# Cross-Compiling ROS2 Humble to WebAssembly

## Master Thesis

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Aachen, 31 March 2023

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Supervisor: Dipl.-Ing. Martin Mustermann

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# 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

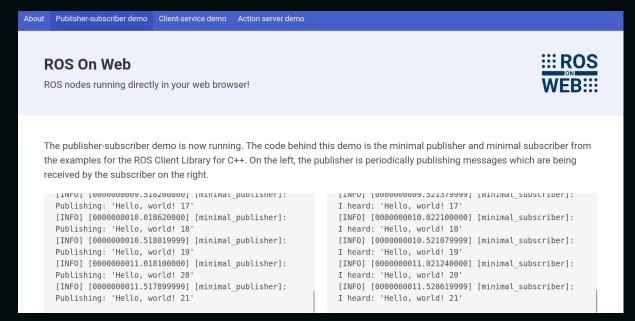# 2. Literature Review

## 2.1. State of the Art

### 2.1.1. ROS on Web



**Figure 2.1.** *ROS on Web* publisher and subscriber demo

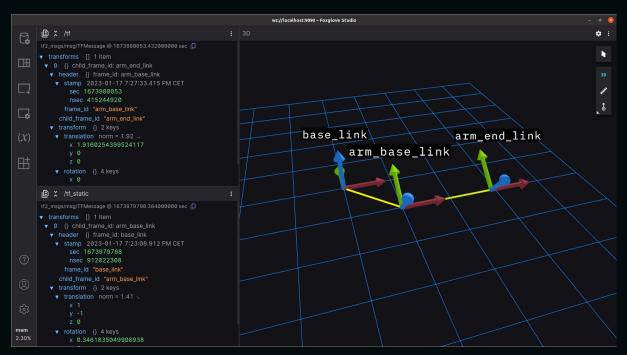Advantages and disadvantagesss

Not open source

ROS1 or ROS2

**Figure 2.2.** Visualizing ROS 2 Transforms with Foxglove Studio

## 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
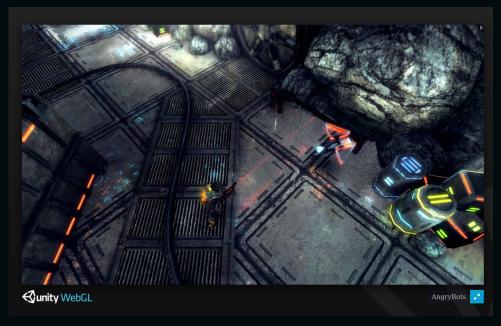
### 2.3.1. Unity in WebAssembly

**Figure 2.3.** Demo of Angry Bots in Unity WebGL

# 3. Concept Realization

## 3.1. Concept

### 3.1.1. Target Scenario

The goals for this project can be defined by an ideal scenario in which a high level of usability is reached by an intermediate user. First, an intermediate user is described as an individual who is familiar with the ROS ecosystem but does not have the need to maintain or test ROS packages across different platforms. In the target scenario, this intermediate user will be capable of performing the following tasks:

- install pre-compiled ROS 2 packages in the browser

- launch nodes including publishers, subscribers, servers, and clients

- interact with the environment to obtain information about running nodes, this would include echoing topics, listing parameters, reviewing log files, etc.

- visualization of URDFs, transforms, point clouds, markers, etc.

- playing and recording bag files

- connecting with robots via bluetooth

## 3.2. Implementation Layers

### 3.2.1. User Levels

**Table 3.1.** Target users categorized by expertise level.

|   | User | Description |
|---|------|-------------|
| 0 | Beginner | Complete beginners who have never used ROS or programmed in any language. |
| 1 | Student | University students with basic programming experience. |
| 2 | ROS User | Students and researchers who actively use ROS for projects. |
| 3 | Roboticist | Robotics software developers including contributors to the ROS ecosystem. |

**Table 3.2.** User interface segmented based on the level of interaction.

|   | Interface | Description |
|---|-----------|-------------|
| 0 | Non-interactive | Nodes run automatically as soon as the site is launched. |
| 1 | Minimal | User can start/stop 1−2 nodes by pressing a button. |
| 2 | Basic | User can select which nodes to run and can analyze the environment by requesting or viewing information. |
| 3 | Intermediate | The graphical interface allows the user to accomplish primary tasks, such as displaying a robot. |
| 4 | Advanced | A complete GUI where the user has full control of the environment, can start/stop nodes, modify params, interact with robots, etc. |
| 5 | Complete | All ROS 2 features are available and packages can be built on the browser |

### 3.2.2. User Levels of Interaction

### 3.2.3. Technical Levels

**Table 3.3.** Implementation categories with increasing technical difficulty.

| Level | Description |
|-------|-------------|
| 0 | A publisher is displayed. |
| 1 | A publisher and subscriber can communicate with each other and offer minimal interaction to start and stop each node. |
| 2 | Multiple nodes and distinct topics with limited interaction. |
| 3 | Graphical display and interaction with a ROS client library. |
| 4 | Manipulation of a physical robot wirelessly. |
| 5 | Visualization of a robot with Zethus. |
| 6 | Simulation of a robotics scenario with Gazebo. |
| 7 | Development workspace for creating and debugging ROS packages. |

## 3.3. Scope of Implementation

### 3.3.1. Middleware Replacement

### 3.3.2. User Interface

### 3.3.3. Automatic Builds

### 3.3.4. Out of Scope

# 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

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