SORTING RECYCLABLE MATERIALS BY A ROBOTIC SWARM

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THE HARRIS CENTRE
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1 Introduction and Acknowledgements

This document comprises the final report for the project "Sorting Recyclable Materials by a Robotic Swarm" which was awarded $15,000 in funding as part of the Harris Centre / MMSB Waste Management Applied Research Fund. The application for this funding was submitted in December, 2012 and awarded in February, 2013. The project began on April 14, 2013 with a planned duration of one year. A request for extension was granted so that the project would conclude on July 1, 2014. We would like to acknowledge the Harris Centre and the Multi Materials Stewardship Board (MMSB) for their financial support of this project.

2 Executive Summary

The purpose of this project was to begin transferring robotic control algorithms developed in swarm robotics towards application in the recycling industry. An algorithm that would allow a set of distributed robots to sort randomly distributed objects was previously developed by the principal investigator, Dr. Andrew Vardy [4]. This algorithm, known as *cache consensus*, relies on the ability of robots to detect and classify local objects, determine their positions in space, and to determine the robot's own position in space—an ability known as *localization*. In previous work, a set of simple robots were tested operating on coloured wooden pucks. Localization was provided externally by using an overhead camera which tracked the robots. Several developments are necessary before this system could be applied in the context of recycling. The ability to recognize and grasp complex shapes such as bottles, cans, and various containers is clearly required. However developing this ability was judged to be overly ambitious for the scale of this project. Instead, the focus has been on developing a set of robots with the ability to localize using on-board computers.

A set of robotic components already purchased by the Department of Computer Science was adopted to develop fully functioning robots with the necessary capabilities to implement cache consensus. These components included iRobot Create bases which provide drive wheels, low-level sensors, and an accessible serial port for external control. The other major components were a set of Hokuyo URG-01 laser range finders, as well as Dell Inspiron m11z notebook computers. A custom printed circuit board (PCB) was designed and fabricated to allow all components to function together and to support powering devices from the robot's rechargeable battery. We also developed a custom gripper mechanism to allow pucks to be grasped and moved about in the environment. On the software side, we developed modules to control the robot using the Robot Operating System (ROS) framework. The use of ROS allowed advanced robot localization algorithms to be easily incorporated into our running system.

The long-term objective of this research is to develop a scalable robotic recycling capability that could be utilized in NL communities remote from the current materials recovery facility at Robin Hood Bay as well as the planned facility for central Newfoundland. Currently, many remote communities do not collect recyclable materials due to the costs of collection, transport, and processing of that material. Our solution is to eliminate the majority of transport costs (including environmental costs) through a scalable robotic processing facility that would not require expensive dedicated facilities and could be tailored for particular communities just by adjusting the size of the robot population. With a scalable swarm robotic recycling system these communities could sort their own recyclables and ship packaged plastics and metals directly to market. Such a system would reduce environmental impact and allow revenue to be captured locally. These benefits would

be in addition to the direct benefits of establishing a new enterprise to develop the swarm robotic solution.

3 Introduction

The focus of this report is to discuss the project's progress and outcomes with respect to the objectives stated in the original application.

3.1 Project Background

Sorting is central to the recycling industry where magnetism, reaction to forced air, and filtering by size and weight are widely-used techniques. The machines used for these sorting tasks are large, costly to run, and generally inflexible once installed. Smaller communities in Newfoundland and Labrador which collect recycled materials ship them to larger centres, primarily the facility at Robin Hood Bay, St. John's. These transport costs increase the carbon footprint and expense of community-level recycling. Smaller communities also lose out on opportunities to independently distribute their recyclates to market. Unlike conventional techniques for automated sorting, a robotic swarm is scalable. That is, the quantity of material to be sorted can be accounted for simply by adjusting the number of robots. This has major potential implications for recycling in Newfoundland and Labrador because it may allow smaller communities to process their own materials and ship them directly to market.

Our approach fits within the research area of swarm robotics. Swarm robotics concerns the design of multi-robot systems which demonstrate a desired collective behaviour in a distributed, decentralized manner. The social insects (e.g. ants and bees) provide the key inspiration that effective collective behaviour can be achieved without hierarchical organization and without access to global information. Colonies of social insects such as bees and ants exhibit behaviour that is remarkably robust and adaptive to changing environmental conditions. Of particular interest is the ability of social insects to sort materials into groups. Honeybees distribute honey, pollen, and brood in a concentric pattern with brood cells surrounded by pollen, and pollen cells surrounded by honey-filled cells [1]. Ants also organize their brood in a concentric pattern according to size [3]. They also appear to cluster waste material (e.g. dead ants) into groups [2]. We are interested in borrowing the strategies used by social insects to sort physical assets into segregated clusters. The overall goal of this research program is to apply these strategies in applications such as recycling and perhaps inherit some of the robustness and adaptability inherent in insect sorting.

3.2 Objectives

The following statement of the project's purpose and objectives are taken from the original proposal:

> *The purpose of this project is to begin transferring robotic control algorithms developed in swarm robotics to their application in the recycling industry. In particular, algorithms for sorting randomly distributed objects into organized clusters will be adapted to fit the mold of a recycling plant, with defined in-flow and out-flow regions.*
>
> 1. *Develop a set of new robots with the ability to sort proxy materials (coloured pucks) and to localize with respect to in-flow and out-flow regions*

2. *Adapt previously developed algorithms for robotic sorting to accommodate the specification of defined in-flow and out-flow regions*
3. *Investigate the scope of requirements to establish a working robotic sorting facility scaled for a small-to-medium sized community in Newfoundland and Labrador*

Satisfying the project objectives requires the design and fabrication of suitable robots with an accompanying localization system, the adaptation of robot control algorithms, and investigation into the desired requirements for a real-world robotic recycling facility.

4 Project Progress and Outcomes

4.1 Objective 1: Robot Hardware

To satisfy objective 1 the original plan was to leverage the efforts of a group of senior students in Electrical and Computer Engineering who were developing a new suite of robots based around Android smartphones for their inexpensive computing and sensing capabilities. These students did develop two prototype robots but they lacked the localization capability required to undertake the work of this project. I determined that the capability of integrating software running on the Android operating system with well-known localization algorithms would be challenging. Therefore, I changed the focus for the robot hardware to utilize an incomplete set of robotic compenents already available within the Department of Computer Science. These robots, known as *Arbots*, consist of the following main components (this list is not exhaustive):

- iRobot Create with battery, charger, USB hub, and cables (value $300)
- **MinSegMega board (value $75)**
- **Custom Arbot board connecting iRobot Create and MinSegMega**
- **Leopard Imaging 5 Megapixel USB Camera (value $90)**
- Acrylic platform (value $100)
- Hokuyo URG-04LX-UG01 laser range finder with 2-port USB cable (value $1400)
- Dell Inspiron 11z netbook computer with power cable (value $1000)

The items indicated in bold were explicitly purchased or developed from this grant. The remaining items were already available from within the Department of Computer Science. The Custom Arbot board is a printed circuit board (PCB) designed in-house for the Arbots. The gerber design file for this PCB is shown in figure 1.

The Arbots have passed through two design iterations. Figure 2 provides images of the fist iteration design. A set of cheap grippers (Robotic Claw - MKII from Sparkfun Electronics) were purchased with the intention of developing small cylinders to grip as the proxy objects. However, these grippers proved to be very imprecisely manufactured and were generally ineffective.

The second design iteration incorporates a passive gripper mechanism using a design similar to one we used previously [4]. We also realized that the profile of the overall robot should be more streamlined to minimize the possibility of damage when multiple robots are operating in close proximity. Images of the new gripper design appear in figure 3

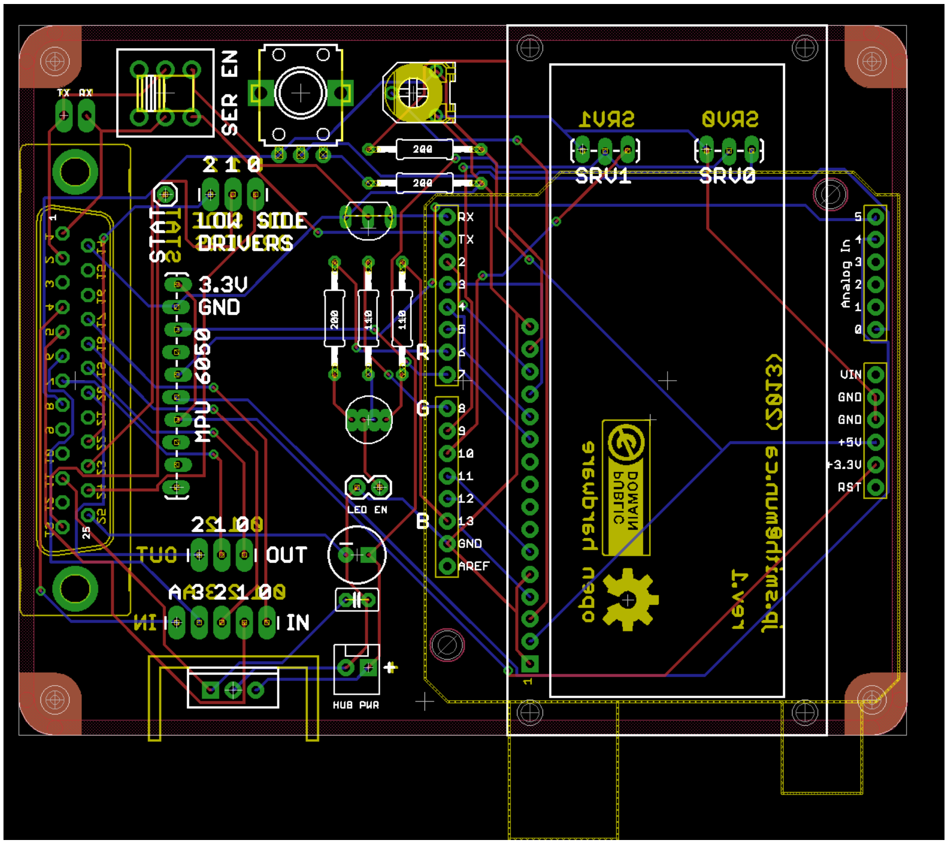

Figure 1: The gerber design file for our custom Arbot board.

4.2 Objective 2: Robot Software

Objective 2 regards the development of software to support the cache consensus algorithm on our new fleet of Arbot robots. This software can be separated into two categories:

Low-level The low-level control software runs on the MinSegMega Arduino board. Its purpose is to interface with the iRobot Create base and to compute odometric pose information by incorporating the wheel encoder counts from the iRobot Create with the angular rate gyro sensor located on our custom board.

High-level The high-level control software runs on the Dell Inspiron m11z notebooks and consists of a set of ROS nodes and defined topics and services for communication amongst these nodes. The details of this software is assumed to be out of scope for this report. Figure 4 provides a snapshot of the ROS nodes and topics involved in our current system.

Note that the low-level software has reached a mature state with relatively infrequent updates required. The high-level software is under active development. The overall system is currently undergoing refinement and we expect the full implementation of the cache consensus algorithm to be complete within two weeks.

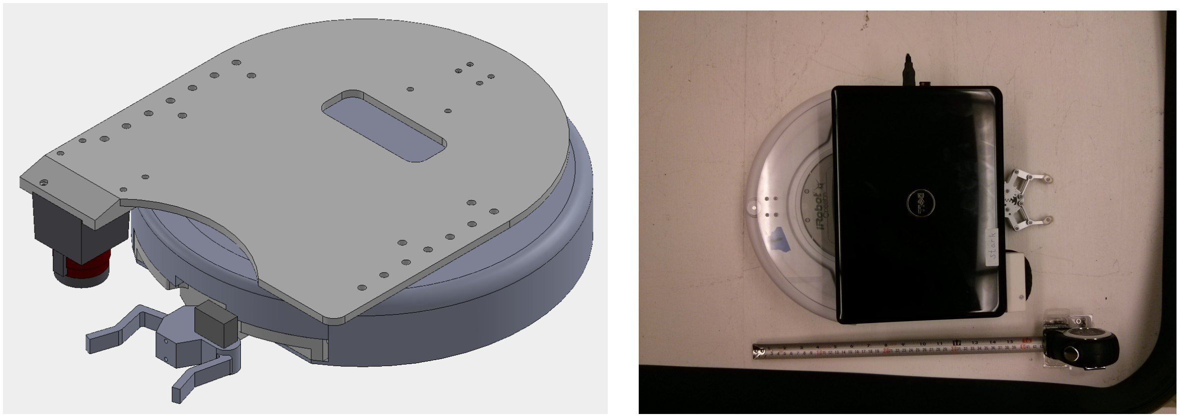

Figure 2: (a) View of the SolidWorks model for the 1^{st} iteration Arbot. (b) Top-down view of the completed Arbot.

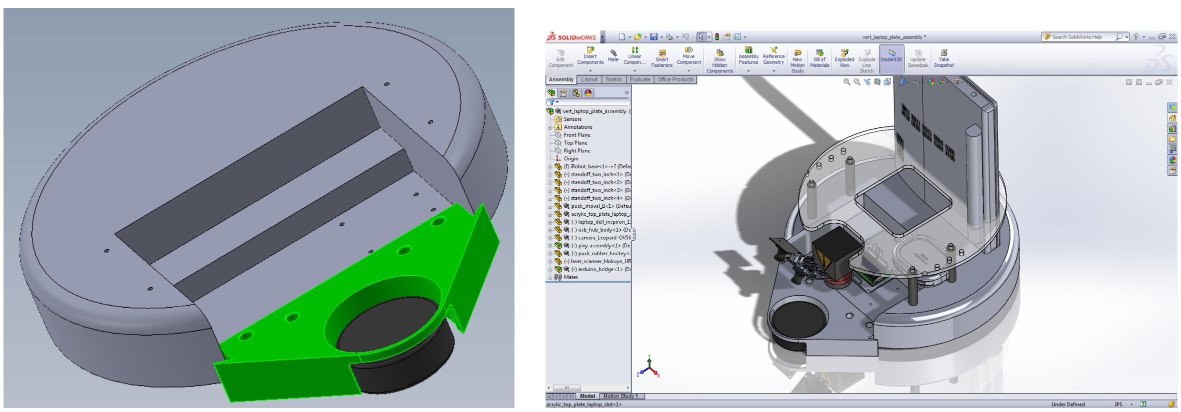

Figure 3: (a) View of the SolidWorks model for the 2^{nd} iteration passive gripper (highlighted). (b) View of the SolidWorks model for the 2^{nd} iteration Arbot.

4.3 Objective 3: Recycling in Small Communities

Objective 3 was intended to address the requirements for a real-world recycling system for remote community in NL. We have had discussions with the staff of the Northern Peninsula Regional Service Board (NPRSP) which is responsible for waste management issues on Newfoundland's Northern Peninsula. This region is relatively remote from the existing materials recovery facility in St. John's as well as the planned facility in Norris Arm. There are currently no municipal programs for household recycling on the Northern Peninsula. It is therefore likely that the majority of potentially recyclable products consumed in this region are directed into landfills. The NPRSP are keen on investigating possible solutions and have requested funds to conduct a feasibility study on recycling options for their region. The estimated cost of such a feasibility study is approximately $25,000. It became clear, therefore, that any similar such investigation would lie outside the scope and budget for this project. Therefore, the pursuit objective 3 has been left for future work. However, we do plan on continuing discussions with the NPRSP and moving towards a partnership on scalable recycling facilities for remote communitites.

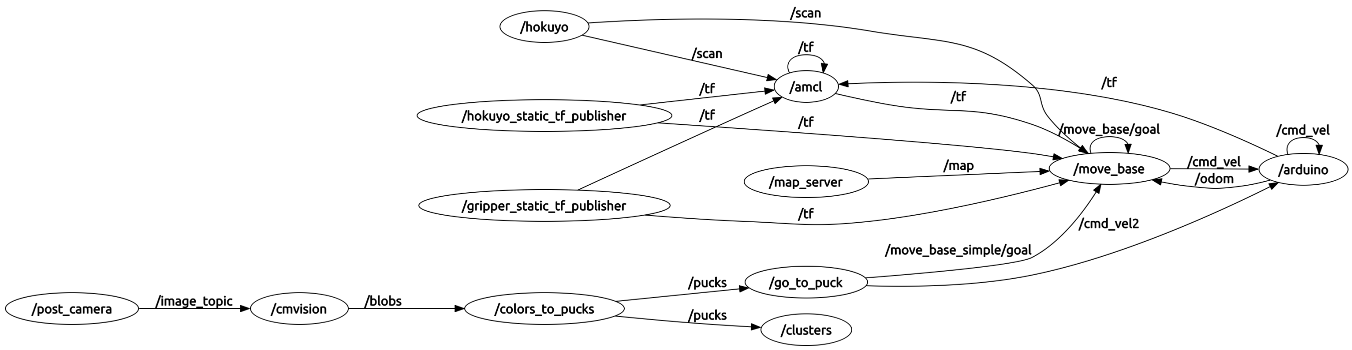

Figure 4: A snapshot of the ROS nodes and topics used in our high-level control software. This snapshot was captured using the `rqt_graph` command-line utility.

5 Conclusions

This report serves as the final required deliverable for the Harris Centre / MMSB sponsored project "Sorting Recyclable Materials by a Robotic Swarm". The main body of work entailed by this project has been the development of a new fleet of robots capable of on-board localization. The software required to implement the cache consensus algorithm on these robots is nearing completion. Finally, our initial objective of investigating the requirements for a real-world recycling system in NL has been judged as out-of-scope. Much work remains before the practical implementation of these ideas to recycling in NL will be seen. However, we now have a set of robots that can be used to move this research closer to that goal.

6 References

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