Development and Operation of Hybrid Humanoid Robot for Naval Use Case
(Technical Topic)

Analysis of the Impact of Automation on Job Availability/Evolution within the Manufacturing Industry
(STS Topic)

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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

Technology has been advancing at an unprecedented rate since the dawn of the Industrial Revolution in the 19th century. Throughout this period, new artifacts have been created that aim to make existing processes more efficient, cost-effective, and safer. Companies discovered that they could create a competitive advantage by redistributing the responsibility of labor from humans to machines. By transferring many of the tedious, repetitive, and labor-intensive jobs to machines, people were able to become radically more productive and reallocate their abilities into more critical positions. As a result, when a new technology is born, many preexisting jobs are eliminated and adjacent roles are created that function within the operation of the new technology (Manyika et al., 2017). For example, the textile industry of the early 19th century demonstrates this pattern. The introduction of the spinning jenny and the cotton gin allowed many human workers to move on from the timely tasks of refining raw cotton and producing thread and instead focus their efforts on other stages of production including the weaving and stitching of the finished product. Human workers moved on from their previous jobs and found new roles to operate these technologies and as a result, cotton textile productivity, as indicated by the rate of economic growth from 1770 to 1831, increased by 862 percent (Jackson, 1992). By becoming more productive, companies were able to make their products faster and cheaper, making the cost of goods much more competitive and accessible to people from lower social classes (Nardinelli, 2020). This trend of allocating labor from humans to machines continued into the digital revolution beginning in the 1900s and today through the rise of autonomous technologies and artificial intelligence used in manufacturing.

The growing use of this technology within the industry can have profound effects on the demographic of workers who are currently working in these fields. Robert Rosenberger describes this dynamic between technology and its impact on specific social groups as multistability

(Rosenberger, 2017). In his work, *Callous Objects*, he argues that certain technologies are inherently unfair and targeted toward the well-being of the homeless population. Here, I look to investigate a similar relationship between the use of autonomy and hybrid humanoid robots with human workers in this field of manufacturing. The goal of this prospectus is twofold. First, I will outline the scope of my technical CAPSTONE project: the design of an autonomous hybrid humanoid robot for applications in a naval setting. Secondly, I will investigate this relationship between humans and robots within manufacturing to determine if jobs are being replaced faster than they are being created and current laws regarding the use of robots as labor in the United States. To protect this demographic of human workers, an analysis of the current trend and social impact of humans in manufacturing will be determined and appropriate legislation will be proposed to mitigate the inevitable risks of autonomous technologies while recognizing and embracing the technology's inevitable benefits.

Technical Description

Our project, undertaken for the U.S. Navy, involves the development of a humanoid robot featuring a unique compliant foot/wheel mechanism. This design aims to facilitate a dual-mode mobility system, enabling the robot to switch between wheeled movement using four points of contact and bipedal walking as required by its environment. The primary focus of this initiative is to enhance the robot's adaptability to different terrains, a crucial aspect for naval operations where conditions vary significantly and increase the robots' current level of operation by implementing a teleoperation system to control the device from a distance.

Bipedal robots, distinguished by their capacity to climb stairs and ladders, offer unparalleled adaptability to human-centric environments. The ability to seamlessly navigate spaces designed for humans positions bipedal robots as promising candidates for applications in homes, offices, and public spaces (Pratt et al., 2007). The humanoid appearance further fosters natural interactions and integration into human-centric environments. However, these benefits come with inherent challenges. Bipedal robots often exhibit slower movement, making them less suitable for scenarios where rapid movement is imperative. Additionally, challenges in achieving stable movements and the demand for high energy consumption present formidable obstacles, impacting the practicality of these robots in certain applications. Furthermore, the limited payload capacity poses restrictions on the types of tasks and functionalities that bipedal robots can effectively perform (Kajita et al., 2003).

In contrast, wheeled robots emerge as efficient and speedy alternatives, offering advantages such as energy efficiency, high-speed operation, and a greater payload capacity (Altagar, 2023). These attributes position wheeled robots as formidable contenders for applications requiring rapid and robust movement, particularly in structured environments like warehouses and manufacturing facilities (Yang & Spenko, 2013). The enhanced payload capacity expands the range of tasks these robots can undertake, making them suitable for scenarios demanding the transportation of heavier loads. Despite these strengths, wheeled robots face notable limitations. Their less-than-human-friendly interaction is a notable disadvantage as it makes social acceptance and integration into human-centric spaces quite challenging. Additionally, the limited adaptability to diverse terrains and the challenges in navigating obstacles constrain their applicability in environments where agility and adaptability are paramount, such as disaster response scenarios or outdoor exploration (Kim et al., 2019).

To navigate the obstacles of a naval ship, such as a watertight door and a 63-degree ladder, while remaining efficient on flat surfaces, a compliant foot/wheel mechanism is required to remain stable on different surface types. To be compliant, the foot mechanism must be able to effortlessly adapt to the surface at hand without requiring activation by the operator. Many current hybrid robot designs incorporate a foot/wheel mechanism that needs to be activated to switch between a rolling and bipedal loading configuration. To avoid unauthorized use of protected designs of similar mechanisms such as that used in a tank's wheel design, our customer has requested that the design of this mechanism be original and has not been used in preexisting robot designs. Consequently, this HHR will feature a "flat tire" foot/wheel design where an axially rolling wheel will be supported by conical compression springs along the face of the rim as shown in Figure 1.

Figure 1: Photograph of Computerized Model of Compliant Foot/Wheel Mechanism

The concept of a foot/wheel mechanism in a humanoid robot is not just a technical advancement but also a practical solution to mobility challenges in varied environments that are common in naval ships. The primary benefit of a compliant mechanism is its simplicity of operation. A compliant foot/wheel will appropriately adapt the geometry of the part to the environment according to the situation in which it is being used. By integrating wheels, the robot can move swiftly on smooth surfaces, a feature beneficial in structured environments like walkways or open floors. Naval ships often incorporate many obstacles for wheeled robots such as watertight doors and steep ladders/staircases. To navigate these barriers, a bipedal design is desired, making the adaptability of the foot mechanism an integral part of maintining stability in these environments.

The HHR designed here operates through the movement of 23 Dynamixel motors connected to an aluminum chassis that mimics the appearance of a human body. Currently, the system functions through signals and processing of an Arduino Uno in conjunction with a Dynamixel Shield I/O board which provides power and data to each motor. The power system of the HHR is still in development and a more robust computing system will be developed in the future.

An essential component of the operation of the HHR is the teleoperation and power system that will be responsible for operating the robot remotely. Using the approach outlined above, a remote transmitter was selected to operate the robot according to the use situations in a naval ship described earlier. As a result, the FLYSKY FS-i6s 2.4G 10 Channel Transmitter and Receiver, shown in Figure 2, was selected to operate the HHR. The transmitter features four switches that can be used to indicate different use situations which can include switching between bipedal and wheeled mode. The joysticks in the center of the device will control the throttle, orientation, and activation of different components of the HHR depending on the switch settings of the transmitter. These switches will decide which components will move at one instance, such as the legs or the arms, and the joystick controls will adjust accordingly to the settings being used meaning that the joysticks will be able to change their function according to the switch orientations. This will permit individual movements of the arms and legs as well as default movement settings when the switches are oriented according to the operator's intent.

Figure 2: Photograph of FLYSKY FS-i6s 2.4G 10 Channel Transmitter & Receiver

When operating as a bipedal robot, the stability of the robot during movement is a primary concern. To ensure stability, the change of the center of gravity during the movement of a component is the most important metric required to determine whether the HHR will remain stable or not. To calculate the center of gravity of the robot, a bill of materials must be created that describes each component's dimensions and local COG. By incorporating static analyses of the expected loading configurations, such as movements required to climb the 63-degree ladder, the COG and stability can be calculated to determine the appropriate range and counter-movements necessary to keep the HHR stable in bipedal situations. The angular velocity of the components, which is proportional to the current sent to each Dynamixel motor, can be discovered and values for the equivalent external force, angular momentum, and external torque on the robot can be calculated, thus indicating the degree of stability for each movement.

This project aims to strike a balance between advanced technology and functional utility. It does not seek to revolutionize robotics but to provide a tangible improvement in the operational capacity of robots in specific contexts. The potential applications of this technology in naval settings are vast, ranging from routine surveillance and maintenance tasks to more complex operational roles. The successful implementation of this technology could lead to enhanced efficiency and versatility in unmanned or robot-assisted naval operations.

Autonomous Technologies within Manufacturing

The potential of adopting autonomous technologies into society is undoubtedly promising. Thousands of lives each year are exposed to dangerous conditions that contribute to the death and compromised health of workers all over the world. According to the U.S. Bureau of Labor Statistics, exposure to harmful substances or environments led to 798 worker fatalities in 2021 (U.S. Bureau of Labor Statistics, 2022). This does not include situations that fail due to lapses in human judgment or behavior including accidents due to hazard communication, lack of fall protection, and machine guarding (U.S. Department of Labor, 2022). Humanoid robots aim to eliminate the likelihood of human injuries or fatalities in these situations through their ability to serve as a 1:1 replacement for humans in any physical environment. By programming HHRs, the speed, consistency, and logic of operations can become consistent and specifically tailored to their situation. This capability eliminates the chance of human error contributing to accidents which currently accounts for 80-90% of serious injuries within the workplace (J.J. Keller Safety Management Suite, 2019).

However, there is a growing fear that automation and the use of robotics in manufacturing are destroying jobs faster than it is creating new ones (Rotman, 2013). In the Industrial Revolution and throughout the 20th century, the majority of technologies served as instruments, meaning that they were able to refine processes to be more efficient by taking responsibility for the tedious and time-consuming tasks of production while still being operated by humans. In the example of textile production during the 19th century, technologies such as the spinning jenny, cotton gin, and powered loom made textiles cheaper and much faster to manufacture. The obsolete jobs of hand-weaving and cotton preparation were replaced by the operation of these artifacts and the advancement of workers into other stages and positions within textile development. Productivity and the output of each person during this period was able to skyrocket due to the optimization of the textile production process and human workers were at no risk of losing their jobs.

In contrast to the use of technology during the Industrial Revolution, robots in a manufacturing setting are used as labor rather than as instruments, which leaves current industry workers' positions vulnerable to being entirely replaced by these technologies without an opportunity for a position in an adjacent role. Hybrid humanoid robots in these settings can serve as a direct 1:1 replacement for humans and can behave autonomously, thus eliminating the need for human operators. In theory, the widespread adoption of autonomous robots throughout the manufacturing industry would significantly reduce the number of manufacturing jobs available for humans. When analyzing recent statistics within this industry, this theory appears to be growing in credibility. According to one study, it was estimated that automation replaced over 400,000 jobs from 1990 to 2007 (Semuels, 2020). Additionally, a McKinsey analysis indicated that the impact of automation on the labor demand of predictable job environments such as production workers, machine operators, and general mechanics decreased by an average of 25 to 34 percent on average (Manyika et al., 2017). It is obvious that automation is replacing many of these jobs, however, the growth of labor demand in adjacent positions within manufacturing is not increasing at anywhere near the same rate. The same McKinsey study revealed that jobs in unpredictable environments had zero net growth in labor demand in the United States. Even worse, within the manufacturing industry, positions such as machinery installation and repair workers job labor demand had dropped as well by 15 to 24 percent. Due to the obvious cost and productivity advantages, many factories have begun to transition from human to robot-centric workforces. For example, Changying Precision Technology, a manufacturing company based in China, reduced their staff from over 650 human workers to just 60 through the addition of several robots to their facilities. As a result, the company increased productivity by 250 percent and reduced the number of defects produced by 80 percent (Javelosa & Houser, 2017).

Through the concept of multistability, it is evident that human workers with repetitive production jobs within the manufacturing industry are adversely affected by the usage of robots and automation in this industry. In Rosenberger's terminology, the impact on job availability for manufacturing workers represents an alternate stability of this technology. To mitigate the effects of automation on this demographic and the availability of manufacturing jobs in the future, it is essential to examine existing legislation surrounding the use of robots in manufacturing and determine how to incentivize the use of human labor in conjunction with robotics. The United States currently incentivizes companies to automate through the 2017 Tax Cuts and Jobs Acts. Previously, a company that paid a worker $100 would have to pay roughly $30 in taxes, however, through this act, that company can invest the same amount of money into automation and instead pay just $3 in taxes (Semuels, 2020). For this reason, companies are encouraged to minimize the number of human workers as possible to keep costs low. Considering that there are 12.7 million manufacturing jobs in the United States (U.S. Bureau of Labor Statistics, 2023) and the declining rate of job demand within this industry as indicated by McKinsey, it can be estimated that about 3.2 million jobs will be eliminated. To create a future where the use of robots and automation does not adversely impact workers in the manufacturing industry, legislation such as the 2017 Tax Cuts and Jobs Act should be revoked or revised to properly balance the availability of human jobs within this industry.

Conclusion

Automation and robotics are quickly taking over the manufacturing industry in the United States. While these technologies are cost-effective, safer, and more efficient compared to human labor, the impact on workers in this industry is significant. Several studies have indicated that the repetitive jobs within this field have continued to be replaced by automated robots and these workers are highly unlikely to find an adjacent role within this industry. This situation has been exacerbated by current legislation such as the 2017 Tax Cuts and Jobs Act which greatly incentivizes investments in robotics rather than investments in human workers. As a result, millions of middle-class workers in manufacturing are vulnerable to the loss of their jobs without any direct replacement into a similar role.

To prevent a future susceptible to these risks, legislation must be enacted to control how companies handle automation and their use of robots. The United States government currently incentivizes companies to automate by allowing tax relief for the purchase of machinery and software (Semuels, 2020). To continue human involvement within this industry, legislation will need to incentivize human labor over machinery. This can be accomplished through the subsidization of human laborers in industries where jobs are being quickly replaced, such as in manufacturing, or by placing additional taxes and fees on products produced using automated machine processes. The benefits of autonomous technologies are clear and have an exceptional potential for increased growth and productivity for the U.S. economy. However, finding a balance between the optimization of business and the social implications of autonomous robots will need to be defined to create a healthy and sustainable future.

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