in technology will be analyzed with a goal to identify any normalized deviance in order to see how things could change and where those changes could apply in the guidelines. The analysis of the consumer robotics socio-technical system will use mutual shaping, identifying how these guidelines could end up influencing the technology itself as well as society and organizations.

Conclusion:

The technical deliverable will be a semi-autonomous robot that can play Connect 4 against a human player. The STS deliverable will be a thesis exploring the safety, security, and privacy risks associated with consumer robotics and creating a set of general guidelines to help engineers design consumer robots that minimize risk to their users. These guidelines will allow

engineers to make good design decisions in the absence of formal standards to address issues present in consumer robotics. The technical deliverable, while not a direct solution to these problems, will allow the research team to more intimately understand the challenges associated with the design of a consumer robot, primarily in user experience and reliability.

References:

Auxier, B., Rainie, L., Anderson, M., Perrin, A., Kumar, M., & Turner, E. (2019, November 15). Americans and privacy: Concerned, confused and feeling lack of control over their personal information. Retrieved October 13, 2021, from https://www.pewresearch.org/internet/2019/11/15/americans-and-privacy-concerned-confused-and-feeling-lack-of-control-over-their-personal-information/

Barack, L. (2020, February 10). Black & Decker Pria Review: A chatty assistant that reminds you to take your meds. Retrieved October 13, 2021, from https://www.gearbrain.com/black-decker-pria-dispenser-review-2645088425.html

Daily, S. B. (2017). Emotions and Affect in Human Factors and Human-Computer Interaction. Retrieved October 13, 2021, from https://www.sciencedirect.com/topics/computer-science/social-robot

Dimov, D. (2015, October 16). Privacy risks of Household Robots: 5 security risks and 10 steps to protect yourself. Retrieved October 13, 2021, from https://resources.infosecinstitute.com/topic/privacy-risks-of-household-robots-5-security-risks-and-10-steps-to-protect-yourself/

Edwards, D. (2021, February 16). Pandemic lockdowns boost consumer robotics market to $10 billion in 2020 revenues. Retrieved October 13, 2021, from https://roboticsandautomationnews.com/2021/02/16/pandemic-lockdowns-boost-consumer-robotics-market-to-10-billion-in-2020-revenues/40492/

GMI Research. (2021, May 20). Consumer Robotics Market Research Reports, Opportunities & Forecast 2020-2027. Retrieved October 13, 2021, from https://www.gmiresearch.com/report/global-consumer-robotics-market/

Gottsegen, G. (2021, July 20). Classroom robots are infiltrating the education industry, but teachers are safe - for now. Retrieved October 13, 2021, from https://builtin.com/robotics/robotics-in-the-classroom

IEEE Spectrum. (2018, May 18). Furby. Retrieved October 13, 2021, from https://robots.ieee.org/robots/furby/

Kramer, A. (2021, May 3). IRobot reports first-quarter 2021 financial results. Retrieved October 13, 2021, from https://investor.irobot.com/news-releases/news-release-details/irobot-reports-first-quarter-2021-financial-results

Martinetti, A., Chemweno, P., Nizamis, K., & Fosch-Villaronga, E. (2021, July 27). Redefining safety in light of human-robot interaction: A critical review of current standards and regulations. Retrieved October 13, 2021, from https://www.frontiersin.org/articles/10.3389/fceng.2021.666237/full

Matthews, K. (2019, November 14). The internet of robotic things: How IOT and Robotics Tech are evolving together. Retrieved October 13, 2021, from https://iot.eetimes.com/the-internet-of-robotic-things-how-iot-and-robotics-tech-are-evolving-together/

Maynard, N. (2019, August 09). The Evolution of Consumer Robotics. Retrieved October 13, 2021, from https://www.juniperresearch.com/resources/analystxpress/august-2019/the-evolution-of-consumer-robotics

Petrara, D. (2019, August 22). Consumer Robotics is a market in transition; smart home will be at the heart of the change. Retrieved October 13, 2021, from https://www.businesswire.com/news/home/20190822005033/en/Consumer-Robotics-is-a-Market-in-Transition-Smart-Home-Will-be-at-the-Heart-of-the-Change

Tarantola, A. (2019, February 27). Sony AIBO Review: Just get a puppy. Retrieved October 13, 2021, from https://www.engadget.com/2019-02-27-sony-aibo-review-just-get-a-puppy.html