Rockly: A graphical tool for programming ROS based robots

MASTER THESIS

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Preamble

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Abstract

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3 Architecture

This chapter describes the architecture and implementation of Rockly (portmanteau of ROS and Blockly). First the purpose and need of it are explained, followed by a architectural overview of HOBBIT, the used robot. Based on this constraints the options implemtenting the tool are presented as well as an explanation of the decision. Then a short description of the robot operating system ROS and the fundamental JavaScript frameworks, Node.js and Express, are given and finally the necessary details of the implementation are documented - for both, the frontend and the backend.

3.1 Requirements

In the field of software engineering constraints are the basic design parameters. Therefore it is necessary to provide them as detailed as possible. In the given case the basic constraints are given by the purpose of the tool and the architecture of the robot.

3.1.1 HOBBIT - The Mutal Care Robot

The HOBBIT PT2 (prototype 2) platform was developed within the EU project of the same name. The robot was developed to enable independent living for older adults in their own homes instead of a care facility. The main focus is on fall prevention and detection. PT2 is based on a mobile platform provided by Metralabs. It has an arm to enable picking up objects and learning objects. The head, developed by Blue Danube Robotics, combines the sensor set-up for detecting objects, gestures, and obstacles during navigation. Moreover, the head serves as emotional display and attention center for the user. Human-robot interaction with Hobbit can be done via three input modalities: Speech, gesture, and a touchscreen. [1]

In terms of technology HOBBIT (see Figure 3.1) is based on the robot operating system ROS (Section 3.3.1), which allows easy communication between all components. The system is set up to be used on Ubuntu 16.04 together with the ROS distribution *Kinetic*. All ROS nodes are implemented in either

Figure 3.1: HOBBIT - The Mutal Care Robot

Name	Type	Message type	Description
/cmd_vel	Topic	geometry_msgs/Twist	move HOBBIT
/head/move	Topic	std_msgs/String	move HOBBIT's head
/head/emo	Topic	std_msgs/String	control HOBBIT's eyes
/MMUI	Service	hobbit_msgs/Request	control UI interface
hobbit_arm	Action	hobbit_msgs/ArmServer	control HOBBIT's arm
move_base_simple	Action	geometry_msgs/PoseStamped	navigate HOBBIT

Table 3.1: Common commands used by HOBBIT

Python or C++. In order to provide a fast and simple way to implement new behaviours several commands should be pre-implemented. These commands are performed either by publishing messages to topics or services, or executing callbacks defined in the corresponding action's client. The common commands and their description are listed in Table 3.1. A detailed list of possible messages for each command will be presented in Section 3.3.1 after furher explanation of the ROS architecture.

3.1.2 Purpose of the tool

HOBBIT became very popular since the above mentioned EU project and demos of it's behaviours has been presenting at large number of fairs. Unfortunally only the following show cases are currently implemented on the robot:

- HOBBIT follows the user

- HOBBIT learns object

- HOBBIT starts an emergency call

- HOBBIT picks up an object

All of the demos can be started via the UI running on HOBBIT's tablet, but re-writing new demos would assume a detailed knowledge of the robot's setup. In order to implement new behaviours and demos more easily it is necessary to provide a programming interface, which provides a powerful, generic base to cover a wide range of HOBBIT's features as well as an intuitive handling.

Furthermore the Automation and Control Institute of the TU Wien is part of the Educational Robotics for STEM (ER4STEM) project, which aims to turn curious young children into young adults passionate about science and technology with hands-on workshops on robotics. The ER4STEM framework will coherently offer students aged 7 to 18 as well as their educators different perspectives and approaches to find their interests and strengths in robotics to pursue STEM careers through robotics and semi-autonomous smart devices. [2] Providing an intuitive programming tool would allow the integration of HOBBIT into the project, which would be an extra input evaluation parameter.

At last the framework should be implement to be re-used for other ROS based robots. This means, that it should not only provide an interface to the mentioned commands for HOBBIT, but an open, adpatable framework. It should be able to allow a flexible configuration and assembly of the provided functions.

3.2 Options

There are several approaches to fulfill the mentioned requirements. In the following subsections three different options are presented by a simple example: the implementation of picking up an object from the floor an putting it on the table. This should give a rough overview in terms of complexity of the usability as well as the implementation of the corresponding approach. For reasons of simplicity tasks like searching and detecting the object or gripper positioning are excluded.

3.2.1 Python/C++ API

The most obvious way to fulfill the requirements is to provide an application programming interface (API) for the desired programming languages (Python, C++). An API is a set of commands, functions, protocols, and objects that programmers can use to create software or interact with an external system. It provides developers with standard commands for performing common operations so they do not have to write the code from scratch. In the present case such a API could consists of the following components:

- Initialization: setting up communication and intial states - e.g. creating ROS nodes, starting the arm referencing or undocking from charger

- Topic management: managing the messages published to ROS topics and creating subscriber nodes if applicable

- Service management: managing the ROS services of HOBBIT - e.g. the tablet user interface

- Action management: creating ROS action clients for e.g. navigation or arm movement

- Common commands: providing common commands (see Table 3.1)

It should be noted, that the components doesn't re-implement ROS functionality, but extend it and prvovide a simpler use of it. Depending of how generic the API is implemented it is possible that the user can control the robot without any detailed knowledge of the technical setup of it. Nevertheless this approach would assume the user to have knowledge of the programming language the API is desigend for. Refering to the required commands in Table 3.1 an API for Python could be designed as shown in Figure 3.2. The highest usability would be reached, if all input parameters are from common variable types such as interger and string. Indeed, this would increase the implementation effort, especially in terms of error handling, as well as the extent of the documentation, which are huge disadvantages of writing an API.

Assuming the API would be implemented as explained before and the Python module would be named *HobbitRosModule*, Listing 3.1 shows a sample code for the mentioned use case to pick up an object. Note that the code is very short and easy to read, which - on the other hand - means that the implementation of the API must cover a broad technical range, such as error handling for unsupported inputs and communication errors.

Figure 3.2: Exemplary design of API for Python

```python
1  import HobbitRosModule   # Import of API module
2
3  node = HobbitRosModule.node('demo') # Create ROS node
4  node.gripper('open')      # Open gripper
5  node.move_arm('floor')    # Move arm to floor pick up
       position
6  node.gripper('close')     # Close gripper = pick object
7  node.move_arm('table')    # Move to table position
8  node.gripper('open')      # Open gripper = drop object
```

Listing 3.1: Example Python code using the API shown in Figure 3.2

3.2.2 SMACH

SMACH is a task-level architecture for rapidly creating complex robot behavior. At its core, SMACH is a ROS-independent Python library to build hierarchical state machines. [3]. Since that, this approach would also end up in providing an API for the user, but allows to create more complex demos with less effort than the one described in Section 3.2.1. SMACH also provides a powerful graphical viewer to visualize and introspect state machines as well as an integration with ROS, of course. Since the aforementioned example is a very simple one and doesn't require a lot of the provided SMACH functionality, this section only covers the needed ones to fulfill the requirements. For a detail description on how to use SMACH refer to [3].

The arm of HOBBIT is controlled via the hobbit_arm action. SMACH supports calling ROS action interfaces with it's so called *SimpleActionState*, a state class that acts as a proxy to an *actionlib* (see Section 3.3.1) action. The instantiation of the state takes a topic name, action type, and some policy for generating a goal. When a state finishes, it returns a so called *outcome* - a string that describes how the state finishes. The transition to the next state will be specified based on the outcome of the previous state. Listing 3.2 shows a possible implementation of picking up a object an placing it on the table. After the imports of the necessary modules (lines 1 to 4), the state machine is instanced (line 7), to which the required states are added (lines 17-22). The parameters passed to *SimpleActionState* are

- the name of the action as it will be broadcast over ROS (e.g. *hobbit_arm*)

- the type of action to which the client will connect (e.g. *ArmServerAction*) and

- the goal message.

For reasons of readability the goals are declared at a seperate code block (lines 11 to 14). The equivalent visualization of the state machine is shown in Figure 3.3.

Providing just the SMACH interface has some disadvantages and would not be practicable. First the user would need an advanced knowledge of Python. Depending on the design of the self-implemented API (Section 3.2.1) the knowledge has to be at least at the same level. Next the user would have to understand the API and needs to find a design to fit for the corresponding demo case. Furthermore it requires the user also to exactly know the ROS

```python
1  from smach import StateMachine
2  from smach_ros import SimpleActionState
3  from hobbit_msgs.msg import ArmServerGoal,
       ArmServerAction
4  from rospy import loginfo
5
6  # Instance of SMACH state machine
7  sm = StateMachine(['finished','aborted','preempted'])
8
9  with sm:
10     # Definition of action goals
11     goal_floor = ArmServerGoal(data='
           MoveToPreGraspFloor', velocity=0.0, joints=[])
12     goal_table = ArmServerGoal(data='
           MoveToPreGraspTable', velocity=0.0, joints=[])
13     goal_OpGrip = ArmServerGoal(data='OpenGripper',
           velocity=0.0, joints=[])
14     goal_ClGrip = ArmServerGoal(data='CloseGripper',
           velocity=0.0, joints=[])
15
16     # Assambly of the full state machine
17     StateMachine.add('INITIAL_POS', SimpleActionState('
           hobbit_arm',ArmServerAction,goal=goal_OpGrip),
           transitions={'succeeded':'FLOOR_POS','aborted':'
           LOG_ABORT', 'preempted':'LOG_ABORT'})
18     StateMachine.add('FLOOR_POS', SimpleActionState('
           hobbit_arm',ArmServerAction,goal=goal_floor),
           transitions={'succeeded':'CLOSE_GRIPPER','
           aborted':'LOG_ABORT', 'preempted':'LOG_ABORT'})
19     StateMachine.add('GRIPPER_CLOSED',
           SimpleActionState('hobbit_arm',ArmServerAction,
           goal=goal_ClGrip),transitions={'succeeded':'
           TABLE_POS','aborted':'LOG_ABORT', 'preempted':'
           LOG_ABORT'})
20     StateMachine.add('TABLE_POS', SimpleActionState('
           hobbit_arm',ArmServerAction,goal=goal_table),
           transitions={'succeeded':'OPEN_GRIPPER','aborted
           ':'LOG_ABORT', 'preempted':'LOG_ABORT'})
21     StateMachine.add('GRIPPER_OPEN', SimpleActionState(
           'hobbit_arm',ArmServerAction,goal=goal_OpGrip),
           transitions={'succeeded':'finished','aborted':'
           LOG_ABORT', 'preempted':'LOG_ABORT'})
22     StateMachine.add('LOG_ABORT', loginfo('Demo aborted
           !'), transitions={'succeeded': 'aborted'})
```

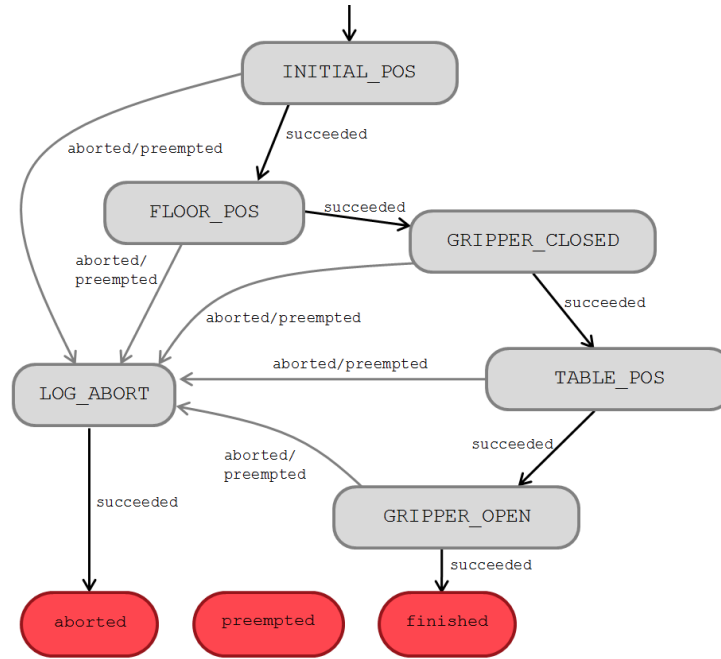Listing 3.2: Using SMACH to generate a state machine

Figure 3.3: State machine generated via Listing 3.2

specification of the robot. So, if SMACH would be choosen as the underlying framework, it would also be necessary to provide a more abstract API - basically with the same interfaces as shown in Figure 3.2.

3.2.3 Blockly

Blockly is a library that adds a visual code editor to web and Android apps. The Blockly editor uses interlocking, graphical blocks to represent code concepts like variables logical expressions, loops, and more. It allows users to apply programming principles without having to worry about syntax or the intimidation of a blinking cursor on the command line. [4] So for the present case, in contrast to the other approaches the user would not need to have any technical knowledge of HOBBIT, it's components and interfaces. Furthermore such a editor would not require the user to master any programming language. On the other hand implementing this approach would require knowledge of web applications (i.e. JavaScript, HTML and CSS) additionally.

Figure 3.4 shows an exemplary injection and use as well as the basic structure of Blockly applications. It consists of a toolbox, from where the progamming blocks can dragged to the workspace, where they are connected. The Blockly

Figure 3.4: A short Blockly demo showing it's structure and use

API [5] provides a function to generate code for all blocks in the workspace to several languages: JavaScript, Python, PHP, Lua, Dart and XML. In the shown example for each of them a tab is avaible to show the generated code. The blocks dragged to the workspace in Figure 3.4 are already customized blocks, with whom an object can be picked up and be placed on the table. There are basically four steps requierd in order to create and use a custom block, which are described briefly in the following paragraphs. A detailed documentation is given in [6].

Defining the block

Blocks are defined in the *blocks* directory of the source code by adding either JSON objects or JavaScript functions to the `Blockly.Blocks` mapping. It includes the specification of the shape, fields, tooltip and connection points. An exampe definition using a JavaScript function of the *gripper* block is shown in Listing 3.3. Attention should be payed to lines 6 to 21, where the input fields are defined (line 8). Here a dropdown field with two options ("Open" and "Close") is created. The name ("gripper_position") is used to refer to it later.

Providing the code

Similar to the definition of a block, the code, which is generated out of them, is stored in a mapping variable inside the Blockly library. Since different languages are supported, the code definition has to be in the right directory. Note that it is not necessary to provided code for each language. The code generation is handled in the *generator* directory of the library. Each language has it's own helper functions file (e.g. `python.js`) and subdirectory, where the code for each

```
1   Blockly.Blocks['hobbit_arm_gripper'] = {
2       init: function () {
3           this.jsonInit({
4               "type": "hobbit_arm_gripper",
5               "message0": "%1 Gripper",
6               "args0": [
7                   {
8                       "type": "field_dropdown",
9                       "name": "gripper_position",
10                      "options": [
11                          [
12                              "Open",
13                              "open"
14                          ],
15                          [
16                              "Close",
17                              "close"
18                          ]
19                      ]
20                  }
21              ],
22              "previousStatement": null,
23              "nextStatement": null,
24              "colour": 360,
25              "tooltip": "Control HOBBIT's gripper",
26              "helpUrl": ""
27          });
28      }
29  };
```

Listing 3.3: Block initialization using a JavaScript function

block is defined. There are several interfaces functions provided by Blockly to manage interaction with a block - such as collecting arguments of the block. A short example to control HOBBIT's gripper is shown Listing 3.4. In line 2 the `block.getFieldValue()` function is used to get the user's selection of the drop-down field. Note that the generator always returns a string variable including the code in the desired language (line 4). So the shown example requires to use a custom Python API (such as Figure 3.2), because `node.gripper()` is not a built-in function of Python.

```
1  Blockly.Python['hobbit_arm_gripper'] = function(block)
       {
2          var dropdown_movement = block.getFieldValue('
           gripper_position');
3
4          return 'node.gripper(\''+dropdown_movement+'\')
           \n';
5  };
```

Listing 3.4: Defintion of a code generator in Blockly for Python

Building

After the customized block and it's code generator are defined, the whole Blockly project has to be rebuilt by running `python build.py`. Building means that the source code, which is usually spread to several - in the given case over a hundred - files, is converted into a stand-alone form, that can be easily integrated. The Blockly build process uses Google's online Closure Compile and outputs compressed JavaScript files for core functionalites, blocks, block generators for each progamming language and a folder including JavaScript files for messages in several lingual languages. In our case the following four files needs to be included:

- `blockly_compressed.js`: Blockly core functionalites

- `blocks_compressed.js`: Defintion of all blocks

- `python_compressed.js`: Code generators for all blocks

- `/msg/js/en.js`: English messages for e.g. tooltips

Add it to the toolbox

Once the building is completed and the necessary files are included to the web application, the custom block needs to be included in the toolbox. The toolbox is specified in XML and passed to Blockly when it is injected. Assuming the blocks shown in Figure 3.4 are build as described in the previous paragraphs, they can be add to the toolbox as shwon in Listing 3.5.

```
1 <xml id="toolbox" style="display: none">
2   <block type="hobbit_arm_gripper"></block>
3   <block type="hobbit_arm_movement"></block>
4 </xml>
```

Listing 3.5: Minimal example of adding two blocks to a Blockly toolbox

3.2.4 Decision

In order to select the best fitting solution the requirements explained in Section 3.1 are summarized as follows:

- The user wants to build as complex demos as possible.

- The user wants an intuitive interface to create demos.

- The user should need as little knowledge of the robot as possible.

- The user should need as little technical knowledge as possible.

- The implementation of the tool should not exceed the usual effort of a master thesis.

- The tool should provide the ability to add new functionalites.

- The tool should be maintable, meaning it should have clear interfaces and as less dependencies as possible

	Python/C++ API	SMACH	Blockly
Complexity of demos	3	4	2
User Interface	2	2	5
Robot specific know-how	3	1	5
Technical know-how	1	1	5
Implementation	2	3	3
Scalability	4	3	2
Maintainability	3	3	1
Σ	18	17	23

Table 3.2: Decision

Message	Description
'center_center'	look straight
'center_right'	look to the right
'center_left'	look to the left
'up_center'	look up
'up_right'	look to the upper right corner
'up_left'	look to the left left corner
'down_center'	look down
'down_right'	look to the lower right corner
'down_left'	look to the lower left corner
'littledown_center'	look little down
'to_grasp'	look to grasp position
'to_turntable'	look to turntable

Table 3.3: Possible messages for topic */head/move*

3.3 Frameworks

3.3.1 ROS

3.3.2 Node.js

3.3.3 Express

3.4 Server implementation

3.5 Frontend implementation

3.6 Python module

4 Evaluation

4.1 Methods

4.2 Results

4.3 Discussion

5 Conclusion

Listings

Bibliography

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