DEXTERITY

THE IMPACT OF TELEOPERATED DRONES IN NUCLEAR DISASTER INVESTIGATION

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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

The rapid evolution of teleoperated systems has fundamentally transformed how engineers approach a given design problem. Various technological sectors often encounter hazardous, toxic environments that cannot be handled in proximity, which calls for the deployment of teleoperated systems to fulfill a specific task. For example, the Fukushima Daiichi Nuclear Power Plant Disaster required the use of investigative, remotely-operated drones to assess and measure the radiation damage of the site (World Nuclear Association, 2024). The socio-technical challenge of hazardous environment/material handling showcases one of the more prominent design problems involving remotely-operated systems.

With the need for remote hazardous materials manipulation in mind, my group and I will develop Project Dexterity: a teleoperated robotic armature used for the handling of hazardous materials in a laboratory setting. Paired with a haptic control glove that drives movement of the arm and provides tactile sensation, this system will allow the user to manually handle dangerous substances from a secure proximity. The system ensures a sense of safety and provides a cost-effective approach to smaller labs working with hazardous materials, such as viruses.

Since both social and technical aspects factor into the deployment of teleoperated drones into the Fukushima nuclear disaster site, it is important to analyze how the parties involved come together to drive the success of the investigation of the toxic environment. Thus, my STS project will use the Actor-Network Theory (ANT) framework to examine the network of socio-technical dependencies that contributed to the success of the investigation of the Fukushima disaster site. Because the challenge of resolving hazardous disasters is a socio-technical problem, it requires the coordinated effort among actors to drive the success of the given design problems, taking both social and technical factors into consideration. In what follows, I set out two related research proposals: a technical project proposal for developing Project Dexterity and an STS project proposal for examining the social and technical factors that contribute to the success of teleoperated systems implemented in the Daiichi Power Plant nuclear radiation investigation.

Technical Project[1]

The manipulation of hazardous materials in laboratories poses significant risks to researchers and technicians. While fume hoods and personal protective equipment provide basic safety measures, direct manual handling of dangerous substances remains a persistent danger. Recent incidents involving chemical burns, toxic exposure, and explosive reactions underscore the need for improved handling methods that maintain precise control while keeping operators at a safe distance (Yang et. al., 2022). To address the need for safer laboratory environments, we are creating a cost-effective, teleoperated robotic armature paired with a control glove. This system aims to deliver precise tracking and reliable haptic feedback, allowing users to conduct experiments at a safe distance.

Before examining our proposed system, we must consider alternative solutions currently available on the market. The Shadow Robot teleoperated robotic arm and control glove retails for about $120,000 (Shadow Robot, 2022). An additional $5000 will get you the HaptX G1 control glove that will provide more precise tracking and better haptic feedback from the Shadow Robot arm (HaptX, 2024). The HaptX glove requires a large external pneumatic system, making the system less portable. This system is very advanced, but its high cost puts it out of reach for most research laboratories. Another control glove that can be used for teleoperation is the $4000

[1] The following section was written in collaboration with Max Titov, whom I am working with on my Capstone design

TouchDIVER Pro glove from Weart, which features full tracking, tactile feedback through texture rendering, and thermal cues (Weart Haptics, 2024). While these features are advanced, the lack of resistive force feedback makes the glove less practical for medical and scientific research. Our glove will have full finger, wrist, and forearm tracking, tactile feedback on the fingertips, and resistive force feedback.

Project Dexterity includes a control glove that directs the movement of a robotic armature, which, in turn, provides haptic feedback as it engages with the environment. Adapted from the open-source Dexhand project, the armature design has been modified to enable forearm movement from the elbow. To track individual finger movements, the glove uses 16 Hall-effect sensors with rotating magnets, alongside two inertial measurement units (IMUs) that monitor hand and forearm orientation. The data from the sensors and IMUs are then used to drive servo motors on the robotic arm which allow movement. The robotic arm is equipped with pressure sensors on its fingertips, which sends data back to the glove to activate linear resonant actuator (LRA) modules on the fingertips to provide tactile feedback when making contact with objects. To mimic variable pressure, the LRAs have multiple vibrational settings that increase in frequency as the force readings from the pressure sensors vary. The system uses two ESP32 microcontrollers – one embedded in the robotic armature and the other in the control glove – that communicate with each other wirelessly. Finally, we will have resistive force feedback driven by servos that restricts finger movement. This combination of components and features provides a low-cost alternative to existing teleoperated robotic arms, making our system an attractive choice for smaller laboratories looking to do research with hazardous materials.

Our design draws from many of the foundational concepts of electronics as well as mechanical design. On a general level, our system contains various electronic and mechanical parts that must communicate with each other to enable dexterous control over the arm. Both the control glove and robotic arm include microcontrollers that direct and regulate signals to its necessary components, such as the hall effect sensors/IMUs for hand and arm orientation as well as LRAs and pressure sensors for haptic feedback. Additionally, the implementation of control algorithms tie the entire system together, ensuring proper communication between the control glove and the robotic arm. Lastly, the mechanical design of the arm involved using CAD to alter the open source Dexhand design to fit the needs of our implementation.

To prove to our stakeholders with evidence that our system works, we will record videos of the hand in action to show how the system can handle precise tasks commonly used in laboratory settings. A good demonstration of the system’s haptic feedback is to have a user manipulate an unseen object, revealing how the feedback conveys valuable information for effective object handling. By combining precise motion tracking, realistic tactile feedback, force feedback, and an affordable open-source design, Project Dexterity will enable laboratories to conduct hazardous material procedures with improved safety and control. The system's focus on laboratory applications and dramatic cost reduction compared to existing solutions makes it a practical option for research institutions seeking to enhance their safety protocols without compromising experimental precision.

STS Project

The March 2011 Fukushima Daiichi Nuclear Power Plant disaster represented a critical moment of technological innovation and crisis response. Traditional investigative approaches were rendered impossible by extreme radiation levels, complex physical destruction, and unprecedented environmental challenges. Thus, teleoperated drones emerged as a transformative technological solution, offering a unique approach to understanding and assessing the disaster's extensive environmental and infrastructural impacts.

Previous analyses of the Fukushima nuclear disaster typically attribute the success of the drone investigation to human actors, primarily focusing on the expertise of nuclear engineers, emergency response coordinators, and technology specialists from Tokyo Electric Power Company (TEPCO). However, this perspective fails to capture the complex network of interactions that enabled the project's success, as non-human actors also played a crucial role in the investigative efforts. The advanced drone platforms with specialized radiation detection sensors played a crucial role in translating human investigative needs into actionable data (Guizzo, 2022). These drones were not merely tools but active participants in the network, capable of navigating complex environmental conditions, collecting precise measurements, and transmitting critical information in real-time. Additionally, environmental actors such as the increasingly radioactive contamination zones demanded constant adaptation from both human operators and the employed technology, as the environment was not a passive backdrop but an active participant that continuously challenged and reshaped the technological approach (Federal Office for Radiation Protection, 2023).

Institutional networks also provided essential infrastructure and legitimacy for the drone investigation. Regulatory frameworks, international scientific collaboration protocols, and emergency response mechanisms created the necessary support structure for the technological intervention. For example, TEPCO had to abide by and compromise with the regulations set forth by the Japanese government, which mainly involved updating and enhancing safety monitoring systems (National Regulatory Commision, 2024). Failure to account for the full range of actors would result in an oversimplification of technological innovation and reduced insights into crisis response methodologies. Thus, accounting for each of the intricate interconnections and adaptive relationships among these actors are crucial to analyzing the success of the Daiichi Power Plant drone investigation.

To analyze the use of teleoperated drones in the investigation of the Fukushima nuclear disaster, I will use Actor-Network Theory (ANT) to assess the various contributing factors that enabled the application of this innovative technology. ANT is a framework that examines how networks of various actors, both human and non-human, shape technological outcomes through their interconnected relationships and dependencies (Latour, 2005). Formed by Bruno Latour and other scholars, ANT is governed by the idea of translation, which is the process of actors aligning or misaligning in a network and thus determining the overall success or failure of the given network (Cressman, 2009). In regards to the Fukushima nuclear disaster drone investigation, I will use translation to establish that the technological intentions and decisions of TEPCO and other human actors are equally as important as the drones that were used to investigate the disaster site. I will use several different sources including TEPCO investigation reports, radiation measurement documentation, and scientific publications regarding this investigation to support my analysis. Together, these reports will illustrate the cohesive network contribution that allowed for successful nuclear site investigation.

Conclusion

The Technical and STS projects cohesively demonstrate the complex interplay between technological innovation and social factors in the development of teleoperated systems. Our technical project delivers Project Dexterity, a cost-effective teleoperated robotic hand system that enables safer handling of hazardous materials in laboratories. By providing precise motion tracking, tactile feedback, and force resistance at a fraction of the cost of existing solutions, this system makes remote manipulation technology accessible to a broader range of research institutions.

The STS research case on the teleoperated drones used in disaster site investigation, specifically the Fukushima Daiichi Nuclear Power Plant disaster, offers crucial insights into how different actors within a network bear equally crucial responsibility in driving the success of an investigative operation. Understanding how human actors and non-human actors work cohesively provides valuable lessons for our laboratory system's implementation. By analyzing teleoperated systems that both have the underlying implication of safety the importance of maintaining a positive and productive moral intentions is made clear. This will ensure that our system addresses not just the technical requirements but also aligns with our ethical values, ultimately benefiting society as a collective.

Together, these projects contribute to addressing the broader sociotechnical challenge of developing beneficial applications for teleoperated systems. The STS Project depicts a safety-driven use of teleoperated robotics, which directly correlates to Project Dexterity and ultimately demonstrates the potential for enhancing human safety and capabilities in research settings. This dual perspective enables us to better navigate the factors and ethical intentions that contribute a positive overall impact on society.

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