An Autonomous Multiple Robot Registration and Control System: Design Implementation and Performance Evaluation

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DECLARATION

I hereby declare that the thesis entitled “An Autonomous Multiple Robot Registration and Control System: Design, Implementation and Performance Evaluation" that is completed and submitted by me for the award of the degree of *Doctor of Philosophy* to Sri Lanka Institute of Information Technology(SLIIT) is a record of work carried out by me under the supervision of Prof.Chandimal Jayawardena, Dean, Faculty of Computing, SLIIT and External -supervision of Prof.Bruce MacDonald, Department of
Electrical, Computer and Software Engineering, Faculty of Engineering in University Of Auckland, New Zealand.

I further declare that the work reported in this thesis has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university.

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ABSTRACT

ROS is the most prominent middleware used by most researchers in robotic application development. Our research mainly depends on ROS technologies because most researchers currently work with ROS as middleware for many research projects. Controlling the robots through the Web interface is essential. Because in some instances, users may not be able to communicate with the robot directly because of some bad conditions in the environment where the robots are currently placed. Therefore, we have developed a Web interface to control all robots through the Internet. However, the ROS topics, nodes, and message formats used to subscribe and publish can differ from one robot to another when we work with multiple robots in the same environment. Therefore, when a user expresses high-level instructions through a Web interface, all multiple robots must understand instructions uniformly and take necessary actions accordingly without considering each robot's internal software and hardware implementation. The first contribution of the research is to develop an algorithm to register all robots based on the main components of the ROS technology through the Web interface autonomously. The robot Registration Engine was developed with algorithms to complete the autonomous robot registration task. The second contribution is identifying the relevant ROS topics and nodes for each action when a user command gives through the Web interface. The ROS topic identification algorithm was developed successfully. The third contribution was to evaluate the system performance under different conditions and derive the equations for the delay in response time through the web interface, validating the equations derived.

We have conducted several experiments to evaluate our system with delays in response time. The worst-case analysis was completed for all algorithms with Big O notation. Users and researchers can utilize Robot Registration Algorithm and ROS Topic Identification Algorithm to work with multiple robots through the Web interface. We have successfully implemented all algorithms in a simulated environment in Gazebo.

Keywords: *Multiple robot*, *Ontology*, *Robot Operating System*, *Navigation*, *Gazebo*, *Big O notation*,*Simulation*,*TurtleBot*,*Husky*,*TiaGo*.

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2. U. U. S. K. Rajapaksha, C. Jayawardena and B. A. MacDonald, "ROS BasedHeterogeneous Multiple Robots Control Using High Level User Instructions,"
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LISTOFTERMSANDABBREVIATIONS

R_{delta} Time taken to retrieve the state from ROS topic xii

$R_{m,d}^{move}$ Delay in moving to specific location by Multiple Robots xii

$R_{s,d}^{move}$ Delay in moving to specific location by Single Robot xii

$R_{s,d}^{start}$ Single robot delay Time at start xii

$R_{s,d}^{start}$ Single robot delay Time at stop xii

S_{delta} Time taken to save the state in ROS topic xii

U_x^s Linear Speed of the Robot in x direction at the start in ms^{-1} xii

U_x^s $tau_{d,ROS}$ Delay in communicating with ROS topics xii

U_x^s $tau_{d,RT}$ Delay in ROS topic identification xii

U_x^s $tau_{d,os}$ Delay in system call execution in Operating System. xii

$tau_{d,pos}$ Delay in getting the current position and orientation of the robot xii

$tau_{d,web}$ Delay in communication through Web interface xii

w_z^s Angular Speed of the Robot in z direction at the start in ms^{-1} xii

w_z^s AI Artificial Intelligence xii

w_z^s AMCL Adaptive Monte Carlo Localization xii

API Application Programming Interface xii

CPE Command Publishing Engine xii

GUI Graphical User Interface xii

HMR Heterogeneous Multiple Robots xii

HTML Hyper Text Markup Language xii

IOT Internet Of Things xii

IP Internet Protocol xii

OWL Web Ontology Language xii

RDF Resource Description Framework xii

ROS Robot Operating System xii

RPC Remote Procedure Call xii

RRE Integrated Development Environment xii

RRE Robot Registration Engine xii

TCP Transmission Control Protocol xii

UDP User Datagram Protocol xii

URDF Unified Robot Description Format xii

URL Uniform Resource Locator xii

W3C World Wide Web Consortium xii

YARP Yet Another Robot Platform xii