UNIVERSITI TEKNOLOGI MARA

ROBOT-MEDIATED TELEREHABILITATION SYSTEM USING INTERNET OF ROBOTICS THINGS (IORT) FOR AUTISM INTERVENTION

MUHAMMAD ALIFF BIN ROSLY

Thesis submitted in fulfilment
of the requirements for the degree of
Doctor of Philosophy in
(Mechanical Engineering)

Faculty of Mechanical Engineering

October 2025

ABSTRACT

The convergence of Fourth Industrial Revolution (4IR) technologies has catalysed growth in assistive technology for special needs, including robot-mediated telerehabilitation systems for autism intervention. These systems aim to bridge the distance between Children with Autism (CwA) and therapists using robots. However, the implementation of telerehabilitation technologies in the systems is still in its infancy, leading to considerable inefficiencies and restricting the deployment of advanced functionalities of humanoid robots such as NAO. Thus, this study aims to develop an Internet of Robotics Things (IoRT)-based robot-mediated telerehabilitation system for autism intervention and investigate its feasibility, functionality, and performance. In this system, a CwA interacts with a robot, assisted by a guardian, while connected to a far-apart therapist via IoRT architecture. IoRT, a multi-layer architecture (network, perception, middleware, and application) was established with infrastructures such as NAO robot, Eclipse Mosquitto Message Queuing Telemetry Transport (MQTT) broker, MySQL database, Node-RED programming tools, Linux server and DigitalOcean cloud hosting. Here, the network layer performance test was prioritised, followed by a feasibility test confirming basic data transmission. Then, comprehensive user-oriented developments for perception, middleware, and application layers were conducted and evaluated using performance or functionality tests, followed by real-world experiments on the integrated system. In terms of results, the network layer's performance tests measured by JMeter showed low latency for MQTT publish-subscribe by achieving 90.0 % percentile below 300 ms, with zero error, affirming its efficiency and reliability. The feasibility test confirmed the successful data transmission across all layers, validating the architecture for a basic intervention module. The perception layer's eye gaze implementation showed good agreement with frame-by-frame video analysis, with acceptable limits in Bland-Altman analysis. Enhanced module functionality tests initially had a 78.2% pass rate, improving to 100% after resolving word-spotting and randomised body language issues. Middleware and application layers, using the same infrastructure, processed and visualised telerehabilitation data, showing 90.9 % functionality success. Adjustments to the nodes' input resolved concerns with enabling/disabling buttons, achieving 100 % functionality. Real-world experiments with CwA showed promising results, with the system transmitting 91.8% of MQTT packets accurately before resolving initial packet loss. The IoRT system’s CwA responses and eye gaze measurements matched the video analysis well, and the System Usability Scale (SUS) feedback rated the guardian and therapist dashboards’ usability as excellent, both above 80 SUS score. In conclusion, the proposed system proven to be robustly feasible, functional, and performs well in the set experiment environments. It successfully achieving targeted objectives and addressing the current system inefficiencies. This innovative system greatly benefits the autistic community by improving remote intervention, bridging distances between children and therapists, and setting a new standard for telerehabilitation.

ACKNOWLEDGEMENT

Firstly, I wish to thank Allah S.W.T for giving me the opportunity to embark on my PhD and for successfully completing this long and challenging journey. My gratitude and thanks go to my supervisor Assoc. Prof. Dr. Hanafiah Yussof and my co-supervisor Ts. Dr. Syamimi Shamsuddin, for their invaluable guidance, encouragement, insightful feedback and constructive critiques throughout this journey.

My appreciation also goes to Assoc. Prof. Dr. Nur Ismarrubie Zahari and Assoc. Prof. Dr. Ahmad Zamir Che Daud for their knowledge sharing. Their constructive feedback and encouragement inspired me to enhance the quality of my work. Special thanks to my research collaborators, Mohd Azfar Miskam, Muhammad Shahir Izzat Ainuddin, Annaz Fadznira Binti Ramli, Herwan bin Sarom, Samshir bin Wahab and Nur Wirdani Binti Rabiun@Ahmad Rabion for their support during the experimental process. Their assistance and motivation made this experience more enjoyable.

Additionally, I would like to acknowledge UiTM Shah Alam, UiTM Bukit Besi, UiTM Puncak Alam and Roboprenuer Sdn. Bhd. for providing the resources and facilities that made my research possible. This research was funded by the Ministry of Education (Malaysia) through the Fundamental Research Grant Scheme (FRGS) - 600-IRMI/FRGS 5/3 (472/2019).

Lastly, I would like to express my heartfelt gratitude to my family, whose unwavering love and support have been my greatest source of strength. I am deeply thankful to my parents, Rosly bin Talib and , for their endless prayers and steadfast encouragement. To my beloved wife, Dayana, I appreciate your unwavering support through both the easy and challenging times. I also wish to acknowledge my children, Anis Safiyyah, Anas Sufyan, Amina Sumayyah, and Aisha Sumayyah, for their love and smiles throughout this journey. This piece of victory is dedicated to all of my family. Alhamdulillah.

TABLE OF CONTENTS

CHAPTER 1
INTRODUCTION

1.1 Chapter overview

Chapter 1 introduces the research background of the research. It is followed by research motivations, problem statements, objectives, scopes, limitations, and significance of the study.

1.2 Research background

Robot-mediated innovations for autism or Autism Spectrum Disorder (ASD) educational intervention research have gained significant momentum in the last decade [1], [2], [3]. Recent studies show that more than 68 types of robots, including NAO, Kaspar, Zeno, Commu and Probo, are being utilised to facilitate autism intervention research [4]. Based on several pioneering Human-Robot Interaction (HRI) studies, these robots have proven to be a highly effective therapeutic tool for autism [5]. Their less complex features compared to humans allow Children with Autism (CwA) to feel safe and less intimidated. Thus, the CwA will be more cooperative, and the intervention can be done more effectively [6]. The promising results from these initial studies underscore the value of this research niche.

However, despite showing great promise, autism-related robot-mediated interventions need to become more accessible to cater to the growing autism population. According to the latest autism epidemiology data, the worldwide prevalence of autism has nearly doubled over the last decade [7], [8]. As a result, much attention has been given to telerehabilitation as an innovative approach to overcoming distance barriers and the shortage of autism specialists in providing rehabilitation services [9], [10].

Several robot-mediated telerehabilitation systems for autism, built on diverse telerehabilitation platforms and therapy modules, with robots such as NAO, CommU, and Android serving as the interaction robots, have been proposed. [11], [12], [13], [14]. The proposed telerehabilitation system makes therapy services more accessible. However, current telerehabilitation technology applications are in their infancy, leading