Institute of Mechanism Theory, Machine Dynamics and Robotics

RWTH AACHEN UNIVERSITY

This thesis was submitted to the Institute of Mechanism Theory, Machine Dynamics and Robotics

Cross-Compiling ROS2 Humble to WebAssembly

Master Thesis

by:

Isabel Paredes B.Sc.

Student number: 415723

supervised by:

Dipl.-Ing. Martin Mustermann

Examiner:

Univ.-Prof. Dr.-Ing. Dr. h. c. Burkhard Corves

Prof. Dr.-Ing. Mathias Hüsing

Aachen, 31 March 2023

Master Thesis

by Isabel Paredes B.Sc.

Student number: 415723

Cross-Compiling ROS2 Humble to WebAssembly

The issue will be inserted here after being drafted and provided by the supervisor beforehand. The issue should contain a detailed list of all work packages. It should not exceed one page and the version handed to the students has to be signed by the professor.

Supervisor: Dipl.-Ing. Martin Mustermann

Eidesstattliche Versicherung

Isabel Paredes Matrikel-Nummer: 415723

Ich versichere hiermit an Eides Statt, dass ich die vorliegende Master Thesis mit dem Titel

Cross-Compiling ROS2 Humble to WebAssembly

selbstständig und ohne unzulässige fremde Hilfe erbracht habe. Ich habe keine anderen als die angegebenen Quellen und Hilfsmittel benutzt. Für den Fall, dass die Arbeit zusätzlich auf einem Datenträger eingereicht wird, erkläre ich, dass die schriftliche und die elektronische Form vollständig übereinstimmen. Die Arbeit hat in gleicher oder ähnlicher Form noch keiner Prüfungsbehörde vorgelegen.

Aachen, 31 March 2023

Isabel Paredes

Belehrung:

§ 156 StGB: Falsche Versicherung an Eides Statt

Wer vor einer zur Abnahme einer Versicherung an Eides Statt zuständigen Behörde eine solche Versicherung falsch abgibt oder unter Berufung auf eine solche Versicherung falsch aussagt, wird mit Freiheitsstrafe bis zu drei Jahren oder mit Geldstrafe bestraft.

§ 161 StGB: Fahrlässiger Falscheid; fahrlässige falsche Versicherung an Eides Statt

(1) Wenn eine der in den §§ 154 bis 156 bezeichneten Handlungen aus Fahrlässigkeit begangen worden ist, so tritt Freiheitsstrafe bis zu einem Jahr oder Geldstrafe ein.

(2) Straflosigkeit tritt ein, wenn der Täter die falsche Angabe rechtzeitig berichtigt. Die Vor-schriften des § 158 Abs. 2 und 3 gelten entsprechend.

Die vorstehende Belehrung habe ich zur Kenntnis genommen:

Aachen, 31 March 2023

Isabel Paredes

The present translation is for your convenience only.
Only the German version is legally binding.

Statutory Declaration in Lieu of an Oath

Isabel Paredes Student number: 415723

I hereby declare in lieu of an oath that I have completed the present Master Thesis titled

Cross-Compiling ROS2 Humble to WebAssembly

independently and without illegitimate assistance from third parties. I have used no other than the specified sources and aids. In case that the thesis is additionally submitted in an electronic format, I declare that the written and electronic versions are fully identical. The thesis has not been submitted to any examination body in this, or similar, form.

Aachen, 31 March 2023 Isabel Paredes

Official Notification:
Para. 156 StGB (German Criminal Code): False Statutory Declarations
Whosoever before a public authority competent to administer statutory declarations falsely makes such a declaration or falsely testifies while referring to such a declaration shall be liable to imprisonment not exceeding three years or a fine.

Para. 161 StGB (German Criminal Code): False Statutory Declarations Due to Negligence
(1)If a person commits one of the offences listed in sections 154 to 156 negligently the penalty shall be imprisonment not exceeding one year or a fine.
(2) The offender shall be exempt from liability if he or she corrects their false testimony in time. The provisions of section 158 (2) and (3) shall apply accordingly. I have read and understood the above official notification:

Aachen, 31 March 2023 Isabel Paredes

Contents

Formula symbols and indices

Lower case latin letters as formula symbols

Upper case latin letters as formula symbols

Lower case greek letters as formula symbols

Upper case greek letters as formula symbols

Indices

List of abbreviations

General abbreviations

1. Introduction

1.1. Robot Operating System 2

1.2. Motivation

2. Literature Review

2.1. State of the Art

2.1.1. ROS on Web

Advantages and disadvantages

2.2. Relevant Works

2.2.1. ROSbridge

2.2.2. ROS Control Center

2.2.3. ROSboard

2.2.4. ROSlink

2.2.5. Foxglove Studio

2.3. State of WASM

2.3.1. Unity in WebAssembly

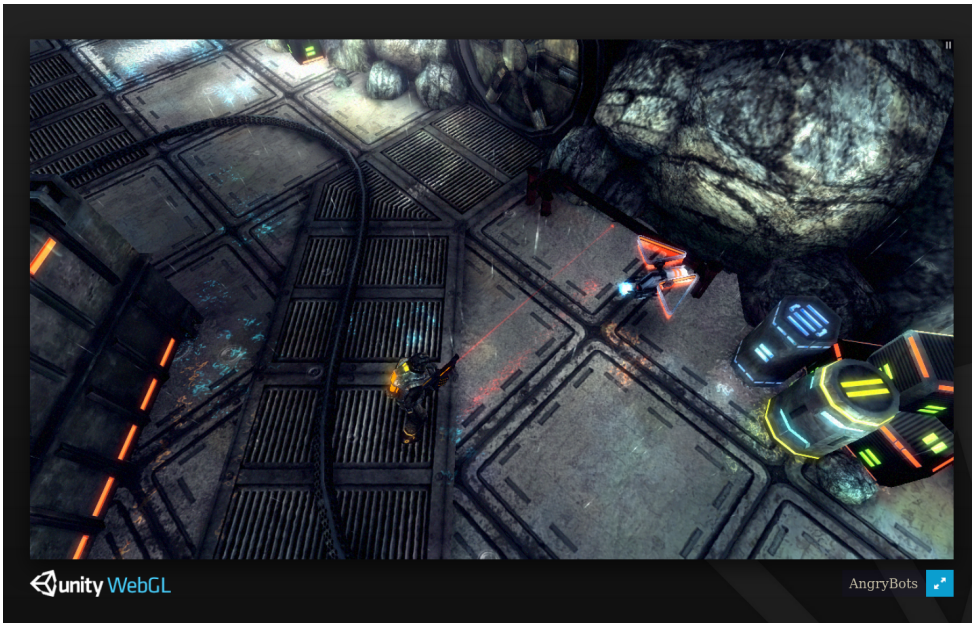

Figure 2.1.: Demo of Angry Bots in Unity WebGL

3. Concept Realization

3.1. Concept

Ideal scenario: - click on a link and run ROS - connect to a robot via bluetooth - share simulations and algorithms

3.2. Implementation Layers

3.2.1. User Levels

Table 3.1.: TODO:

User	Description
Beginners	Complete beginners who have never used ROS or programmed in any language.
Students	University students with minimal programming experience.
ROS Users	Students and researchers who actively use ROS for projects.
Roboticists	Robotics software developers including contributors to the ROS ecosystem.

3.2.2. User Levels of Interaction

Table 3.2.: TODO:

UI Level	Description
Non-interactive	Nodes run automatically as soon as the site is launched.
Minimal	User can start/stop $1-2$ nodes by pressing a button.
Basic	User can select which nodes to run and can analyze the environment by requesting or viewing information.
Intermediate	The graphical interface allows the user to accomplish primary tasks, such as displaying a robot.
Advanced	A complete GUI where the user has full control of the environment, can start/stop nodes, modify params, interact with robots, etc.
Complete	All ROS2 features are available and packages can be built on the browser

3.2.3. Technical Levels

Table 3.3.: TODO:

Level	Description
L0	A publisher and subscriber example on the console.
L1	Multiple nodes and topics with limited interaction.
L2	Graphical display with user interaction.
L3	Simulation of a robot (urdf).
L4	Manipulation of physical robot.
L5	Simulation of a robotics scenario.

3.3. Scope

Middleware replacement (why sockets don't work)

JavaScript "ROS master"

4. Methodology

- Development environment - Building tools - Testing tools (chrome, firefox)

4.1. Development Environment

4.2. Cross-Compilation Tools

4.3. Testing Environment

5. Middleware Implementation

- What does the middleware do? - ROS supported middleware implementations - Why it needs to be replaced - Minimal implementation (minimal set of functions) - Design of middleware packages (tree diagram or something)

5.1. DDS Middleware

5.1.1. FastDDS

default

5.1.2. Eclypse

5.1.3. Gurum

5.2. Custom Middleware

5.2.1. Email

5.2.2. Zenoh

5.3. Substituting ROS 2 Middleware

At run time

At build time

5.4. Custom Middleware Design

6. Package Building Process

- Emscripten - Colcon - Toolchains

7. Design of Web Elements

7.1. Web Workers

7.1.1. Communication Channels

7.2. Message Queues

- Web workers, what are they? why are they needed? - Communication channels - Registry of topics/subs/pubs - Message handling

8. Package Management and Distribution

- Automating package building - robostack?

9. Concept Assessment

- Survey - Performance measures - Limitations

10. Summary

11. Outlook

- Compiling on the browser - Packaging Gazebo - WASI

List of Tables

List of Figures

A. Illustrations

B. Tables