PROJECT DEXTERITY

ANALYSIS OF TELEOPERATED ROBOTS AT CHERNOBYL

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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 1986 Chernobyl nuclear disaster represented one of humanity's greatest technological catastrophes, creating an unprecedented challenge in managing extreme radiological hazards while protecting human life. After numerous failed attempts at using teleoperated robots to clean up the nuclear waste, Soviet authorities deployed thousands of workers, known as "liquidators," to contain the radioactive contamination, leading to numerous casualties from radiation exposure (Anderson, 1990). This human toll highlighted a critical technological gap: the need for robotic systems capable of operating in highly radioactive environments where human presence would be lethal. The development of teleoperated robots for nuclear disaster response emerged not merely as a technical challenge of building radiation-hardened machines, but as a vital sociotechnical mission to protect human life while enabling critical disaster response operations.

With the insights gained from the successes and failures of the Chernobyl teleoperated robots, I propose the development of Project Dexterity, a teleoperated robotic armature that is controlled with a haptic glove. This glove will track the user's fingers, wrist, and forearm and send these commands to the robotic armature. There will be pressure sensors on each fingertip of the robotic armature, which will drive the haptic buzzers on the control glove's fingertips to provide tactile feedback to the user. This system is targeting the medical and scientific research field, to provide a safe way for researchers to handle hazardous contents in labs without sacrificing the dexterity of a human hand. This technical project requires the integration of several elements, such as control systems, reliability of robotic systems, and operator training. To examine such mechanisms, I will draw on the STS framework of actor-network theory to analyze the deployment of various robotic systems at Chernobyl. Specifically, I will investigate how interactions among technical and social factors such as radiation hardening capabilities, operator training programs, and emergency response protocols contributed to these systems' successes and failures.

Neglecting the role interactions among diverse factors play in a project's success by treating the proposed robotic system as somehow isolated from its sociotechnical context runs the risk of creating a system that cannot properly function in real scenarios. If this outcome were to occur, the system's ability to handle hazardous materials would be compromised, either ruining the experiment or even endangering the human operator. Because the challenge of effective teleoperation of robots is sociotechnical in nature, it requires attending to both its technical and social aspects to accomplish successfully. In what follows, I set out two related research proposals: a low-cost teleoperated robotic arm and an STS project proposal for examining the complex social networks that caused the failures in the Chernobyl nuclear disaster cleanup.

Technical Project

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. 2023). To address the need for safer laboratory environments, we are creating a cost-effective, teleoperated robotic hand 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 will review alternative solutions currently available on the market. The Shadow Robot teleoperated robotic arm and control glove retails for about $120,000 ("How much does a robot hand cost?" 2023). 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 ("Gloves G1," 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 TouchDIVER Pro glove from Weart, which features full tracking, tactile feedback through texture rendering, and thermal cues ("Touchdiver Pro Haptic Gloves," 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 (to measure magnetic fields) 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 is controlled by 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 Proposal

In the immediate aftermath of the 1986 Chernobyl nuclear disaster, Soviet authorities faced an unprecedented challenge: how to clean up highly radioactive debris from the reactor roof without exposing human workers to lethal doses of radiation. Their solution was to deploy teleoperated robots, including the notable STR-1 robot and modified German-made MF-2 and MF-3 construction machines (Williams, 2021). However, while some robotic deployments achieved limited success, many of these early attempts failed due to various technical and organizational factors, ultimately requiring human liquidators to perform much of the dangerous cleanup work manually.

The story of robotic deployment at Chernobyl represents more than just a series of technical successes and failures. It illustrates the complex interplay between human operators, machines, radiation, organizational structures, and international politics during a crisis. While conventional accounts often focus on the technical limitations of the robots, such as radiation-induced electronics failures (Anderson, 1990), this analysis argues that the effectiveness of teleoperated robotics at Chernobyl was fundamentally shaped by the network of relationships between human and non-human actors, their interactions, and the broader socio-political context in which they operated.

Drawing on Actor-Network Theory (ANT), I contend that the varying success of robotic cleanup efforts at Chernobyl can be better understood by examining how different actors -

including robots, operators, radiation, Soviet bureaucrats, international experts, and the physical infrastructure - were enrolled into the network and how their interactions either strengthened or weakened the network's ability to achieve its goals. Developed by STS scholars like Michel Callon, Bruno Latour, and John Law, this theory claims that all technical projects can be viewed as a network of human and non-human actors assembled by a network builder to accomplish a particular goal. Key to ANT is the idea that the connections and interactions among the various actors determine the network's relative strength and whether it succeeds or fails (Cressman, 2009). Specifically, I argue that the failures were not simply due to technical limitations but resulted from breakdowns in the translation process between these various actors, exacerbated by the Soviet system's institutional barriers to international collaboration and knowledge sharing.

The evidence for this analysis will be drawn from multiple sources, including technical reports from the International Atomic Energy Agency (IAEA, 2021), documentation of the robotic systems deployed ("Chernobyl Robots," 2021), and contemporary news coverage of the cleanup efforts (Williams, 2021). Key sources include the technical documentation of the STR-1 robot ("STR-1 Specialized Transport Robot," 2012), interviews with cleanup participants collected by the Chernobyl Project ("*Hero of chernobyl: An Interview with engineer Alexei Ananenko," 2021*), and official Soviet reports on the cleanup effort.

This analysis of the Chernobyl case has important implications for my technical project on modern teleoperated robotics in hazardous environments. Understanding how various actors - human, technical, and institutional - need to be successfully enrolled and aligned can help inform the design and implementation of more effective robotic systems for future disaster response scenarios. Particularly relevant are lessons about the importance of operator training, the need for robust communication systems, and the critical role of institutional support and knowledge sharing in determining the success or failure of teleoperated robotic deployments.

Conclusion

In conclusion, Project Dexterity will deliver an affordable and effective teleoperated robotic system, providing laboratories with a practical solution for handling hazardous materials safely. Meanwhile, the STS analysis of Chernobyl's robotic deployment efforts will yield valuable insights into how technical and social factors interact in crisis response scenarios. Together, these projects address the critical sociotechnical challenge of protecting human life while maintaining precise control in hazardous environments. The technical project contributes by creating an accessible tool that reduces direct exposure risks, while the STS research reveals essential patterns in successful teleoperated robotic system deployment. Key insights from the Chernobyl analysis, particularly regarding operator training, communication systems, and institutional support, will directly inform Project Dexterity's development and implementation strategy. This integrated approach ensures the system will effectively serve its intended purpose within modern laboratories.

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