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

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Aachen, 31 March 2023

Master Thesis

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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

GUI	Graphical User Interface
ROS	Robot Operating System
URDF	Universal Robotic Description Format
WASM	Web Assembly

1. Introduction

1.1. Robot Operating System 2

Robot Operating System (ROS) 2

1.2. Motivation

Web Assembly (WASM)

2. Literature Review

2.1. State of the Art

2.1.1. ROS on Web

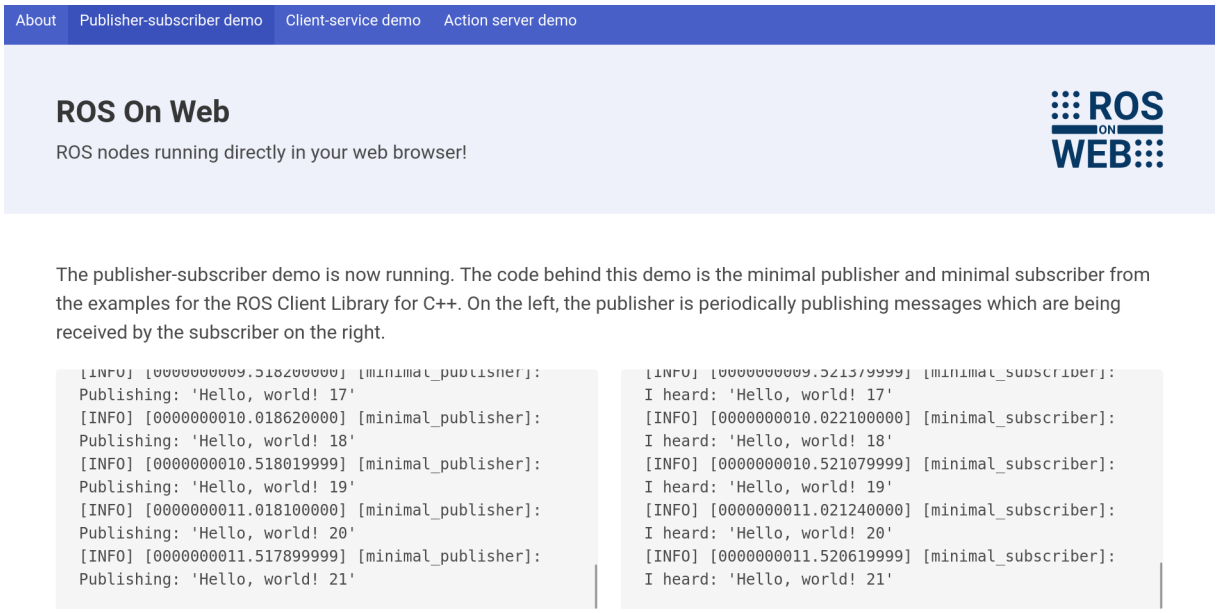

Figure 2.1. *ROS on Web* publisher and subscriber demo

Advantages and disadvantages

Not open source

ROS1 or ROS2

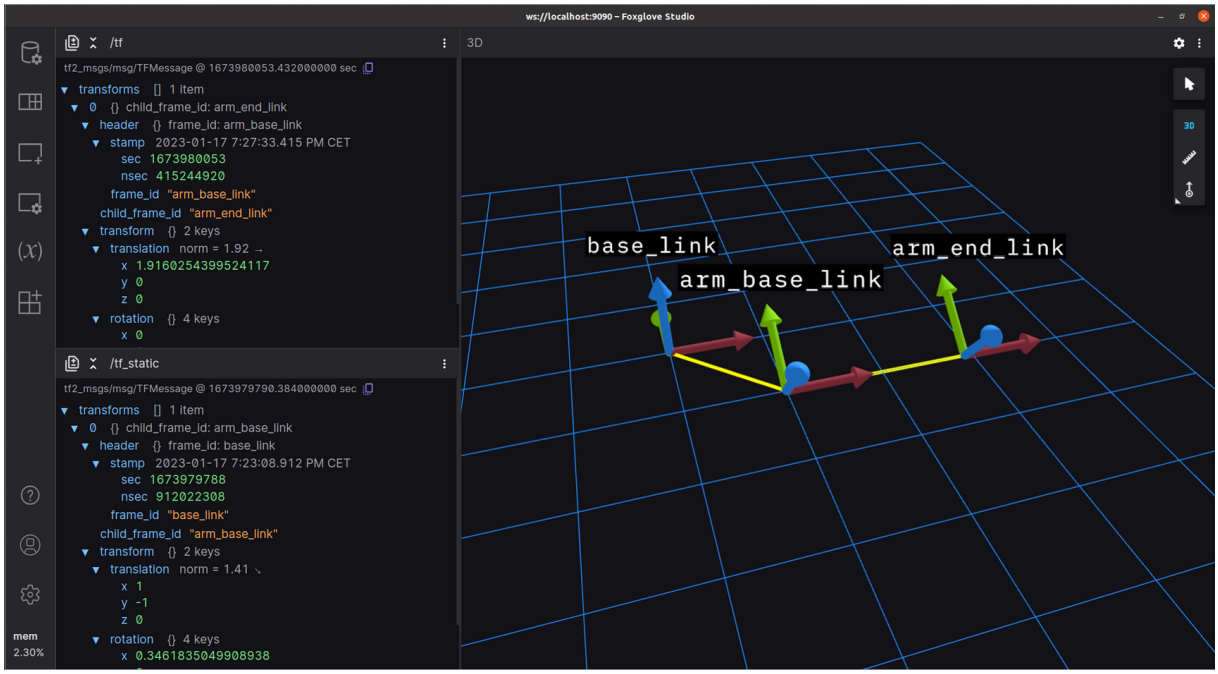

Figure 2.2. Visualizing ROS 2 Transforms with Foxglove Studio

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

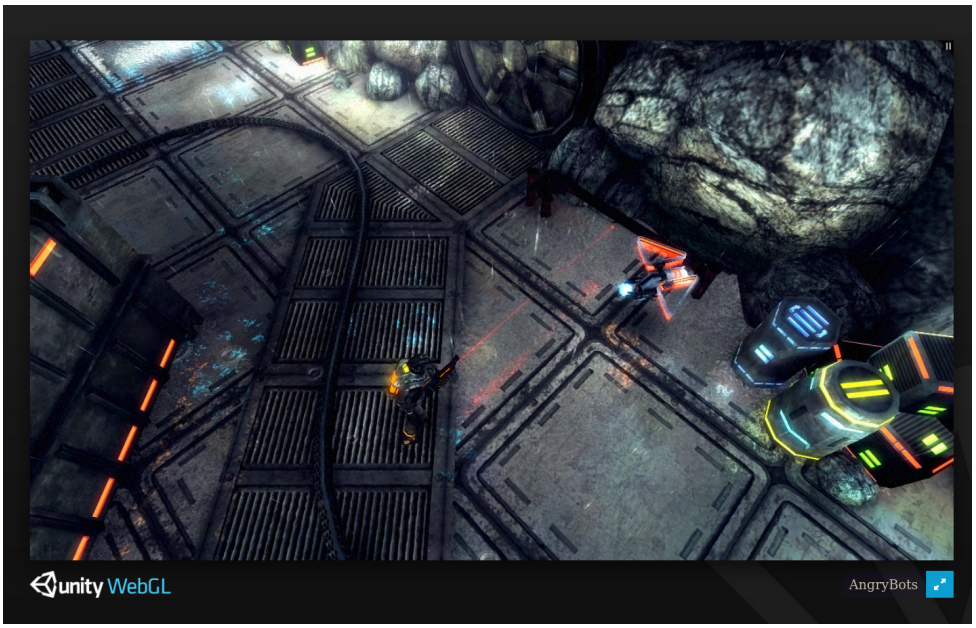

Figure 2.3. Demo of Angry Bots in Unity WebGL

3. Concept Realization

This section provides the major milestones from the project beginning with a brief description of the overall concept solution to the challenges presented in the Introduction, followed by the layers of implementation accomplished during the development phase.

3.1. Target Scenario

To introduce the concept, a "target scenario" is first considered. In this scenario, an intermediate ROS user should be able to reach a high level of usability with the tools developed in this project. 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 Universal Robotic Description Format (URDF) files, transforms, point clouds, markers, etc.
- playing and recording bag files
- connecting with robots via bluetooth

Outside of this scenario, another goal for this project includes making the developed tools available to the general public by distributing them as open-source software. This will allow other roboticists to compile their own packages and share them on the web.

3.2. Implementation Layers

TODO: add some introduction to these layers

Note

If the reader would like to follow along with the demonstrations provided in the following pages, it is recommended to visit `ros2wasm.dev`. Throughout the text, links will be provided to redirect the reader to specific examples.

3.2.1. User Levels

For the purpose of establishing target users for the developed tools, potential users were categorized based on expertise level with ROS and programming in general, as observed in Table 3.1.

Commencing with Level 0, the *Beginner* category is reserved for students in secondary education who have had little to no experience with programming, and therefore are not familiar with ROS. The tools developed in this project would serve as an initial introduction to robotics for this category of users.

Level 1 consists of university students who have completed elementary programming courses but have not yet been introduced to ROS. For this type of user, this project will provide essential tutorials to become acquainted with the inner workings of ROS.

With a slightly higher level of expertise, Level 2 comprises students or other enthusiasts who are already familiar with ROS and have collaborated in projects which use ROS as the main system to handle communications of multiple robotics elements. This ROS user is equivalent to the intermediate user described in the target scenario (Section 3.1).

Lastly, the highest level of experience is dedicated to roboticists who actively use and contribute to the development of ROS. For this category of users, the intention of this project will be to involve more contributors in order to more promptly meet the needs of most ROS users.

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.

3.2.2. User Levels of Interaction

Graphical User Interface (GUI)

3.2.3. Technical Levels

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

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.

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

6.1. Environment

6.2. Tools

6.3. Post Processing

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