

Concepts for operating ground based rescue robots using virtual reality

Bachelor thesis by Jingyi Jia
Date of submission: June 30, 2021

1. Review: Prof. Dr. Max Mühlhäuser
2. Review: Julius von Willich
Darmstadt



TECHNISCHE
UNIVERSITÄT
DARMSTADT

Computer Science
Department

Telekooperation
Prof. Dr. Max Mühlhäuser

Erklärung zur Abschlussarbeit gemäß §22 Abs. 7 und §23 Abs. 7 APB der TU Darmstadt

Hiermit versichere ich, Jingyi Jia, die vorliegende Bachelorarbeit ohne Hilfe Dritter und nur mit den angegebenen Quellen und Hilfsmitteln angefertigt zu haben. Alle Stellen, die Quellen entnommen wurden, sind als solche kenntlich gemacht worden. Diese Arbeit hat in gleicher oder ähnlicher Form noch keiner Prüfungsbehörde vorgelegen.

Mir ist bekannt, dass im Fall eines Plagiats (§38 Abs. 2 APB) ein Täuschungsversuch vorliegt, der dazu führt, dass die Arbeit mit 5,0 bewertet und damit ein Prüfungsversuch verbraucht wird. Abschlussarbeiten dürfen nur einmal wiederholt werden.

Bei der abgegebenen Thesis stimmen die schriftliche und die zur Archivierung eingereichte elektronische Fassung gemäß §23 Abs. 7 APB überein.

Bei einer Thesis des Fachbereichs Architektur entspricht die eingereichte elektronische Fassung dem vorgestellten Modell und den vorgelegten Plänen.

Darmstadt, 30. Juni 2021

Jingyi Jia

Contents

1	Abstract	4
2	Introduction	5
3	Implementation	7
3.1	Overview	7
3.2	System Architecture	7
3.3	Robot	8
3.4	Interaction techniques	8
3.4.1	Handle Mode	10
3.4.2	Lab Mode	10
3.4.3	Remote Mode	10
3.4.4	UI Mode	10
3.5	Test Scene	10
4	Evaluation of User Experience	11
5	Results	12
6	Conclusion and future work	13



1 Abstract

2 Introduction

In recent years, natural disasters such as earthquakes, tsunamis and potential nuclear, chemical, biological and explosives have seriously threatened the safety of human life and property. While the number of various disasters has increased, their severity, diversity and complexity have also gradually increased. The 72h after a disaster is the golden rescue time, but the unstructured environment of the disaster site makes it difficult for rescuers to work quickly, efficiently and safely.

Rescue robots have the advantages of high mobility and handling breaking capacity, can work continuously to improve the efficiency of search and rescue, and can achieve the detection of graph, sound, gas and temperature within the ruins by carrying a variety of sensors, etc. Moreover, the robot rescue can assist or replace the rescuers to avoid the injuries caused by the secondary collapse and reduce the risk of rescuers. Therefore, rescue robots have become an important development direction.

In fact, rescue robots have been put to use in a number of disaster scenarios. The Center for Robot-Assisted Search and Rescue (CRASAR) used rescue robots for Urban Search and Rescue (USAR) task during the World Trade Center collapse in 2001 [1] and has employed rescue robots at multiple disaster sites in the years since to assist in finding survivors, inspecting buildings and scouting the site environment etc [2]. Anchor Diver III was utilized as underwater support to search for bodies drowned at sea after the 2011 Tohoku Earthquake and Tsunami [3].

Considering the training time and space constraints for rescuers [4], and the goal of efficiency and fluency collaboration [5], the appropriate human-robot interaction approach deserves to be investigated. Some of the existing human-computer interaction methods are Android software [6] [7], gesture recognition[8] [9] [10], facial voice recognition [11], adopting eye movements [12], Augmented Reality(AR)[13] and Virtual Reality(VR), etc.

Among them, VR has gained a lot of attention due to its immersion and the interaction method that can be changed virtually. VR is no longer a new word. With the development of technology in recent years, VR devices are gradually becoming more accessible to users. With the improvement of hardware devices, the new generation of VR headsets have higher resolution and wider field of view. And in terms of handle positioning, with the development of computer vision in the past few years, VR devices can now use only the four cameras mounted on the VR headset to achieve accurate spatial positioning, and support hand tracking, accurately capturing every movement of hand joints. While VR are often considered entertainment devices, VR brings more than that. It plays an important role in many fields such as entertainment, training, education and medical care.

The use of VR in human-computer collaboration also has the potential. In terms of reliability, VR is reliable as a novel alternative to human-robot interaction. The interaction tasks that users can accomplish with VR devices do not differ significantly from those using real operating systems[14]. In terms of user experience and operational efficiency, VR displays can provide users with stereo viewing cues, which makes collaborative human-robot interaction tasks in certain situations more efficient and performance better [15].

However, there remains a need to explore human-computer interaction patterns and improve the level of human-computer integration[16]. Intuitive and easy-to-use interaction methods can enable the user to explore the environment as intentionally as possible and improve the efficiency of search and rescue.

For this purpose, this paper presents a preliminary VR-based system for the simulation of ground rescue robots with four different modes of operation and corresponding test scenes imitating a post-disaster city. The test scene simulates a robot collaborating with Unity to construct a virtual 3D scene. The robot has a simulated radar, which makes the display of the scene dependent on the robot's movement. In order to find a control method that is as intuitive and low mental fatigue as possible, a user survey was executed after the development was completed.

Section 3 provides details of the purposed system, including the techniques used for the different interaction modes and the structure of the test scenarios. Section 4 will talk about the design and process of user study. Section 5 presents the results of the user study and analyzes the advantages and disadvantages of the different modes of operation and the directions for improvement. Finally, in Section 6, conclusions and future work are summarized.

3 Implementation

In this chapter, the tools and techniques used in building this human-computer collaborative VR-based system are described. The focus will be on interaction techniques for different modes of operation. In addition, the setup of the robot and the construction of test scenes will also be covered in this chapter.

3.1 Overview

The main goal of this work is to design and implement a VR-based human-robot collaboration system with different methods of operating the robot in order to find out which method of operation is more suitable to be used to control the rescue robot. Further, it is to provide some basic insights for future development directions and to provide a general direction for finding an intuitive, easy-to-use and efficient operation method. Therefore, the proposed system was developed using Unity, including four modes of operation and a corresponding test environment for simulating post-disaster scenarios. In each operation mode, the user has a different method to control the robot. In addition, in order to better simulate the process by which the robot scans its surroundings and the computer side cumulatively gets a reconstructed 3D virtual scene, the test environment was implemented in such a way that the picture seen by the user depends on the direction of the robot's movement and the trajectory it travels through.

3.2 System Architecture

The proposed system runs on a computer with the Windows 10 operating system. This computer has been equipped with an Intel Core i7-8700K CPU, 32 GB RAM as well as a NVIDIA GTX 1080 GPU with 8 GB VRAM. HTC Vive is used as a VR device. It has a resolution of 1080×1200 per eye, resulting in a total resolution of 2160×1200 pixels, a refresh rate of 90 Hz, and a field of view of 110 degrees. It includes two motion controllers and uses two Lighthouses to track the position of the headset as well as the motion controllers.

Unity was chosen as the platform to develop the system. Unity is a widely used game engine with a Steam VR plugin ¹, which allows developers to focus on the VR environment and interactive behaviors in programming, rather than specific controller buttons and headset positioning, making VR development much simpler. Another reason why Unity was chosen as a development platform was the potential for collaboration with the Robot Operating System (ROS), a frequently used operating system for robot simulation and manipulation, which is flexible, low-coupling, distributed, open source, and has a powerful and rich third-party feature set. In terms of collaboration between Unity and ROS, Siemens provides open source software libraries and tools in C# for communicating with ROS from .NET applications ². Combining ROS and Unity to develop a collaborative human-robot interaction platform proved to be feasible[17]. Since the focus of this paper is on human-robot interaction, collaboration and synchronization of ROS will not be explored in detail here.

3.3 Robot

To simulate the process of a robot using a probe camera to detect the real environment and synchronise it to Unity, a conical collision body was set up on the robot. The robot will transform the Layers of the objects in the scene into visible Layers by collision detection as it is driving. In addition, the robot's driving performance, such as the number of collisions, average speed, total distance, etc., will be recorded in each test. The detailed recorded information can be seen in Fig.3.1. The movement of the robot depends on the value of the signal that is updated in each mode. In addition, the robot's GameObject has the NavMeshAgent ³ component, which supports the robot's navigation to the specified destination with automatic obstacle avoidance in the test scene.

3.4 Interaction techniques

This system has 4 different approaches to control the robot. Each mode has its own distinctive features:

1. In Handle Mode the user will send control commands directly using the motion controller.
2. In Lab Mode a simulated lab is constructed in the VR environment and the user will use virtual buttons in the lab to control the rescue robot.
3. In Remote Mode the user can set the driving destination directly.
4. In UI Mode the user has a virtual menu and sends commands via rays from the motion controller.

¹<https://assetstore.unity.com/packages/tools/integration/steamvr-plugin-32647>

²<https://github.com/siemens/ros-sharp>

³<https://docs.unity3d.com/ScriptReference/AI.NavMeshAgent.html>

In order to improve the reusability of the code and to facilitate the management of subsequent development, the classes that manage the interaction actions of each mode implement the same interface. A graphical representation of the system structure is given in the UML activity diagram in Fig.3.1.

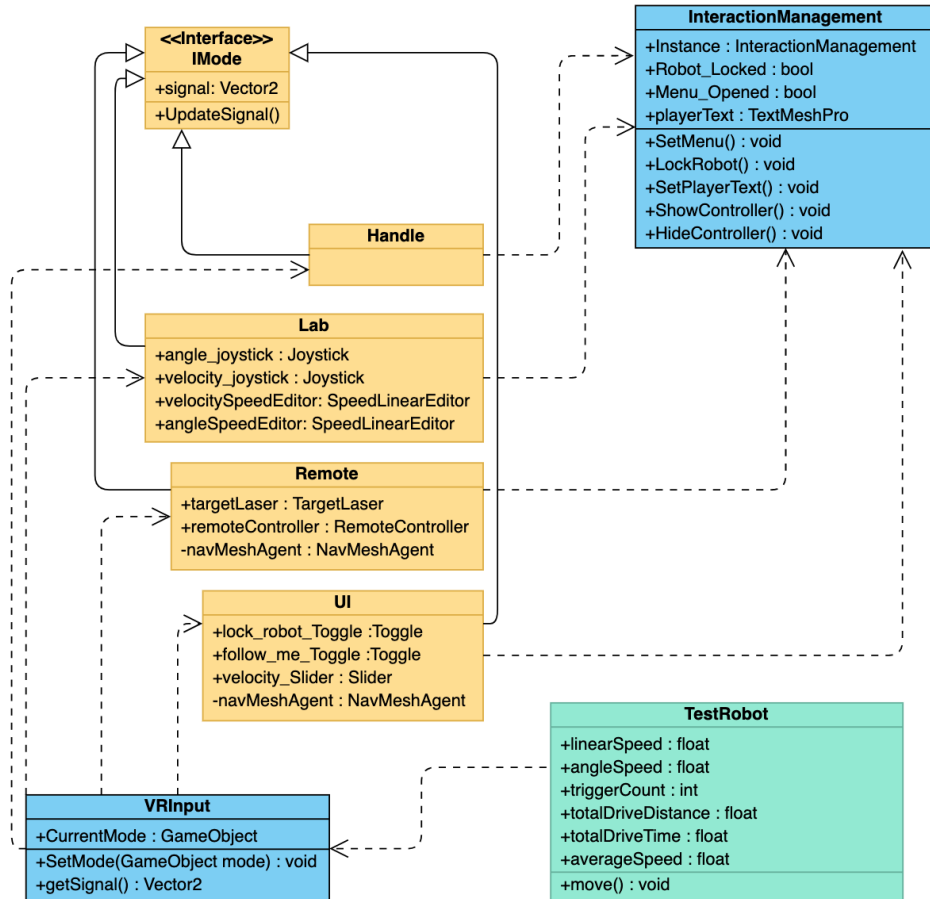


Figure 3.1: UML Class diagram for the main structure of the system

3.4.1 Handle Mode

3.4.2 Lab Mode

3.4.3 Remote Mode

3.4.4 UI Mode

3.5 Test Scene

In order to simulate the use of rescue robots in disaster scenarios, the test scenes were built to mimic the post-disaster urban environment as much as possible. The POLYGON Apocalypse⁴, available on the Unity Asset Store, is a low poly asset pack with a large number of models of buildings, streets, vehicles, etc. Using this resource pack as a base, additional collision bodies of the appropriate size were manually added to each building and obstacle after the pack was imported, which was needed to help track the robot's driving crash in subsequent tests.

Considering that there are four modes of operation to be tested, four scenes with similar complexity, similar composition of buildings but different road conditions and placement of buildings were constructed. The similarity in complexity of the scenes ensures that the difficulty of the four tests is basically identical. The different scene setups ensure that the scene information learned by the user after one test will not make him understand the next test scene and thus affect the accuracy of the test data.

The entire scene is initially invisible, and the visibility of each objects in the test scene is gradually updated as the robot drives along. Ten interactable sufferer characters were placed in each test scene. The place of placement can be next to the car, the house side and some other reasonable places.

⁴<https://assetstore.unity.com/packages/3d/environments/urban/polygon-apocalypse-low-poly-3d-art-by-synt-154193>



4 Evaluation of User Experience

5 Results



6 Conclusion and future work

Bibliography

- [1] J. Casper and R. R. Murphy. “Human-robot interactions during the robot-assisted urban search and rescue response at the World Trade Center”. In: *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)* 33.3 (2003), pp. 367–385. DOI: 10.1109/TSMCB.2003.811794.
- [2] R. R. Murphy. “A decade of rescue robots”. In: *2012 IEEE/RSJ International Conference on Intelligent Robots and Systems*. 2012, pp. 5448–5449. ISBN: 2153-0866. DOI: 10.1109/IROS.2012.6386301.
- [3] Ya-Wen Huang et al. “Operation of underwater rescue robot anchor diver III during the 2011 Tohoku Earthquake and Tsunami”. In: *OCEANS’11 MTS/IEEE KONA*. 2011, pp. 1–6. ISBN: 0197-7385. DOI: 10.23919/OCEANS.2011.6107198.
- [4] R. R. Murphy. “Human-robot interaction in rescue robotics”. In: *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)* 34.2 (2004), pp. 138–153. DOI: 10.1109/TSMCC.2004.826267.
- [5] Guy Hoffman and Cynthia Breazeal. “Effects of Anticipatory Action on Human-Robot Teamwork Efficiency, Fluency, and Perception of Team”. In: *Proceedings of the ACM/IEEE International Conference on Human-Robot Interaction*. HRI ’07. Arlington, Virginia, USA: Association for Computing Machinery, 2007, pp. 1–8. ISBN: 9781595936172. DOI: 10.1145/1228716.1228718. URL: <https://doi.org/10.1145/1228716.1228718>.
- [6] S. Sarkar et al. “Earthquake rescue robot: A purview to life”. In: *2017 Second International Conference on Electrical, Computer and Communication Technologies (ICECCT)*. 2017, pp. 1–7. DOI: 10.1109/ICECCT.2017.8118044.
- [7] F. Faisal and S. A. Hossain. “DOORMOR: A Functional Prototype of a Manual Search and Rescue Robot”. In: *2019 1st International Conference on Advances in Science, Engineering and Robotics Technology (ICASERT)*. 2019, pp. 1–6. DOI: 10.1109/ICASERT.2019.8934515.
- [8] Patrick Sousa et al. *Human-Robot Interaction Based on Gestures for Service Robots*. Vol. 27. Oct. 2017, pp. 700–709. ISBN: 978-3-319-68194-8. DOI: 10.1007/978-3-319-68195-5_{_}76.
- [9] Alessandro Giusti et al. “Human-Swarm Interaction through Distributed Cooperative Gesture Recognition”. In: *Proceedings of the Seventh Annual ACM/IEEE International Conference on Human-Robot Interaction*. HRI ’12. Boston, Massachusetts, USA: Association for Computing Machinery, 2012, pp. 401–402. ISBN: 9781450310635. DOI: 10.1145/2157689.2157818. URL: <https://doi.org/10.1145/2157689.2157818>.

-
- [10] J. Nagi et al. "Human-swarm interaction using spatial gestures". In: *2014 IEEE/RSJ International Conference on Intelligent Robots and Systems*. 2014, pp. 3834–3841. ISBN: 2153-0866. DOI: 10.1109/IROS.2014.6943101.
- [11] S. Pourmehr et al. "'You two! Take off!': Creating, modifying and commanding groups of robots using face engagement and indirect speech in voice commands". In: *2013 IEEE/RSJ International Conference on Intelligent Robots and Systems*. 2013, pp. 137–142. ISBN: 2153-0866. DOI: 10.1109/IROS.2013.6696344.
- [12] J. Ma et al. "A Novel EOG/EEG Hybrid Human–Machine Interface Adopting Eye Movements and ERPs: Application to Robot Control". In: *IEEE Transactions on Biomedical Engineering* 62.3 (2015), pp. 876–889. DOI: 10.1109/TBME.2014.2369483.
- [13] João Soares, Alberto Vale, and Rodrigo Ventura. "A Multi-purpose Rescue Vehicle and a human–robot interface architecture for remote assistance in ITER". In: *Fusion Engineering and Design* 98-99 (2015). Proceedings of the 28th Symposium On Fusion Technology (SOFT-28), pp. 1656–1659. ISSN: 0920-3796. DOI: <https://doi.org/10.1016/j.fusengdes.2015.06.148>. URL: <https://www.sciencedirect.com/science/article/pii/S092037961530199X>.
- [14] V. Villani, B. Capelli, and L. Sabattini. "Use of Virtual Reality for the Evaluation of Human-Robot Interaction Systems in Complex Scenarios". In: *2018 27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*. 2018, pp. 422–427. ISBN: 1944-9437. DOI: 10.1109/ROMAN.2018.8525738.
- [15] O. Liu et al. "Understanding human-robot interaction in virtual reality". In: *2017 26th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*. 2017, pp. 751–757. ISBN: 1944-9437. DOI: 10.1109/ROMAN.2017.8172387.
- [16] P. Wang et al. "A novel human-robot interaction system based on 3D mapping and virtual reality". In: *2017 Chinese Automation Congress (CAC)*. 2017, pp. 5888–5894. DOI: 10.1109/CAC.2017.8243836.
- [17] D. Whitney et al. "ROS Reality: A Virtual Reality Framework Using Consumer-Grade Hardware for ROS-Enabled Robots". In: *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. 2018, pp. 1–9. ISBN: 2153-0866. DOI: 10.1109/IROS.2018.8593513.