Autonomous Robot Safety

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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

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Introduction

According to Locus Robotics, an autonomous robot is "an intelligent machine that can perform tasks and operate in an environment independently, without human control or intervention. [1]". This idea of self-sufficiency requires the entity to be able to perceive its surroundings, make decisions based on that information and proceed to engage in a movement in accordance with that decision. The primary purpose of autonomous machines is to assist humans in completing a mundane, time-consuming, or even dangerous tasks. Having a supply of autonomous or semi-autonomous robots has been a key factor in the growing efficiency of factories and tech companies today.

Some common uses of robots are Automated Guided Vehicles (AGVs) which move materials around in warehouses, flying drones that are integral in disaster response or a vacuum capable of cleaning an entire room without assistance. Most of these applications oversimplify the meaning of robot and can be hardly considered autonomous. The misuse of the term "robot" likely stems from companies' desire to represent their products as a highly sophisticated artificial intelligence when it's not entirely true. Differentiating between a pre-programmed machine capable of performing a specified task when a button is pressed and a robot that can sense and respond to real-time stimuli is crucial to address the concerns that arise when they operate without user input.

For my Major design Experience Course at the University of Virginia, my team and I created a robot gantry system capable of playing checkers against a human opponent. I was primarily responsible for the circuit board design as well as assisting with the gantry that will control the robot's movement. The robot was able to operate autonomously and use a Checkers playing algorithm along with a camera to select its next move. In light of societal concerns that could present themselves if our project were to become public, I intend to research and potentially resolve ethical concerns that could arise from having a machine that moves on its own around regular people. I hope to cover these ethical issues that could manifest from an automated system, primarily it's relationship to human interaction. This distinction forms the basis of my STS topic and how it correlates with my technical project.

Thesis: Autonomous Robot Safety

There have been cases in the past where safety concerns have become a prominent issue in autonomous machines using Machine Learning, artificial intelligence or even pre-programmed responses. My primary research question focuses on what potential software or hardware standards can be instituted to eliminate or at least limit the risk of human endangerment with the increasing capabilities of Machine Learning and the growing popularity of commercially deployable robots. My experience in my technical project encouraged me to promote safety for technicians and consumers alike, and I firmly believe that expanding the regulations governing thse devices is the best first step in achieving this goal.

In order to provide suggestions for future regulations, I researched and surveyed current standards that autonomous robots that interact with humans have to adhere to and compared their effectiveness in practice to pinpoint deficiencies. My hope in finding these deficiencies is to contribute to the success of related autonomous systems in the future and help them be easier to integrate into the day to day life of the average consumer. I chose the cases below based on how focused they were on the robot's perception abilities and how well they respond to humans and other machines. I also considered how well they fit in the general topic of robotic safety and more specifically for use cases in social settings.

Case # 1: Dynamic Social Zone for Human Safety in Human-Robot Shared Workspaces[]

Xuan-Tung Truong, Voo Nyuk, et all wrote a paper to present a safety framework for robotic systems in shared workspaces with humans. The framework is comprised of three main stages: human detection and tracking algorithms, human social signal estimation and dynamic social zone created from an estimation model. The end goal of this model is to integrate it with the navigation system of the robots so that they can better guide robots to move safely in human populated environments.

The primary target for this project were service mobile robots. In areas where robots are deployed, the authors believe it is critically important to have safeguards in place to prevent any harm from coming to anyone."Working in the same workspace, the risks of human essentially come from the attack of robots caused by its functioning failures or misunderstanding between the human and the robots."[2] If the robot doesn't have a fixed travel path or the human's work to overlap with the machine's, people can find themselves get bumped, hurt or severely inconvenience because of the lapse of communication between the two entities.

The main way to keep the robots in check, according to the authors is to focus on agile mobility. "Mobility is an essential navigation problem of mobile robots as robots must be able to move safely and freely in their environments. In order to do so, mobile robots have to address all the standard issues such as perception, localization, motion planning, and motion control."[2] Figure 1 below shows the relationship between these standard issues and how a dynamic social zone interacts with the navigation process of a robot. Put simply, the detection and tracking algorithms aim to keep the autonomous robot outside of the personal space of humans it is working with. A huge contributing factor to the effectiveness of this logic train is the tracking of human body movements and signals to determine how the dynamic social might need to be expanded or narrowed.

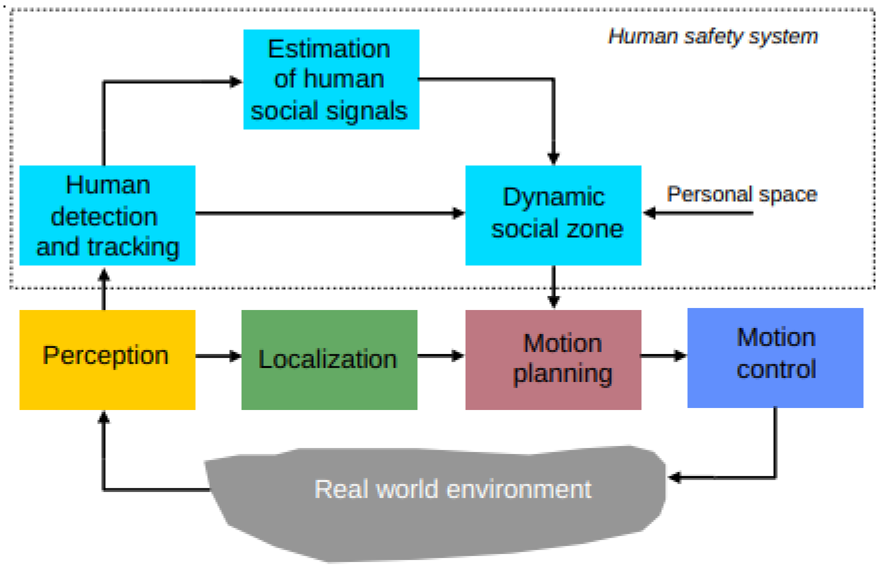

Figure 1. Human Aware Control Scheme of Mobile Robot Systems [2]

To create a quantitative idea of what a social dynamic zone would look like for a person and how the robot will use it in it's navigation system, the authors designed a mathematical model using a coding software, Matlab. To run simulations, the model used the following variables to determine the dynamic social zone at any given time: a person p, located at coordinated x and y, facing direction d. These variable form a function capable of calculation the social zone of a person within the robot's sight, and can be duplicated to account of multiple people in the same space. Figure 2 shows an example dynamic social zone for two people.

The model uses the distance and other factors between persons to determine the safety of continuing on the same trajectory or shifting to guarantee safety. Personal space is "defined as the interactive space between humans and robots."[2]. The paper breaks down this concept into four smaller distinct zones which are represented by the different colors around the humans in

Figure 2. The zones are public, social, personal amd intimate, in order of decreasing distance. The closer a robot is to the intimate zone, the more keenly it must account for human signals and states of motion and activity.

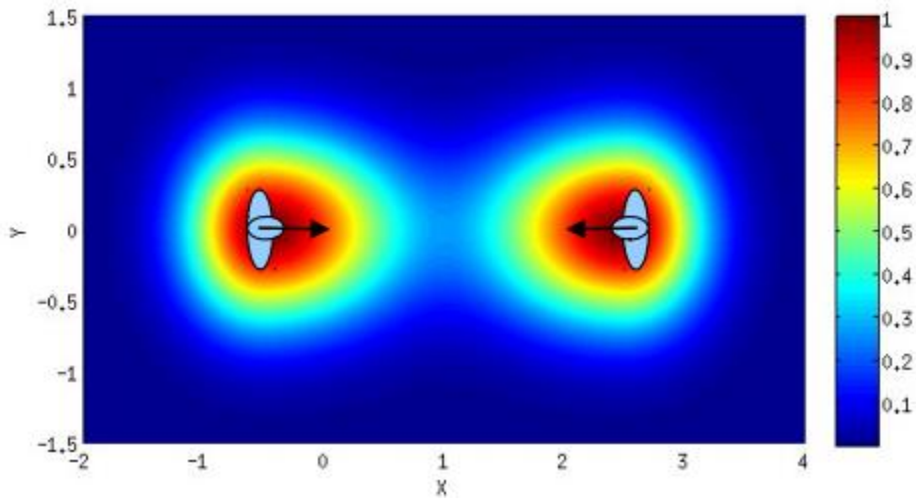

Figure 2. Dynamic Social Zone for 2 People [2]

The experimentation in this paper focused on having a robot be able to see and sense a human in a shared workspace and dynamically navigate to avoid breeching predetermined distance thresholds. The conclusion that the authors draw from their work is that the framework presented is a good starting point for autonomous robot safety in terms of mobility and navigation.

Discussion of Case 1

In this paper, Xuan-Tuan Truong, et all deliver a compelling and promising framework for robot safety in terms of mobility. The algorithms implemented to identify and measure human signals were efficient, but were lacking in complexity. “Human social signals are defined as a communicative, informative signals or a cue that, either directly or indirectly, provides information about social facts, such as social interactions, social emotions, social relations, and social identities.”[2] Using emotions and social identities sounds good in theory, but the concepts themselves are so complicated and have so much variance from individual to individual that there is a glaring limitation on how they can account for emotional states when in operation. As an improvement, I would suggest robots being used in a business or less public environment have a secondary set of social facts that can be specific to people based on face recognition of persons who will frequently be working alongside the robot.

Another issue I foresee arising is when the operation of the robot required is to enter and exit the intimate dynamic zone of a person frequently. It's hard enough for the machine to perceive, calculate and actuate a motion as is, but when it comes to making these movements in close quarters, the risk of physical injury goes up dramatically if the robot needs to make sudden movements in response to a human partner. There is no immediate remedy I can think of outside of increasing the time between sensing and actuation or increasing the training required to work around a robot utilizing dynamic zones. All in all, this paper and the dynamic zone framework it presents would be an amazing candidate for a industry standard for all autonomous robots.

Case #2: Generic ROS-based Architecture for heterogeneous Multi-Autonomous Systems Development[3]

This paper presents a design and implementation of a generic ROS(Robot Operating System) that can be adapted and used across various autonomous robot platforms and applications. The architecture includes inter-robotic data exchange to allow communication between devices which is a key component of promoting robotic safety. The three main platforms that Mustafa Alberri and his colleagues hopes their design would be usable for are the autonomous vehicle, autonomous quad-copter and autonomous mobile robot. A major focus in creating this architecture is making it portable, transferable on a general scale as well as affordable, powerful and expansible.

The authors of this work described an autonomous robotic system as “a system that has the freedom to control and govern self affairs.”[3] The backbone of this system is the Robot Operating System that functions as the brain of the system and can be built upon to accommodate different applications. The ROS framework is a free open source software that is available to anyone and everyone with internet. This ease of access was a major selling point for the authors to encourage readers to adopt their framework into their systems.

The data tansferrance in ROS is primarily done in the form of messages, forming a direct relationship between the ROS master and the robot nodes. One node or nodes is the sender (or publisher) of a given message and another node or nodes have to receive (be subscribers) through topics as seen in Figure 3. below. This simple communication flow can be expanded by adding multiple ROS Masters, enabling several different robot entities to talk via inter-vehicular channels. The beauty of the proposed framework is the ease of integration between different types of robotic platforms.

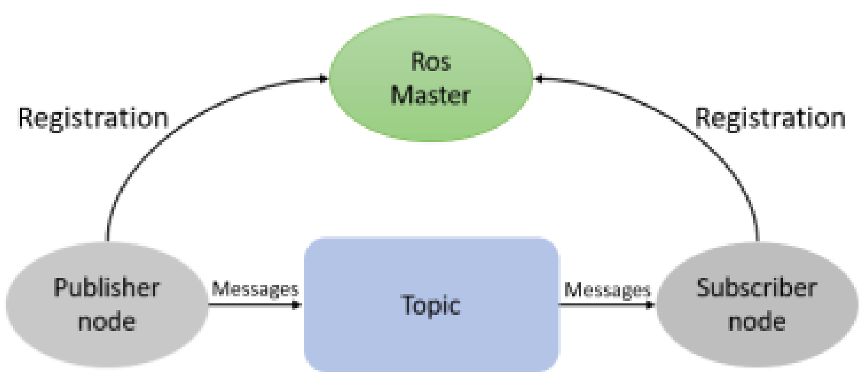

Figure 3. Basic Communication in ROS [3]

Discussion of Case 2

The strongest selling point for this paper in my research is the generic, non-restrictive properties of the Generic ROS-based Architecture presented in this paper. One of the most important factors to consider when developing standards for a field of technology is freedom within reason. Requiring commercial businesses to adhere to a set of rules is very challenging when their primary concern is efficiency and profit, not safety. Having a through communication framework like ROS with built in safety algorithms like the dynamic social zone from case 1, could be the key to ushering in a safer route for the future of autonomous systems.

As a subsection of standardizing autonomous robot communication, I believe that creating a priority scheme to avoid the most dangerous interactions as much as possible. When it comes to industrial grade autonomous systems especially, these robots can be cause severe injury to death in a split second. Because of the higher risk of these machines, protocols concerning swift motions and avoiding the intimate section of a human's dynamic social zone are imperative. A multi-system communication framework would be a great way to promote safety because heterogenous machines could work in tandem to not get in each other's way, but more importantly work together to ensure the safety of human operators and users. Implementing the architecture proposed in this paper will encourage a higher level of system synchronicity that wouldn't normally be enforced.

Results/STS Application

The two case studies show a microcosm of the research currently being conducted in the field of autonomous robotics. From self driving cars to defense drones, the field of autonomous systems has never been more quickly expanding, and with it, ethical concerns. The first case on dynamic social zones addresses the risk of personal space invasion and how intelligent technology must be aware of these boundaries and how not to cross them. Although some applications require intimate interaction with autonomous machinery, the advent of a new regulation that would require software to track social zones will be extremely important with integration of robots into day to day life. Privacy concerns turn rampant all over the tech industry and autonomous robot safety is no different.

The second case study on a generic Robot Operating System software could be useful in the regulation of autonomous systems used in tandem. With more minute control from robot to robot, the risk of devices accidentally sabotaging themselves or another party goes down. The ROS architecture includes a node for a human user, which completes the communication train and allows the autonomous robots to be more flexible in yielding to whatever the operator is requiring of it. This provides an ethical safeguard for danger the robots could pose if left alone to complete its tasks unchecked.

Discussing my research with my peers and analyzing their review led me to understand that a topic like this needs to be even more specific and nailed down. The ethical concerns surrounding autonomous or semi-autnomous systems is a hot topic with so many avenues and arguments in terms of the regulations. One of the major improvements I was suggested was to be more specific with the safety concerns I was hoping to avoid. To answer this, I began listing the potential hazardous situations that could be created by an autonomous robotic arm, moving with no bearing of social zones, but the list became endless. Some of the worst engineering disasters are the ones that never come to mind before they happen. A lot of designing and programming requires you to be as pessimistic as possible and plan for the most undesirable outcomes possible. Instead of worrying about avoiding specific scenarios that would be problematic, increasing standards and regulations across the board will lower the chance of all hazards happening to any party involved.

As a whole, the societal influence of autonmous robotics will grow with the ground break developments in artificial intelligence and more capable CPUs to accompany them. The rise of A.I. chatbots and automated social and technological services risks a human dependance on these machines that could be deemed unhealthy. Regardless of the promise that surgical robots and self driving cars delivers, they bring an equal and oppositie cause for worry that requires regulations and liability concerns to fall somewhere. People, technicians and engineers especially love the idea of not being held responsible for systems that can be somehow detached from their creators when they fail or cause safety, privacy and ethical issues.

Conclusion

In order to promote robot safety, my team and I designed, built and tested a semi-autonomous checkers playing gantry system. Creating this project provided an avenue to implement safety requirements and procedures to minimize the risk of dangerous events occurring as well as be an example of the benefits that can come from additional autonomous robot regulations. Researching the current state of machine safety standards and exploring how they can be further improved helped me form suggestions for the rise of autonomous systems.

To do this, I delved into the basics of autonomous machinery and nailed down a definition of what I should consider to be autonomous to specialize the proposed regulations. An autonomous robot system is a machine or network of machines that can sense its surroundings, process that information and dynamically perform tasks without human input. The main concern I addressed in this paper were the safety issues that present themselves in a robot that can act independently. In my team's Capstome project, we accounted for the danger if a human player being injured by the robot gantry by having warning LEDs flash bright red when the gantry was in motion. We considered programming the robot's camera to sense whenever a person's hand was within the danger zone while it was moving and turn the motors off, but it didn't work out. Outside of the time constraint, there proved to be too many variables such as skin color, lighting, reaction speed, etc that were major challenges. With more time and a standard framework to work within, we could've implemented a more robot safety protocol.

Thankfully, from researching the current state of autonomous robot safety I was able to form guidelines for what should be required in autonomous systems moving forward. Largely in part due to the two case studies above on Dynamic Social Zones[2] and Generic ROS(Robot Operating System)[3], I highlighted factors that will increase in importance as time moves forward. Building a system that is constantly analyzing and maintaining comfortable distance from the dynamic social zones of humans and other robot entities in the vacinity. This paired with the ROS communication architecture would allow for fluid and safe cooperation between linked robots as well the humans working alongside them.

In further research endeavors I would like to expand this autonomous robot framework to include requirements and restrictions on the kinds of movements and tasks that should be allowed by different applications. It is important to have more specific regulations for commercially sold and distributed autonomous systems as opposed to industrial ones due to the exponentially higher usage among children and inexperienced persons. Increasing the utilization of autonomous systems has many potential ethical drawbacks, which is why it's so important for the standards that govern them to keep up.

References

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[1] Walker, J., & Hart, M. (2022, September 22). *What are autonomous robots? 8 applications for today's amrs*. Locus Robotics. Retrieved October 27, 2022, from https://locusrobotics.com/what-are-autonomous-robots/

[2] X. -T. Truong, V. N. Yoong and T. -D. Ngo, "Dynamic social zone for human safety in human-robot shared workspaces," 2014 11th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI), Kuala Lumpur, Malaysia, 2014, pp. 391-396, doi: 10.1109/URAI.2014.7057375.

[3] M. Alberri, S. Hegazy, M. Badra, M. Nasr, O. M. Shehata and E. I. Morgan, "Generic ROS-based Architecture for Heterogeneous Multi-Autonomous Systems Development," 2018 IEEE International Conference on Vehicular Electronics and Safety (ICVES), Madrid, Spain, 2018, pp. 1-6, doi: 10.1109/ICVES.2018.8519589.

Autonomous Robots and the future of Supply Chain. Deloitte United States. (2021, September 2). Retrieved October 31, 2022, from https://www2.deloitte.com/us/en/pages/manufacturing/articles/autonomous-robots-supply-chain-innovation.html

What are autonomous robots? : Stanley Innovation. Stanley Innovation, Inc. (2018, March 5). Retrieved October 31, 2022, from https://stanleyinnovation.com/what-autonomous-robots/

Rose, D. C., Lyon, J., de Boon, A., Hanheide, M., & Pearson, S. (2021, May 20). *Responsible development of autonomous robotics in agriculture*. Nature News. Retrieved October 31, 2022, from https://www.nature.com/articles/s43016-021-00287-9

M. Zribi and E. Sung, “An Autonomous Robot Playing the Board Game Checkers,” The International Journal of Electrical Engineering & Education, vol. 35, no. 1, pp. 14–28, Jan. 1998, doi: 10.1177/002072099803500102.

D. J. Brooks, E. McCann, J. Allspaw, M. Medvedev, and H. A. Yanco, “Sense, plan, triple jump,” in 2015 IEEE International Conference on Technologies for Practical Robot Applications (TePRA), May 2015, pp. 1–6. doi: 10.1109/TePRA.2015.7219681.

M. Zribi and E. Sung, “An Autonomous Robot Playing the Board Game Checkers,” The International Journal of Electrical Engineering & Education, vol. 35, no. 1, pp. 14–28, Jan. 1998, doi: 10.1177/002072099803500102.

Bailey, D. G. (n.d.). *(PDF) a checkers playing robot - researchgate*. ResearchGate. Retrieved March 4, 2023