University of Nevada, Reno

Roslyn: The Tour Guide Robot

A thesis submitted in partial fulfillment
of the requirements for the degree of

BACHELOR OF SCIENCE, COMPUTER SCIENCE & ENGINEERING

by

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Abstract

The tour guide robot Roslyn is an autonomous system that can provide tours to anybody on the second floor of the Scrugham Engineering and Mines building. The robot is not only able to navigate the halls, but navigate them in a socially acceptable manner. This means it does not collide with pedestrians while in motion and takes walking speed into consideration. In order to interact with the user, there is a touch-screen display mounted on top of the moving robot base. As the robot moves throughout the hall, information appears on the screen related to the landmarks being passed (i.e. laboratories and offices). The user is also able to select a destination on the screen in order to begin the tour.

Acknowledgements

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Chapter I

First Chapter

I.1 Introduction

The tour guide robot Roslyn is a socially aware autonomous system that can lead tours of the Computer Science and Engineering Department at the University of Nevada, Reno. This requires socially acceptable navigation within the second floor of the Scrugham Engineering and Mines building. Tours of the Computer Science and Engineering Department are currently given by faculty and staff, or student ambassadors (typically from other departments). This creates some difficulties for visitors:

- A tour can only be scheduled when a faculty or staff member is available. This may conflict with class times, office hours, or other responsibilities
- Giving tours distracts faculty and staff from their normal studies, teaching, research, etc. especially with large groups
- Tours given by student ambassadors are generally limited to superficial knowledge of the department, such as the location of the department office. A typical student

ambassador would not be able to answer specific questions about a program, lab, or other facility.

A robotic tour guide could address many of these issues:

- A tour with a robot could be scheduled for any time the building is accessible, even after normal working hours. Tours could be scheduled in real-time without concerns about a faculty or staff member's conflicting schedule. Tours could also be given on demand for visitors on site without an appointment
- A robot could be dedicated entirely to giving tours, and would not become distracted by other activities
- A robot could be provided up-to-date information by a departmental authority, or lookup information in real time.

Some challenges are present for a robotic tour guide in a situated academic environment, all of which shall be addressed in this thesis:

- Safe navigation: both globally and locally. A global plan must be generated for every destination which will optimize the route taken to the destination. A local plan must also be generated which avoids obstacles such as walls, items in a hallway, and moving people. This local plan must also lead the user on a reasonable path and a reasonable pace.

- Self safety: the robot must not endanger itself. Some potential safety concerns include stairwells and objects mounted outside of the robot's view (i.e. drinking fountains, which are mounted above a laser range finder's plane of view).

- Power and portability constraints: the wireless network installed in the Scrugham Engineering and Mines building is insufficient for real-time sensor data transmission, thus all processing must be performed on the robot. Thus there are constraints on the amount of power the robot can deliver to its computational components, the battery life of the robot and these components, and the maximum reasonable size of these components.

In order for the robot to be socially aware, it must not only lead its user at a comfortable distance and pace, but also keep other humans and obstacles at a safe distance. A human tour guide would not walk exceptionally fast away from their group or walk uncomfortably close to them, thus the robot should not either.

The tour guide robot is primarily composed of three distinct nodes, which are each discussed independently due to their complexity. The first node, labeled ROS Nodes in Fig. 1, is a collection of pre-existing open source ROS nodes which provide data and processing facilities to the system. These nodes are not being developed by the team, but are distributed by the Open Source Robotics Foundation.

The second node, labeled User Interface in Fig. 1, provides a user-friendly interaction between the robot and user(s). This allows the users to select a destination, as well as request and view more information about their surroundings via a touchscreen tablet on the robot.

The third node, labeled Social Navigation in Fig. 1, safely navigates the robot through the dynamic environment and ensures proper social interactions with the user.

Roslyn is composed of two independent programs:

- Roslyn is able to map an environment and use the map for future navigation. This is done the first time Roslyn is introduced to a particular building and does not have to be repeated.

- Roslyn uses the building map in its second program along with its sensors and communication pathways to communicate with the user interface and drive itself.

Roslyn is composed of a number of hardware components:

- The robotic base: a Pioneer 3DX
- An internal computer: a Raspberry Pi Model B Revision 2
- A laser rangefinder: a SICK LMS 100 or a Hokoyu URG-04LX-UG01
- A laptop: Intel Core i5-2450M @ 2.50GHz with 8 GB of RAM or better
- The user interface: a Nexus 7 2013
- A custom stand for the Nexus 7 2013

The rest of this thesis is organized as follows. Chapter II presents a literature review of prior and related work. Chapter III describes our need-finding approach and results.

Chapter IV presents our requirements, use cases, and system design. Chapter V presents our approach to the user interface and interface screen shots. Chapter VI presents a glossary of terms used in this thesis. Our reference list and appendicies follow.

Chapter II

Second Chapter

II.1 Related Work

Other projects have been developed similar to this tour guide robot, however few (if any) have provided a complete, end-to-end framework to accomplish to task including training and execution. [1] provides a physical description of a robot capable of maintaining a predefined distance from the user. The robot uses a mechanical arm and rotational encoder to determine the distance between the robot and user, and then adjusting the robot velocity to maintain a distance. The user must hold on to a handle throughout the run. This project improves on [1] by performing the distance maintenance via non-contact vision.

[3] provides a vision mechanism which determines where a user is directing their attention, either via gaze detection or pointing detection (as well as other methods not related to this project). This project improves on [2] by adding a socially aware navigation

component, as well as generalizing the method into an architecture which can be used in an arbitrary environment.

Finally, this project is believed to be interesting based on the relative amount of research done in this area, as sampled by the articles already referenced, but a limited number of actual deployments. At time of writing, there seems to be a very few (such as [4]) commercially deployed tour guide robot which are regularly providing tours.

Chapter III

Third Chapter

III.1 Need Finding

A survey was distributed to the engineers developing this project, several current students, and two prospective CS students currently in high school. A total of ten individuals responded. The interview questions are included in Appendix A.

III.1.1 Interview Findings

Almost all of the interviewees claimed to prefer voice or touch screen interfaces to the tour guide robot. Half of the individuals believed that a robot tour guide had the potential to be as good as a human tour guide. The choice between an established path and a custom path selected by the users was highly controversial. This result suggests that users may want the option to select either option. The one unanimous answer was that the robot should move at a normal walking pace. Unfortunately, our robot cannot travel at full walking speed.

Surprisingly, almost all individuals want the robot to stop at interest points and wait for the user's input to continue. None selected to continue automatically, and only a couple wanted the robot to slow near the interest point. The desired humanness of the robot varied greatly across responses. For human questions, the results were split; some wanted a FAQ, some wanted to have the question forwarded to a human, and some wanted both. Additionally, there was an even split between who would select a human tour guide versus a robot tour guide given the option.

Regardless of the type of tour guide, interviewees wanted a primarily friendly and informative tour guide. When asked to evaluate positive experiences with tour guides, most referred to tour guides telling personal stories, being funny, or simply friendly. On the other hand, poor tours consisted of bored guides who were uninformative, rushed, boring, and not funny. The final question asks for feature requests. No trends existed in the responses, but several sought to address the limitations of a robot; one person wanted the robot to have a human remotely answer questions.

Chapter IV

Fourth Chapter

IV.1 Requirements Specification and Use Cases

This section describes the design of Roslyn's internal systems.

IV.1.1 Functional Requirements

Table IV.1 describes the functional requirements of Roslyn. All functional requirements have been implemented.

Table IV.1: The functional requirements of Roslyn

Requirement	**Description**
R01	The possible destinations shall include professor offices.
R02	The possible destinations shall include classrooms.
	Continued on next page

Table IV.1 – continued from previous page

Requirement	Description
R03	The possible destinations shall include the Engineering Computing Center (ECC).
R04	The possible destinations shall include the Computer Science & Engineering (CSE) Office.
R05	The possible destinations shall include the male and female restrooms and drinking fountains.
R06	The possible destinations shall include the elevator.
R07	The possible destinations shall include the stairwells and emergency exits.
R08	The possible destinations shall include the research labs.
R09	The robot shall keep an internal map of the environment.
R10	The robot shall select a new navigation route if a stationary object is detected in its global plan.
R11	The robot shall select a local plan which is not obstructed by any obstacles.
R12	The robot shall have a software or hardware emergency stop which will cease all external movement within 1 second of activation.

Continued on next page

Table IV.1 – continued from previous page

Requirement	Description
R13	A software emergency stop shall be activatable from a remote terminal.
R14	The robot shall maintain a reasonable distance from the user.
R15	The navigation system shall consider a goal unachieveable if it cannot generate a global plan to it.
R16	The robot shall log its odometry, laser sensor input, provided navigation goals, and position/orientation transformation tree in a ROS bag file.
R17	The robot shall have an instruction to take the user on a predefined tour.
R18	The interface shall show a map of the SEM building with markers for possible destinations.
R19	The interface shall send a goal to the navigation system when the user selects a destination.
R20	The navigation system shall send a confirmation to the interface when a goal is achieved.
R21	The interface shall accept a goal confirmation from the navigation system and then show the user a table of information about the goal.

Continued on next page

Table IV.1 – continued from previous page

Requirement	Description
R22	The robot shall provide auditory, locale-based announcements.

IV.1.2 Non-Functional Requirements

Table IV.2 describes the non-functional requirements of Roslyn. All non-functional requirements have been satisfied.

Table IV.2: The non-functional requirements of Roslyn

Requirement	Description
T01	The robot shall help guide users to destinations on the second floor of the Scrugham Engineering Mines (SEM) building
T02	The robot shall accept instructions from an onboard touch screen tablet.
T03	The interface shall be appealing to users.
T04	The robot shall not deliberate for more than one second at any time unless such deliberation is necessary to comply with safe navigation requirements.
T05	The robot shall utilize the Robot Operating System (ROS).

Continued on next page

Table IV.2 – continued from previous page

Requirement	Description
T06	The robot shall utilize the ROS Navigation Metapackage (see Glossary).
T07	The robot shall allow parallel processing on multiple distinct machines.
T08	The robot shall be platform-independent among wheel-driven, ROS-compliant robots.
T09	The robot robot shall not injure a person or, through inaction, allow itself to harm a person.
T10	The robot shall halt all movement within one second if any safety-related sensor provides impossible data or no data for more than one second, and alert the operator.
T11	The robot shall halt all movement within one second if any safety-related processing node does not provide expected data within one second of scheduled time.
T12	The interface shall utilize the Android Webview Development kit.

IV.1.3 Hardware Requirements

Table IV.3 describes the hardware requirements of Roslyn. All hardware requirements have been satisfied.

Table IV.3: The hardware requirements of Roslyn

Requirement	**Description**
H01	The robot shall have a maximum linear velocity of 1 meter per second
H02	The robot shall have a maximum linear velocity of 0.5 meters per second
H03	The robot shall have a maximum linear acceleration of 4.5 meters per second per second
H04	The robot shall have a minimum linear acceleration of 0.5 meters per second per second.
H05	The interface shall have a wireless communication system to transmit and receive messages with the ROS system.
H06	The computer(s) used for navigation shall have at least the combined equivalent of a quad-core 2.5 GHz Intel i5 processor.
H07	The robot shall have a high-torque shutoff system which prevents excessive force being applied to any obstacle which may come in contact with it.
H08	The robot shall be powered by batteries for no shorter than two hours on a single charge.

Continued on next page

Table IV.3 – continued from previous page

Requirement	Description
H09	The laser rangefinder shall return laser scans with a field of view no less than 180 degrees.
H10	The laser rangefinder shall return laser scans at a frequency no less than 4 Hz (note: see T10 for requirements regarding processing frequency requirements of laser scans).
H11	The robot's odometry system shall provide odometry information at a frequency no less than 4 Hz (note: see T10 for requirements regarding processing frequency requirements of odometry messages).

IV.1.4 Use Cases

Table IV.4 describes the use cases of Roslyn. All use cases have been implemented.

Table IV.4: The use cases of Roslyn

Use Case	Name	Description
UC01	CreateMap	The operator runs the mapping launch file. The robot sets itself up for mapping and prompts for waypoints.

Continued on next page

Table IV.4 – continued from previous page

Use Case	Name	Description
UC02	EnterTourMode	The operator runs the touring launch file. The robot sets itself up for navigation, localizes itself, then displays the user interface.
UC03	UpdateMap	The operator has run the touring launch file. The robot updates the internal map with every observation.
UC04	GotoPOI	The user selects a POI using the touchscreen. The robot guides the user to it, maintaining social acceptability.
UC05	RemainSafe	The user has caused navigation to run and an obstacle is detected. The robot executes evasive maneuvers to avoid colliding with the object.
UC06	GiveFeedback	The user is following the robot to a waypoint. The robot provides information about POI's in the area.
UC07	EmergencyOff	The operator activates the emergency stop. The robot halts all movement within one second and saves the log file.

Continued on next page

Table IV.4 – continued from previous page

Use Case	Name	Description
UC08	EmergencyHold	The operator allows a safety-related node or sensor to stop reporting correct data. The robot halts all movement within one second and saves the log file.

IV.1.5 Requirements Traceability Matrix

Table IV.5 is a requirements traceability matrix between the functional requirements and each use case.

Table IV.5: Requirements Traceability Matrix

	U01	**U02**	**U03**	**U04**	**U05**	**U06**	**U07**	**U08**
	U01	U02	U03	U04	U05	U06	U07	U08
R01	X	X		X				
R02	X	X		X				
R03	X	X		X				
R04	X	X		X				
R05	X	X		X				
R06	X	X		X				
R07	X	X		X				

Continued on next page

Table IV.5 – continued from previous page

	U01	**U02**	**U03**	**U04**	**U05**	**U06**	**U07**	**U08**
R08	X	X		X				
R09	X	X		X				
R10				X	X			
R11				X	X			
R12							X	X
R13							X	X
R14		X		X	X	X		
R15	X	X	X	X	X			
R16	X	X					X	X
R17		X		X				
R18		X		X		X		
R19		X		X	X	X		
R20		X		X	X	X		
R21		X		X	X	X		
R22		X						

IV.2 System Design

This section provides details about the implementation of Roslyn.

IV.2.1 System Classes

This subsection presents a set of figures describing Roslyn's internal class structure.

Figure IV.1 shows the system architecture showing relationship between high level nodes in the system. The ROS Nodes are open source nodes (not developed in this project) which provide data to the system and control the robot hardware.

Figure IV.2 shows the Social Navigation class diagram showing the relationship between classes and the rest of the system's data flow.

Figure IV.3 shows the internal description of the user interface bridge, its intraconnections to itself, and connections to other nodes and to the interface itself.

IV.2.2 Top Level Activity Diagram

Figure IV.4 shows the top-level activity diagram for Roslyn. It presents two views: the operator view is used by the system maintainer to create a map of the world and set a robot up to navigate in it. The guest view is used by a non-technical guest to interface with the robot via the touchscreen user interface.

IV.2.3 Detailed Design

This section presents state charts for Roslyn's components.

Figure IV.5 shows the message passing statechart. ROS uses an asynchronous and parallel messaging scheme, however it is convinient and appropriate to represent it in this discrete way.

Figure IV.6 shows the navigation statechart.

Figure IV.7 shows the user interface statechart.

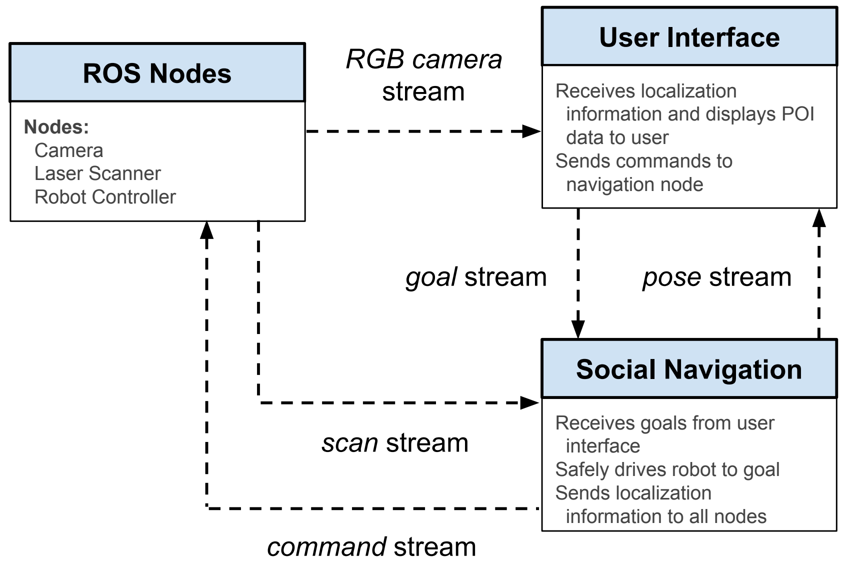

Figure IV.1: System architecture

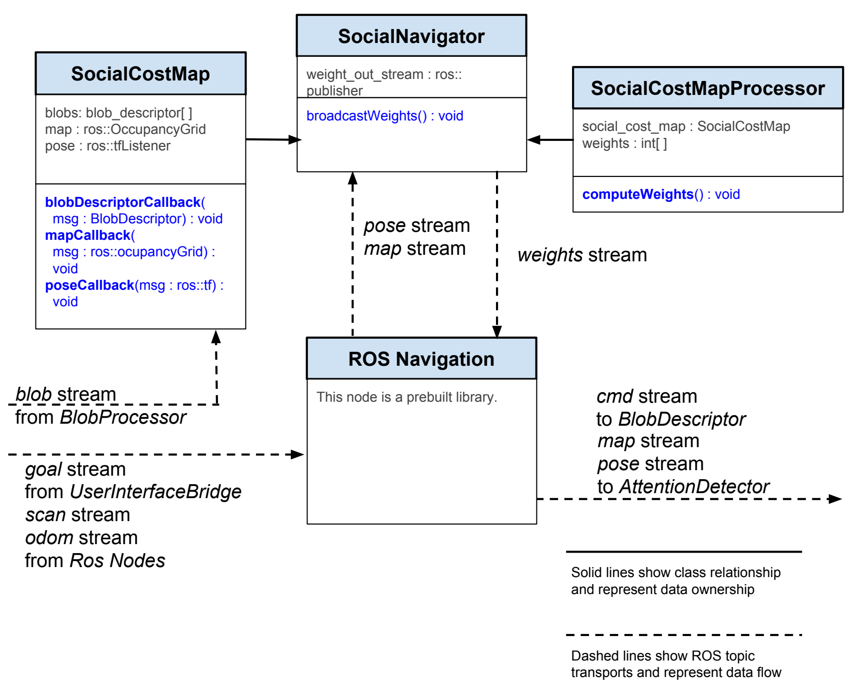

Figure IV.2: Social Navigation classes

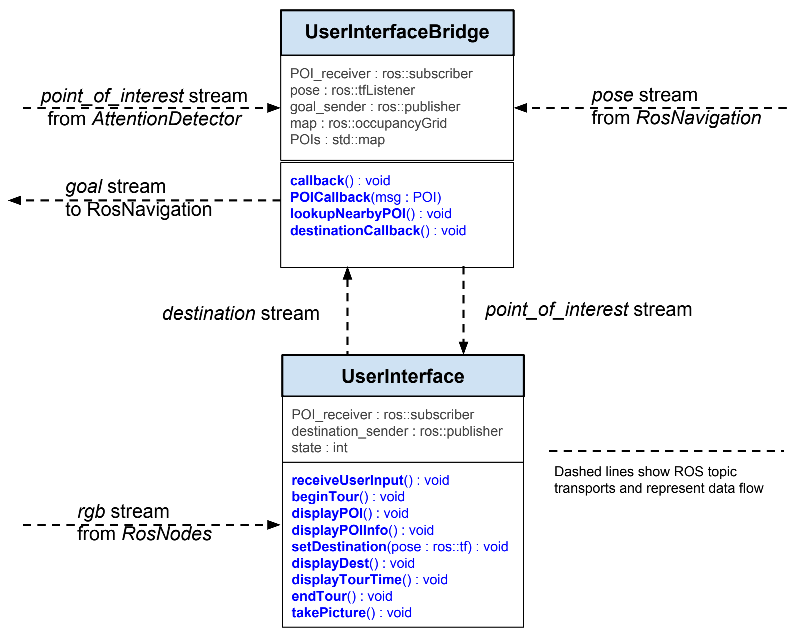

Figure IV.3: User Interface classes

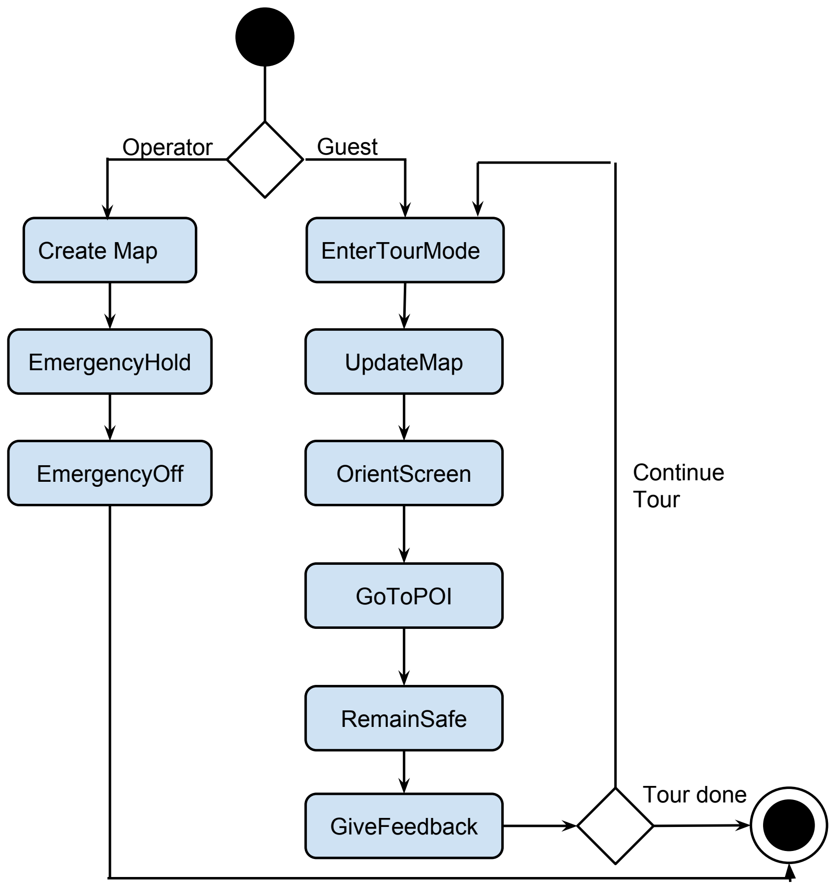

Figure IV.4: Top-level activities

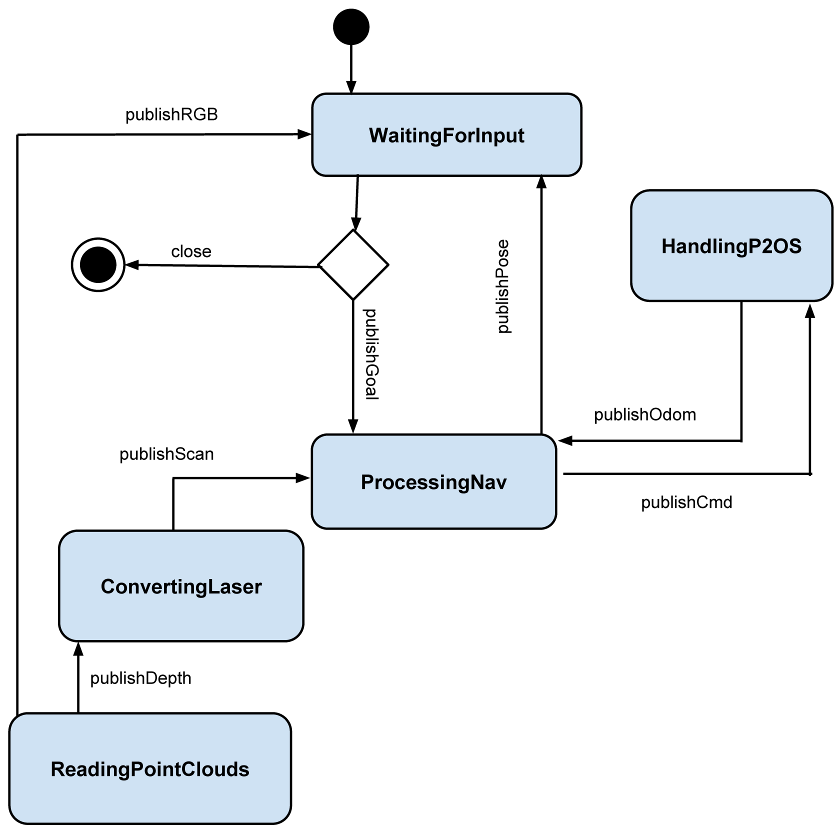

Figure IV.5: Statechart for message passing system.

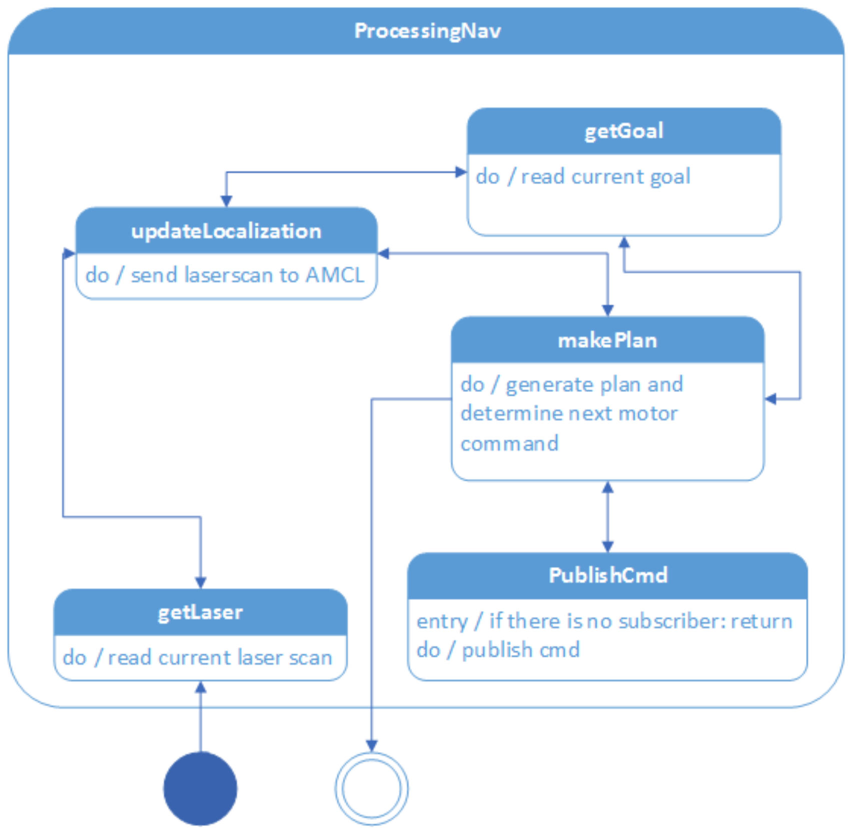

Figure IV.6: Statechart for navigation system.

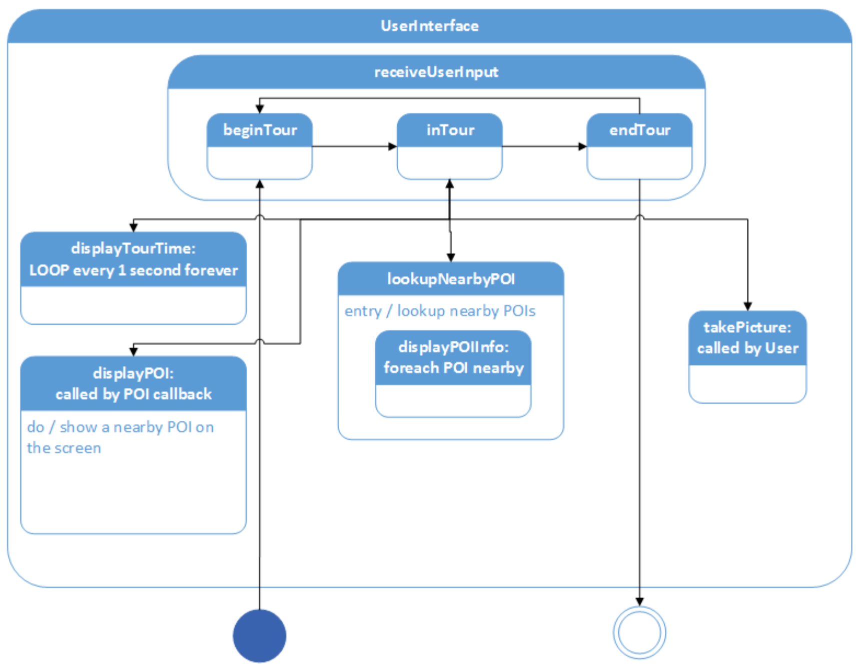

Figure IV.7: Statechart for the user interface.

Chapter V

Fifth Chapter

V.1 User Interface

This section provides a set of images of the user interface.

Figure V.1 is the home screen that the user will see before beginning a tour. It displays the begin tour button, as well as the map and interactive mode buttons for different views.

When the map view is selected or "Begin Tour" is selected, Figure V.2 is the screen that appears. This screen displays a map of the environment. Green circles represent multiple points in an area and must be zoomed in to view. The other icons represent points of interest that can be selected as destinations. It is important to note that this map view has the same menu overlay as shown on the welcome screen above that contains the title bar and buttons.

The map view contains zoom capability, Figure V.3 shows this functionality of the interface. Zooming can be done using pinch gestures on the touch screen.

Figure V.4 shows the popup (shown above the blue marker) which appears above the location providing details about the point of interest.

Figure V.5 shows the interface when the user decides to partially zoom in. This shows that certain markers can now be displayed outside of clusters, using their own individual icons, while others are still too close together and are considered grouped.

The help popup shown in Figure V.6 appears if the user presses an area of the map that is not a point of interest. It provides instructions on how to choose a destination and begin heading there.

Figure V.7 displays most of the types of destinations. Blue icons represent offices, red for research labs, green for classrooms, and elevator/stair icons.

If the user decides to choose "interactive" mode, Figure V.8 appears, showing a description of the point of interest that is nearest to the robot's location.

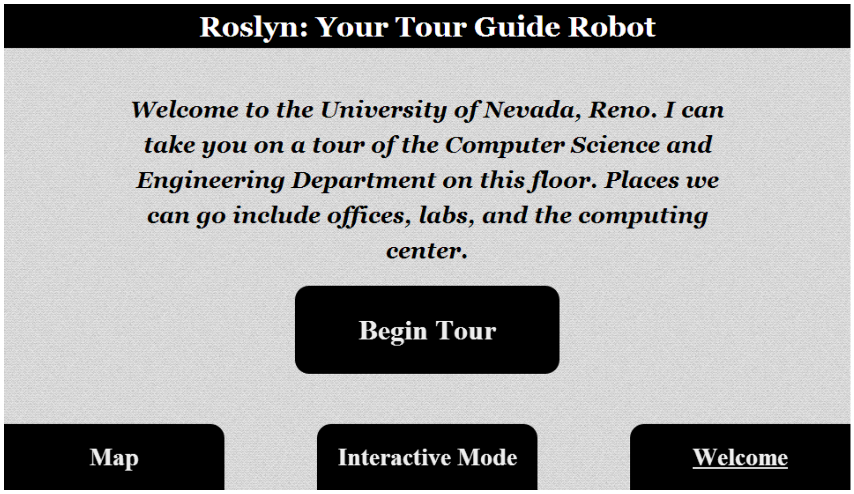

Figure V.1: User Interface - Welcome

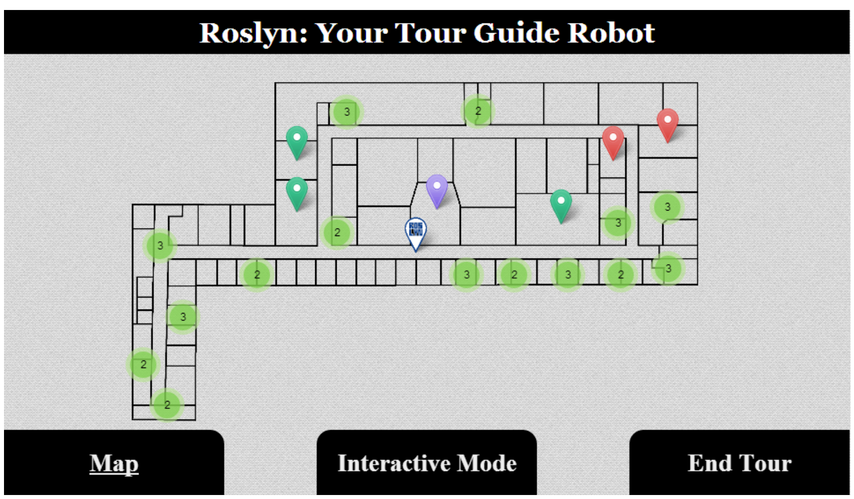

Figure V.2: User Interface - Begin Tour

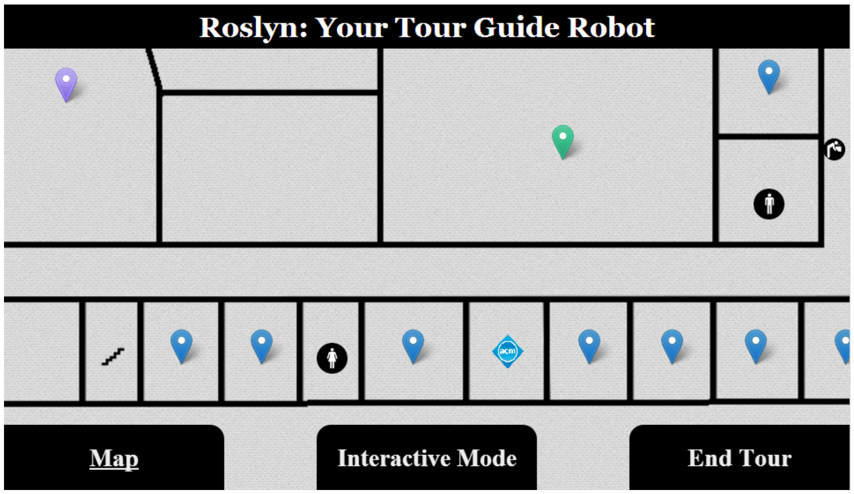

Figure V.3: User Interface - Full Zoom showing different icon styles

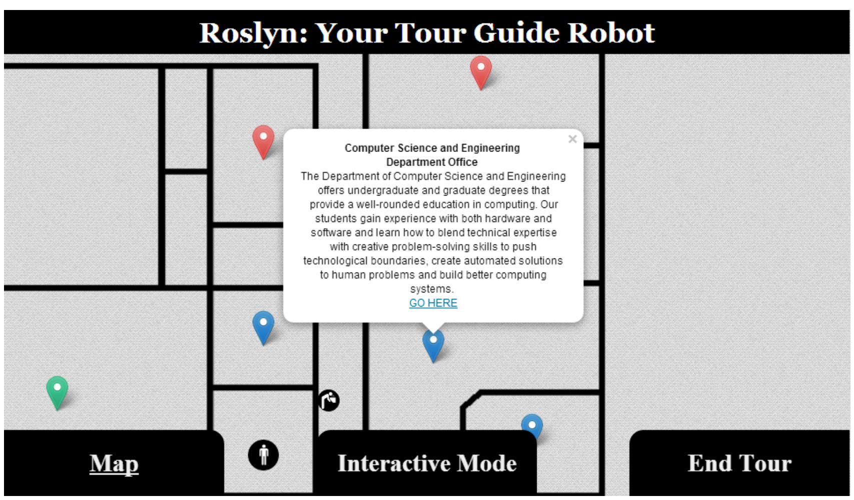

Figure V.4: User Interface - Example destination description

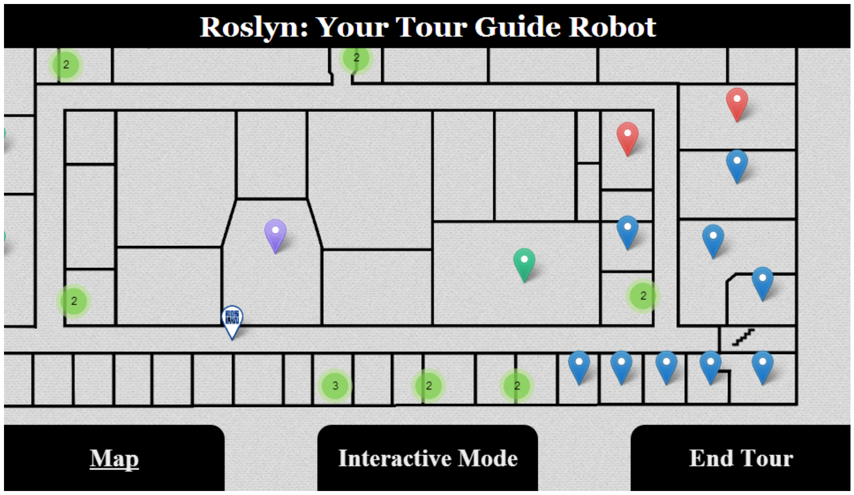

Figure V.5: User Interface - Half Zoom showing some clusters and more points

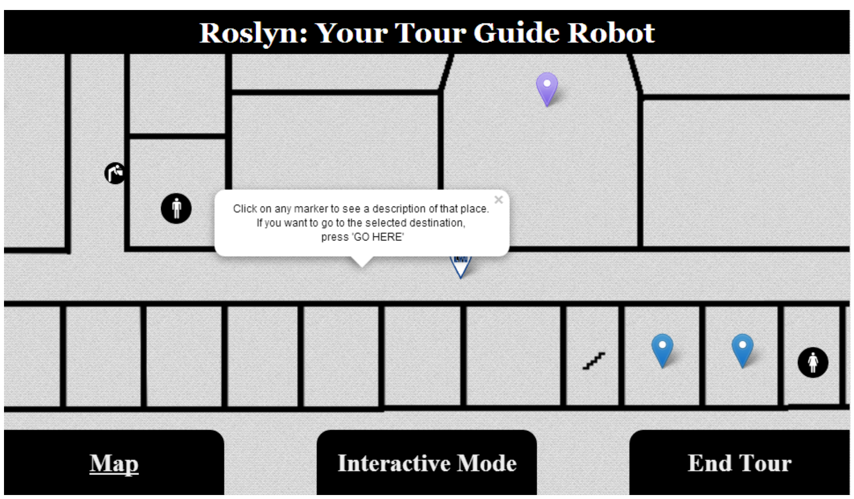

Figure V.6: User Interface - Help popup

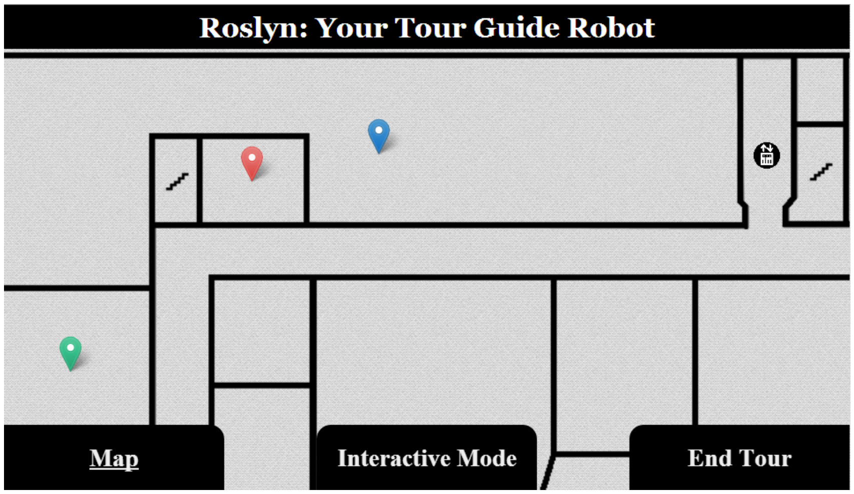

Figure V.7: User Interface - Elevator and stairs icon examples in top right corner

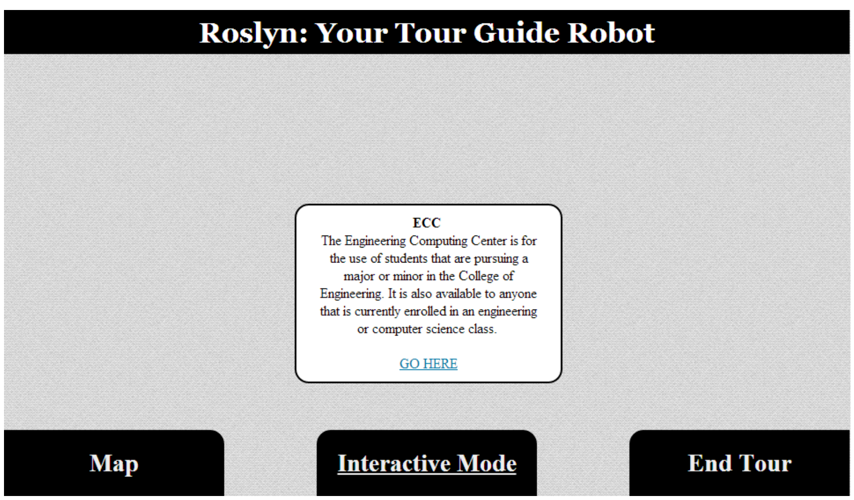

Figure V.8: User Interface - Interactive Mode shows description of nearest point

Chapter VI

Sixth Chapter

VI.1 Glossary

Table VI.1: Glossary of Terms

Term	Definition
AMCL	A ROS package that uses Monte Carlo localization and particle filtering to determine the location and orientation of the robot.
Autonomous	A type of system that operates without continual guidance of an external operator.

Continued on next page

Table VI.1 – continued from previous page

Term	Definition
Costmap	A representation of the robot's possible paths using weighted mathematical functions to represent the cost of points in certain paths. A form of optimization is used on the costmap to produce a plan consisting of velocity outputs for the robot's motors.
GUI	A physical interface that the user will interact with in order to provide commands to the robot. The GUI will also provide information to the user about POIs.
Gmapping	A ROS package that uses AMCL and SLAM to generate a map of the environment from a laserscan.
Landmark	A distinctive feature in the map that can be used for robot localization and navigation.
Laserscan	A vector of depth values at discrete positions on a line.
Launch file	A Robot Operating System file which contains parameter information for various robot control systems.
LeafletJS	A JavaScript library that allows the creation and manipulation of a clean and usable map; this is compatible with a touchscreen interface.

Continued on next page

Table VI.1 – continued from previous page

Term	Definition
Localization	The task of finding a robot's pose with respect to a given map.
Map	A representation of an environment, such as the location of all walls and objects in an area.
Navigation	The process of travelling to a destination safely by processing a map and localization information to issue commands to the robot actuators.
Node	A distinct subsystem of the robot which only passes messages to other components via ROS.
Obstacle	An unexpected object detected by the robot that is not included in the map.
Point of Interest (POI)	A classroom, office, lab, or center that the robot can navigate towards or describe.
Pose	The position and orientation of the robot.
RGBD camera	A camera, such as the Microsoft Kinect, that captures both an RGB image and a depth IR map.

Continued on next page

Table VI.1 – continued from previous page

Term	Definition
Robot Operating System (ROS)	A software package that manages the connections between various software modules (including localization, navigation, and robot control) designed specifically for controlling robots.
Route	The robot's plan on how to reach a destination from its present pose through a map of its environment.
Roslibjs	A JavaScript library for ROS that allows a web document publish and subscribe to ROS topics.
Safety	The state of not being within a set distance from any obstacle, known object, or the user.
Simultaneous Localization and Mapping (SLAM)	The process of constructing and updating a map of the environment while determining the robot's pose. Many approaches exist to solve this fundamental robotics problem.
TF transform	A transformation between coordinate frames used by the Robot Operating System to maintain dependant relationships between reference frames.
Tour	The robot's complete interaction with an individual user, from initiating contact to reaching its destination.

Continued on next page

Table VI.1 – continued from previous page

Term	Definition
User	An individual human who initiates contact with the robot in order to complete a tour.
Waypoint	A point of interest that is selected as the robot's destination.

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Appendices

Appendix A

Need Finding Interview

Which interfaces would you like to use to communicate with a tour guide robot?

- Voice
- Touchscreen
- Mouse
- Keyboard
- Gestures
- Mobile Device

Do you think a robot could provide as good of a tour as a human guide?

- Yes
- No

In a new environment, would you prefer to customize your own tour or follow an established tour path?

- Custom tour path
- Established tour path

How fast should a tour guide robot move? Remember, the tour guide will comment on points of interest the tour passes.

- Fast
- Normal Walking Pace
- Slow

At each point of interest on a tour, the robot should:

- Stop, give information, and automatically continue on the tour
- Stop, give information, and wait for user input to continue the tour
- Move slowly past the point while offering information

How human-like should a robot tour guide be?

- 1 - Humanoid
- 2
- 3
- 4
- 5 - Non-humanoid

How should the tour guide robot handle questions?

- Have a FAQ item in its interface
- Record questions for later answering by a human
- Attempt to use language processing to answer the question and report an attempted answer or failure
- Other:

If you were offered the option of using a robot tour guide or a human tour guide to tour a school's Department of Computer Science, would you choose:

- Human tour guide
- Robot tour guide

What attribute is most important for a tour guide for a CS department (robot or human)?

- Informative
- Entertaining
- Fast
- Friendly
- Interactive

Describe your best experience with a tour guide.

Describe your worst experience with a tour guide.

What features would you like to see in a tour guide robot?