Design of Romulus, a Handheld, Aim-Assistive Airsoft Robot
(Technical Project)
The Growing Role of Amateurs Innovation in Radical Robotics
(STS Project)
A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Computer Engineering

By
Jacob Cochran

December 6th, 2024

Technical Team Members
Tryn Dunne, Andrew Morrison, Elijah Smith

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

Rider Foley, Department of Engineering and Society

Adam Barnes, Department of Computer & Electrical Engineering

Introduction

Robots are here. But where? We clearly have the technology: everything from automated manufacturing, to robotic exoskeletons, and even handheld self-correcting surgical instruments (Gasparetto & Scalera, 2019; Hockstein et al., 2007; Kazerooni & Steger, 2005). However, few of us experience robots in our day-to-day lives. It's a shame. If the technology is here now, why don't movers and our elderly wear assistive exoskeletons? Why doesn't your dad, who's always asking you for an extra hand, *literally* wear one? In this technical paper, I consider a fun application of robotics in the sport of airsoft.

Recreational airsoft is a shooting sport like paintball, but focused on tactical realism (Nowacki & Wiśniewska, 2015). Unlike paintball guns, airsoft weapons shoot small plastic pellets called BBs and are meant to emulate real military weapons. This is why airsoft guns are often called "replicas" (ibid). Airsoft play varies, but is typically team-based elimination, often with an objective like capture the flag. The gameplay is fast, cooperative, and precise so players tend to value skills like teamwork, reaction time, and physical coordination (Daniel, 2015). But, the gear, such as backpacks, magazines, and airsoft guns, is designed to replicate real military equipment, so it is often cumbersome (Tornero-Aguilera et al., 2020). This restricts who can succeed in airsoft, especially those with motor-coordination limitations. Which is especially unfortunate, as airsoft has been shown to have both excellent physical (Tornero-Aguilera et al., 2020) and social benefits (Nowacki & Wiśniewska, 2015).

Luckily, the airsoft community is uniquely suited to adopt high-technology solutions; the game has a deep culture of amateur and professional after-market upgrades and redesigns (Szarucki & Menet, 2018). This makes airsoft a fertile testing ground for assistive robotics. It likely has interest from players with motor limitations, those looking for an edge, and technical airsoft modification subcultures alike. Therefore, the technical portion of this paper is dedicated to the design of *Romulus*, a handheld robot designed to assist airsoft players' aim by tracking opponents in real time. In the Romulus system players mount their airsoft gun into the vice of a robotic grip. Then using an onboard camera, image classification, and real-time physics, the robot corrects the angle of the airsoft weapon to aid the player's aim. In the sociotechnical analysis I'll ask: *where is Romulus?* I will examine the history and present of assistive robotics, question who designs radical robotics, and research the groups primed for their wider creation and adoption. All to ask: Does the future of robotics lie with amateur innovators?

Technical Design of Romulus: The Handheld, Aim-Assistive Airsoft Robot

To design Romulus, we started by considering the needs of our users: players with diminished motor coordination, average players looking to improve their aim, and the airsoft technical community. Each comes with their own values, but in general, we decided that Romulus needed to be cheap, ergonomic, adaptable, and intuitive.

In essence, Romulus is a robot arm designed to help you hold and aim your airsoft gun (see Figure *1*). The user doesn't hold the airsoft gun directly. Instead, the user holds the back end of a robot arm using a two-handed grip and shoulder stock. Inside the grip are an external trigger and additional interface buttons. These buttons are meant to toggle the tracking on and off or reset the system as needed. The external trigger lets the player pull the trigger and fire the airsoft gun without ever needing to touch it directly. This separation is important because we felt it would be unintuitive if the robot forced the user's body to move with it.

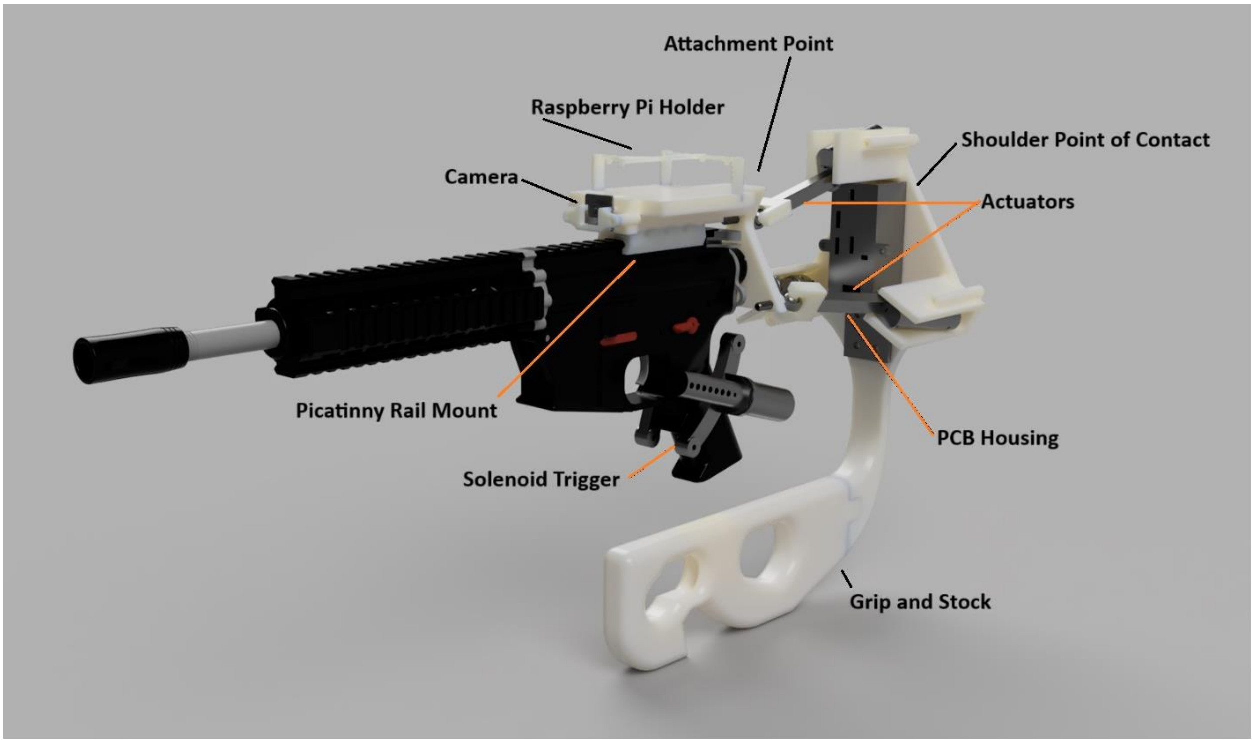

Figure 1. Annotated CAD rendering of Romulus. The users hold onto the grip and stock with both hands and lean their shoulder into the back triangle. The motorized actuators contract and expand to point the robot at the correct angle to track a target.

The robot arm holds the airsoft gun by clipping into an attachment point at the front side. Most airsoft guns have a standardized rail along their top (see Figure *1*) meant for attachments such as scopes or laser sights. This type of rail is called a picatinny rail (United States Military Standard, 1995) and because it is standardized, using it as our attachment point lets Romulus easily interface with most commercial airsoft guns.

Also installed on this attachment point is a Raspberry Pi computer and front-facing camera. The Raspberry Pi runs a type of machine learning called an object detector, which finds targets in the camera feed in real-time. Once a target is found, the Raspberry Pi tells the robot how it should turn to follow the target. But the robot is made of three linear actuators, essentially motors that only expand and contract, and two types of joints. The upper platform is connected to these actuators by ball joints (like your shoulder) and to the base by pin joints (like door hinges).

This lets it rotate freely, but it also unfortunately requires some additional physics. So to figure out how to move the actuators in a way that accurately points the robot, we use a type of real-time physics called inverse kinematics detailed by (Lee & Shah, 1988b, 1988a; Rao & Rao, 2013).

To power it while also being fully mobile, we use RC-car batteries that attach into the shoulder mount. The batteries plug into a custom printed circuit board (PCB) which powers the Raspberry Pi, linear actuators, and some additional chips used to control the speed of each of the linear actuators.

Overall, we sought to design Romulus in a way that is cheap, accessible, and easy to modify. The Raspberry Pi is famously approachable. The mechanical parts are either custom 3D-printed parts, or off-the-shelf hardware. The machine learning aspect of the project was done using Edge Impulse, a beginner friendly framework already familiar to many amateurs (*Object Detection (Images) | Edge Impulse Documentation*, 2024). This all ensures it's both simple to use for casual players but is also easy to adapt for technical players looking to make it their own.

Sociotechnical Research: The Growing Role of Amateurs Innovation in Radical Robotics

Background and Research Question

While building this project, family, friends, and everyone I showed always asked the same question: *Why doesn't this exist already?* The idea of Romulus is nothing special. In fact, I'd bet that I had countless near-identical ideas as a teenager. So, if it's not an idea problem where are robots like Romulus in our day-to-day lives? The future of robotics was meant to be here by now, right? But where is it? Well, manufacturing robots have existed since at least the 1950s. Even the highly sophisticated delta robots used in pick-and-place assembly and sorting have been in use since the late 1990s (Gasparetto & Scalera, 2019). In 2005 an autonomous lower-body exoskeleton was successfully developed (Kazerooni & Steger, 2005) and was followed by countless assistive wearable exoskeletons, (Martinez-Hernandez et al., 2021) pecuniary limbs, and prosthetics (Stolzenwald, 2021). In handheld robotics, the dominant focus of applications has been in medical devices (ibid). Meanwhile consumer markets have mostly focused on smart home, service, and entertainment robots (Zachiotis et al., 2018).

Recently, the open source, do-it-yourself, and maker communities have created an explosion in relatively low-cost and radical robotics technologies. These communities are characterized by an attitude of creation, creativity, and sharing (Kuznetsov & Paulos, 2010; Milne, n.d.). They engage through both online forums such as Adafruit and Instructible and conventions like MakerFaire and ROSCon (Kuznetsov & Paulos, 2010) and build with open hardware and software platforms (Tanenbaum et al., 2013).

In software, Open Robotics was founded as a non-profit in 2012 and is dedicated to open development and robotics research; it maintains several software platforms such as the Robotic Operating System, the Gazebo simulator, and Open-RFM for robot coordination ("A History of ROS (Robot Operating System)," 2019; *Open Robotics*, 2023). Commonly used open hardware platforms are SparkFun, Arduino, and Arducam (Gibb, 2014; *Simplifying Embedded Vision for All.*, 2024; Tanenbaum et al., 2013). But the maker-corporate collaboration is mutually beneficial, as can be seen from their sponsors (*Sponsors*, 2024a; *Sponsors*, 2024b; Tanenbaum et al., 2013). From these conventions, companies take radical ideas, recruit talent, and poach specialized skills (see Dougherty, 2012).

At the outset I questioned why projects like Romulus are not widespread. But they *do* exist. Just in amateur online communities. Take for instance two projects like Romulus popularized on YouTube (3DprintedLife, 2020; Excessive Overkill, 2024). Or a mimicking teleoperated robotic hand, (*DexHand - An Open Source Dexterous Humanoid Robot Hand*, 2023). So, what caused the shift from large academic and industrial players to an amateur innovation? And how and why have these amateur communities challenged and reshaped radical innovation in robotics?

Technological Momentum

To understand why, despite decades of successful industrial and academic research and innovation, it has been amateurs delivering radical innovation in robotics, I will draw upon Thomas Hughes' pattern for technological development lain out in *The Evolution of Large Technical Systems* (Hughes, 1989). In his pattern for technological development, Hughes outlines stages for the development of large technological systems as a process of invention, development, innovation, transfer, growth, competition, and consolidation. The key feature of Hughes' framework is the concept of technological momentum, which describes how large technological enterprises reach a quasi-determinism that limits their flexibility. Because of this momentum they are only incrementally affected by external action, causing them to focus on internal and incremental problems rather than radical innovation. Hughes these as competencies and reverse-salients.

Hackers, Makers, and Amateurs

Makers and amateurs are so different from other sources of innovation because of their motivations. These communities have a passion for innovation and creativity that defies profit-seeking motivations (Dougherty, 2012; Milne, n.d.; Tanenbaum et al., 2013). Which can be difficult to reconcile with many models for technological development. However boundary research in *Open Innovation* (Bogers et al., 2010), *Human Computer Interaction* (Kuznetsov & Paulos, 2010; Milne, n.d.; Tanenbaum et al., 2013) and the *Maker Movement* (Davies, 2017) all have promise for understanding these groups, why they choose to innovate, how they innovate, and the problems they pursue. Overall, these research disciplines will be an important interface to Hughes' framework.

Method

To explain how amateurs leapfrogged academia and industry in radical robotics, I intend to undertake a Case Study approach. First, to understand the historical context for how robotics research and technology got to where it is today, I will perform a review of several of review of academic research, amateur projects, and industry trends. I will look at keywords from academic papers over time to see what topics and applications were studied. To understand the commercial applications, I will review the significant areas of focus from industrial conferences in Robotics. I will also look at project sharing platforms such as Github and Instructables to understand the types of projects amateur innovators develop.

Having set a background context, I will then shift my focus to attending a Maker Faire, Lynchburg 2025. At this event I will look at the interface between corporate sponsors and amateur projects. By interviewing amateurs and attendees to understand their projects, background, and motivations, I will gain a deeper insight into what drives their technical development. The main goal is to understand how these two communities cross-pollinate and mutually benefit one another. Then I will apply this data to Hughes' framework of technological momentum to understand why amateurs have seemingly succeeded where their predecessors failed.

Conclusion

While we have yet to fully see a robotic revolution in our daily lives, that horizon inches closer each day. The open hardware and software movements, and the amateur communities that surround them, seem to have taken the reigns from the slow development of yesterday. Now more than ever cheap, reliable, and amateur-friendly platforms empower us all to participate in the future of robotics. In the social dimension of this project, I analyze how radical robotics technology came to be dominated by amateurs, and the how traits of these communities created the conditions for radical innovation.

The technical component, *Romulus,* is our contribution to the community of shared innovation. It was designed with amateur technologies like a Raspberry Pi, open-source software tools, and accessible techniques like 3D printing. The PCB is designed as a low-cost, ready-made solution that future amateur projects can adapt to their own needs. Romulus not only adds to the airsoft community by augmenting the performance players and improving accessibility, but it also gives its amateur technical community the tools and techniques to make.

Works Cited

3DprintedLife (Director). (2020, October 9). *I Made an Auto-Aiming Nerf Blaster—It CAN'T Miss* [YouTube]. https://www.youtube.com/watch?v=GoZubkaNvcE

A History of ROS (Robot Operating System). (2019, July 9). *The Construct*. https://www.theconstruct.ai/history-ros/

Bogers, M., Afuah, A., & Bastian, B. (2010). Users as Innovators: A Review, Critique, and Future Research Directions. *JOURNAL OF MANAGEMENT*, *36*(4), 857–875. https://doi.org/10.1177/0149206309353944

Daniel, R. (2015). Participants Profile in Airsoft Sport. *Procedia - Social and Behavioral Sciences*, *180*, 1316–1321. https://doi.org/10.1016/j.sbspro.2015.02.270

Davies, S. R. (2017). *Hackerspaces: Making the Maker Movement*. John Wiley & Sons.

DexHand—An Open Source Dexterous Humanoid Robot Hand. (2023). DexHand - An Open Source Dexterous Humanoid Robot Hand. https://www.dexhand.org/

Dougherty, D. (2012). The Maker Movement. *Innovations: Technology, Governance, Globalization*, *7*(3), 11–14.

Excessive Overkill (Director). (2024, April 6). *I Made Real-life Airsoft AIM-ASSIST: Aimbot V3* [YouTube]. https://www.youtube.com/watch?v=miRnNy7ZvIc

Gasparetto, A., & Scalera, L. (2019). A Brief History of Industrial Robotics in the 20th Century. *Advances in Historical Studies*, *08*(01), 24–35. https://doi.org/10.4236/ahs.2019.81002

Gibb, A. (2014). 1. History of the Open Hardware Movement. In *Building Open Source Hardware: DIY Manufacturing for Hackers and Makers*. Addison-Wesley Professional. https://learning.oreilly.com/library/view/building-open-source/9780133373912/ch01.html

Hockstein, N. G., Gourin, C. G., Faust, R. A., & Terris, D. J. (2007). A history of robots: From science fiction to surgical robotics. *Journal of Robotic Surgery*, *1*(2), 113–118. https://doi.org/10.1007/s11701-007-0021-2

Hughes, T. P. (1989). The Evolution of Large Technological Systems. In W. E. Bijker, T. J. Pinch, & T. Pinch, *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (pp. 51–82). MIT Press.

Kazerooni, H., & Steger, R. (2005). The Berkeley Lower Extremity Exoskeleton. *Journal of Dynamic Systems, Measurement, and Control*, *128*(1), 14–25. https://doi.org/10.1115/1.2168164

Kuznetsov, S., & Paulos, E. (2010). Rise of the expert amateur: DIY projects, communities, and cultures. *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, 295–304. https://doi.org/10.1145/1868914.1868950

Lee, K.-M., & Shah, D. K. (1988a). Dynamic analysis of a three-degrees-of-freedom in-parallel actuated manipulator. *IEEE Journal on Robotics and Automation*, *4*(3), 361–367. IEEE Journal on Robotics and Automation. https://doi.org/10.1109/56.797

Lee, K.-M., & Shah, D. K. (1988b). Kinematic analysis of a three-degrees-of-freedom in-parallel actuated manipulator. *IEEE Journal on Robotics and Automation*, *4*(3), 354–360. IEEE Journal on Robotics and Automation. https://doi.org/10.1109/56.796

Martinez-Hernandez, U., Metcalfe, B., Assaf, T., Jabban, L., Male, J., & Zhang, D. (2021). Wearable Assistive Robotics: A Perspective on Current Challenges and Future Trends. *Sensors*, *21*(20), Article 20. https://doi.org/10.3390/s21206751

Milne, A. (n.d.). *What Makes a Maker: Common Attitudes, Habits and Skills from the Do-It-Yourself (DIY) Community*.

Nowacki, M., & Wiśniewska, I. (2015). Determinants of recreational activity – through the example of ASG players (airsoft gun). *Studia Periegetica*, *14(2)*, 69–81.

Object detection (Images) | Edge Impulse Documentation. (2024, May 9). https://docs.edgeimpulse.com/docs/edge-impulse-studio/learning-blocks/object-detection

Open Robotics. (2023). Open Robotics. https://www.openrobotics.org

Rao, P. S., & Rao, N. M. (2013). *POSITION ANALYSIS OF SPATIAL 3-RPS PARALLEL MANIPULATOR*.

Simplifying embedded vision for all. (2024). Arducam. https://www.arducam.com/

Sponsors. (2024a). Maker Faire. https://makerfaire.com/bay-area/sponsors/

Sponsors. (2024b). ROSCon 2024. https://roscon.ros.org/2024/

Stolzenwald, S. J. I. (2021). *Interacting with a Handheld Robot: Prediction of User Intention and Assisted Remote Collaboration* [Doctoral dissertation]. University of Bristol.

Szarucki, M., & Menet, G. (2018). Service Marketing, Value Co-Creation and Customer Satisfaction in the Airsoft Industry: Case of a Technology-Based Firm. *BUSINESS MANAGEMENT AND EDUCATION*, *16*, 94–107. https://doi.org/10.3846/bme.2018.2138

Tanenbaum, T. J., Williams, A. M., Desjardins, A., & Tanenbaum, K. (2013). Democratizing technology: Pleasure, utility and expressiveness in DIY and maker practice. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2603–2612. https://doi.org/10.1145/2470654.2481360

Tornero-Aguilera, J. F., Sanchez-Molina, J., & Clemente-Suárez, V. J. (2020). Airsoft: An efficient and motivating cardiovascular training choice. *The Journal of Sports Medicine and Physical Fitness*, *61*(1). https://doi.org/10.23736/S0022-4707.20.11167-8

United States Military Standard. (1995). *MIL-STD-1913 DIMENSIONING ACCESSORY MOUNTING RAIL SMALL* (MIL-STD No. 1913). http://everyspec.com/MIL-STD/MIL-STD-1800-1999/MIL-STD-1913_17705/

Zachiotis, G. A., Andrikopoulos, G., Gornez, R., Nakamura, K., & Nikolakopoulos, G. (2018). A Survey on the Application Trends of Home Service Robotics. *2018 IEEE International Conference on Robotics and Biomimetics (ROBIO)*, 1999–2006. https://doi.org/10.1109/ROBIO.2018.8665127