11-1-2012

Bruce, the multi-function robot

Terence Stewart

ROCHESTER INSTITUTE OF TECHNOLOGY

A Thesis Submitted to the Faculty of
The College of Imaging Arts and Sciences
In Candidacy for the Degree of
MASTER OF FINE ARTS

"Bruce, The Multi-Function Robot"

by

Terence L. Stewart

November 2012
Rochester, New York

Bruce, The Multi-Function Robot
Terence L. Stewart
Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Fine Arts in Industrial Design
Rochester Institute of Technology
College of Imaging Arts and Sciences
Rochester, New York

Committee Aproval:

Chief Advisor:

Stan Rickel ________________________________

Date: _______________

Associate Advisor:

David Colwell ________________________________

Date: _______________

Acknowledgements

This Thesis project can not be completed without assistance and guidance from the co-students of Industrial Design Graduate Program, David Colwell of National Technical Institute for the Deaf - Computer Integrated Machine Technology, Walter Wayne of Rochester Institute of Technology - Mechanical Engineering Chairperson, Corey Tamas, Shannon Clancy, Linda Bishop, Mary Bonello, Molly Estes, Bill Newman, Pieter Kuyntjes, John Lee, Heather Smith, especially Julie and Tova Stewart.

Table of Contents

Introduction
Hypothesis
Background
Current Robotic Technology
Challenges to Consumer-Level Adoption
Bruce: Concept
Research and Relevant Questions
Inspiration from Existing Design
Programming and Physical Design
Design Phase
- First Mockup
- Second Mockup
- Revisions

Custom-Made Materials
Assembly
Bruce: The Multi-Purpose, Personal Robot
Design and Function
- T-Slot System
- Double Axles
- Control System
- Dimensions
- Wheels
- Attachments

Accessibility to the Consumer Market
Conclusions
- Future Plans
  - Programs
  - Accessories
  - Maintenance-Free Bruce Service Stations

Conclusion

Introduction

This thesis presents a working solution to bring robotic technology into the consumer market in a relevant and meaningful way. Although a thesis which centers around the construction and application of a functional robot may initially seem outside the scope of a typical Industrial Design thesis, it is distinctly relevant to the aims of the field. In this thesis, I propose the use of a unique tool, detail the user experience, and elaborate on its diverse functions. This work represents the culmination of Industrial Design Graduate courses and elective courses at R.I.T.'s N.T.I.D.'s CMIT- Computer Integrate Machine Technology Institute with help of R.I.T.'s Mechanical Engineering.

Hypothesis

The vast potential of robotic technology to serve the consumer market is nearly unlimited. Robots in the home can provide comfort, security, and can greatly reduce the need for humans to perform grueling or distasteful tasks. For example, consumers can use robots to patrol the home looking not only for intruders but also for urgent or dangerous maintenance issues. A robot can also reduce the drudgery of simple, mundane tasks such as carrying groceries in from the car or moving large quantities of soil to a specific place in a garden. Most important of all would be the user's ability to customize a robot to perform new jobs which are specific to the household in which it's being used, or even to more precisely tune the jobs that it already does. To evolve household robotic technology from the level of toy or dedicated device into a customizable tool seems not only like a realistic goal, but an obvious one.

Background

The concept of "robots" originated with Czech writer Karel Čapek, who portrayed them in a stage play entitled Rossum's Universal Robots (published in 1920). The word was actually coined by his brother Josef, but the idea of robots as workers who take on the burdens that humans are either unable or unhappy to shoulder was Karel's. In the intervening 98 years, technology and its capacity to bring the science-fiction concept of robotics into reality has not only arrived but also allowed us to explore its usefulness to humans. Despite these advances, there's still great potential in the field and sound reason to believe we should be pushing harder to see its growth. While industries such as automobile manufacturing (in which robots perform repetitive tasks without interruption), rescue operations and scientific research have largely adopted robotics to aid in human endeavor, the average person rarely benefits directly from robotic technology. The potentiality of robotic use in our homes and daily lives is all but untapped.

<u>Current Robotic Technology</u>

Image Source: http://www.investing.calsci.com

Image Source: rendbird.biz

Image Source: templetons.com

Image Source: wikipedia.org

There are four different kinds of robots. The first type [is] performs automated and repetitive tasks which humans find fatiguing and hard to perform at a comparable speed and consistency. These robots are common to a variety of work environments, such as the automotive industry where they appear on assembly lines; “mail delivery” robots (Automated Guided Vehicle, AGV) found in corporate offices where they circulate and distribute letter mail; and laboratory robots which work alongside researchers and lab technicians while handling dangerous substances or performing tasks which are too difficult or dangerous for humans. While these are not necessarily the most complex sorts of robots, their cost is consistently far above consumer reach.

Image Source: eebeat.com

The second variety of robot is the simple kind, which is available commercially as toys for children. While entertaining and affordable for the average consumer, they are typically neither durable nor capable of accomplishing complex tasks and duties, thus making more practical and advanced applications unrealistic.

Image Source: greenia.com

The third type of robot is also commercially available, and is created for simple, repetitive home maintenance such as lawn mowing or vacuuming floors and rugs. While usually more rugged than toy robots, they're often even less sophisticated in their software design and are not typically customizable or diverse. Even compared to the repetitive work of industrial-level robots, this variety is very simple and lacks the same level of precision (though that accounts for the considerably lower price tag). While technically robots, this sort is not adaptable enough to exploit the potential of robot technology in the home.

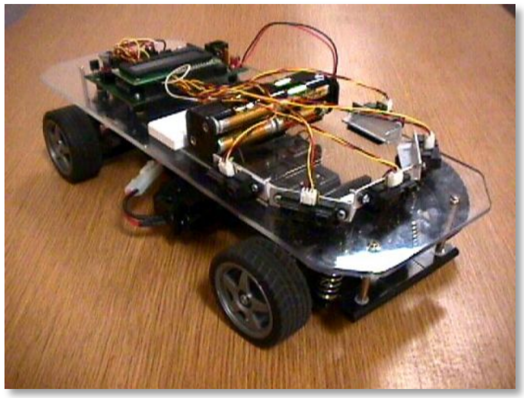


Image Source: soni2006.hubpages.com

A case can be made to define the last variety of robot as the custom-made type which is normally designed and assembled by hobbyists. The advantage of a custom-made robot is that it can be designed to perfectly perform the task for which it's intended, which is even more useful if there's no comparable product on the consumer market. The obvious difficulty is that the robot which is designed and built by even a very capable hobbyist will only be used by him or her in specific applications and often cannot easily be adapted to purposes which weren't originally envisioned by the designer.

Challenges to Consumer-Level Adoption

While readily adopted in industrial or hazardous settings where they complete infinitely diverse, precise and sophisticated tasks, consumer adoption is paltry at best and only taps a small sliver of robotic potential which is more robustly realized in non-consumer applications. To ascertain all the reasons why fully-featured robotics are slow to penetrate the consumer market is beyond the scope of this thesis, but cost, functionality and a steep learning curve could potentially be the biggest barriers.

The subject of barriers between the consumer market and robotics technology would be the basis of a different academic study. For the purposes of this thesis in which a very specific solution to bridge that gap is presented, it's important to mention some of the obvious to consumer adoption. First, one must consider that in order to offer the sort of flexibility and specialization, the consumer must be able to manipulate its software. Whether this is done directly through coding and compiling or through more user-friendly means such as a simple graphical user interface, specialization and personalization of the robot's functionality requires the user to interact with a robot's programming. It's also important to recognize that only a production-level robotic product would suit most consumers, as the education and training required to build their own is both intimidating for all but the most technologically-savvy (for good reason). Even if this weren't a consideration, the cost of a one-off robot would be prohibitive for most home users.

<u>Bruce: Concept</u>

Image Source: communities.sportsnet.ca

The original idea for the Bruce robot was born from a personal anecdote in which I witnessed an elderly woman walking to the local grocery store with the assistance of a cane. She was carrying empty cloth bags – obviously to bring home her own groceries from the store. It was clear that she wanted to enjoy the nice weather of that particular day and walk instead of taking a taxi or being driven by a friend or relative. It was also clear, however, that her choice to enjoy that independence would result in a terrible burden for her to return with after she was finished her shopping. At that time, I began to consider a powered carrier or wagon that would be usable by an elderly or handicapped person.

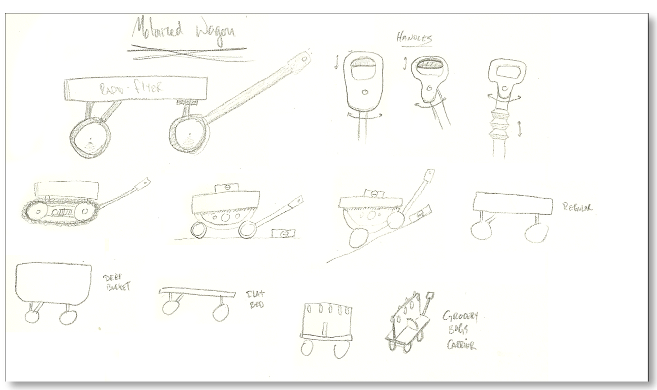


Image of Concept Sketches: Motorized Wagon

As the initial design sketches for a motorized wagon were completed, it became clearer that the functionality should be more diverse and adaptable, and that it should be usable by a wider range of users (such as children, among others). This is where the concept transitioned from a simple motorized wagon or cart to a more fully-fledged robotic solution.

To directly copy the design and application of established robotic technologies (such as those which appear in manufacturing plants, as mentioned above) would be an insufficient solution for consumer needs. Cost would be prohibitive and even simple factors such as size and power supply were beyond the practical limits of consumer home use.

For these reasons, this project seeks to use existing technology which can be easily reproduced for a mass market to create a consumer-level robotic device (which I have code-named “Bruce”) that can be customized to perform a variety of specialized and consumer-defined tasks.

Research and Relevant Questions

Research for the developmental process of Bruce began with a survey intended to establish interest among those who may potentially be part of the target audience. The question was simply “Why is it that you don’t own a robot?”, and the survey was conducted among students and staff on and around the Rochester Institute of Technology campus. The answers were divided among the following reasons:

- Lack of availability of the robotic technology for home and consumer use
- Fear about difficulty of use
- Concerns about prohibitive cost

- Lack of information about what a robot can do (i.e. "I don't know anything about robots")
- Nerd "stigma" which creates awkwardness about self image and concerns that friends will think them "geeky" for using a robot

The most important discovery from the results of this survey is that fears and anxieties about the use of robots in the home are almost entirely based upon pre-conceived notions and trepidation that is common during early adoption of technologies which eventually become commonplace. The survey did not yield any data-driven negative feedback about consumer-level robotics, which is the only sort of negative feedback which would directly affect this thesis.

Inspiration From Existing Design

Image source: www.irobot.com

The current landscape of consumer-level robotics may fail to exploit the full potential of this technology in the home, but there is still a great deal of inspiration that can be drawn upon to create something more robust. In particular, the design of the Roomba (a simple robot designed to vacuum floors and carpets) is such that it can be left to autonomously execute its tasks, and can even take care of simple self-care such as finding its own power supply and recharging itself – thus putting even less burden on the owner. This speaks largely to necessary philosophical considerations for robotic implementation in the home; namely, that it should lessen or eliminate work and labor in an unobtrusive and mostly invisible manner and not add new tasks to replace them.

Image Source: www.lego.com

LEGO design, while intended for children as a plaything, conveys an important philosophical perspective for robotics design. The electromechanical "core" of the design offers mobility and transportation, but allows for modular customizability. Often (particularly in classic LEGO design) a core motor in a housing can be adapted with axles, brackets, wheels and any other elements for which the system allows. Giving the user the option to adapt the function of the machinery to their own needs is a core philosophy of consumer robotics, which must come to bear on any design work.

Programming and Physical Design

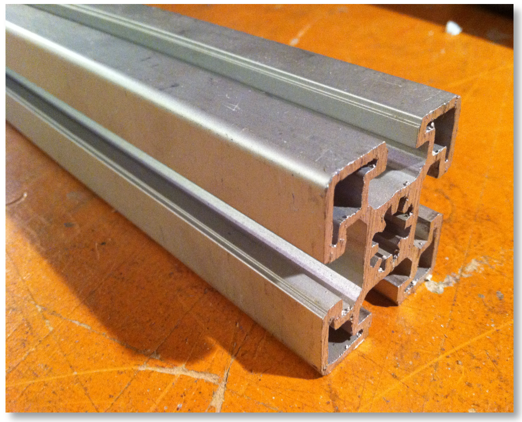
Bruce's prototype was created for the purpose of showing how principles and philosophies of good robotic design can be leveraged for consumer use.

Predictably, the core construction and programming requires considerable thought and this section of the thesis will explain the process by which it was built.

For the user to customize Bruce's functions, they'll need to access the programming code which dictates its functionality. However, expecting laypeople to manipulate complex code such as C++ or COBOL is expecting way too much as they will be put off by the learning curve and are not likely to think the return on investment is worth it. For this reason, a simple push-button interface must be added (even if it's a skeuomorphic touch interface) which allows users to visually design code and have the underlying code reflect those edits. An option to program more directly can be integrated into the interface, but anything that requires a steep learning curve without an alternative and simpler interface will be rejected by users and isn't realistic to expect of them.

Naturally, certain elements of programming customization are going to require hardware with the capacity to adapt to custom mechanical features. For this reason, Bruce uses aluminum extrusion, better known as "frame fabrication." This approach was taken because it opens up options for users to attach modular extensions to the body to extend functionality. These extensions could range from simple hooks (to support bags) to something as complex as a snow-blower. With a user interface that's ready for user-level customization and a physical housing, which can support attachments, Bruce offers economical adaptability.

Design Phase



Aluminum Extrusion Profile

To serve its purpose properly, Bruce’s physical design requires certain elements be present in order for it to be appropriate for consumer use. Size is a basic but valuable consideration because, in order to serve its purpose properly, the robot must be able to carry large items but still be able to move easily through doorways in a typical home while carrying attachments. An obvious source of inspiration is standard wheelchair design: A typical, non-motorized wheelchair's dimensions are 48" in length, 30" width and minimum of 30" in height. I have designed Bruce to be 36" in length, 28" width and 22" height; similar dimensions but slightly smaller.

Bruce was designed using a combination of sketches, mock-ups in Adobe Illustrator, Spectacular’s Infini-D (CAD software) and Google’s “Sketchup” for later phases of the project.

First Mockup

Using foam and cardboard, a scale mockup of Bruce was created which clearly showed design and measurement. Within this “model” version of Bruce, I represented the internal mechanics accurately in order to get a clear sense of how the various pieces would fit and interact. The integration of the gears with the double axles is a key factor in design and function and so, for this reason, a physical mockup was vital.

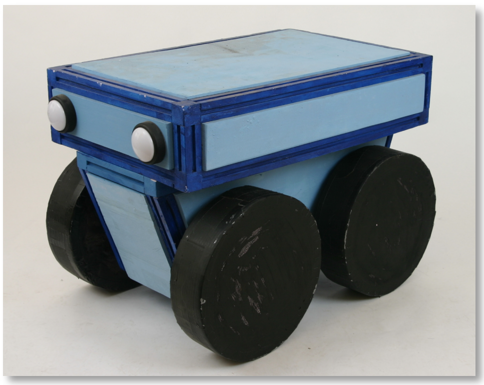


Image of First Mock up Model

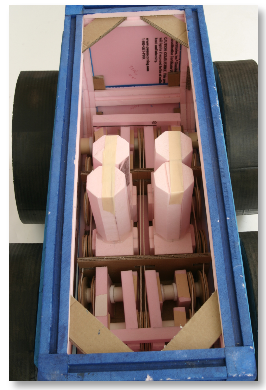


Image of Motor/Gears layout

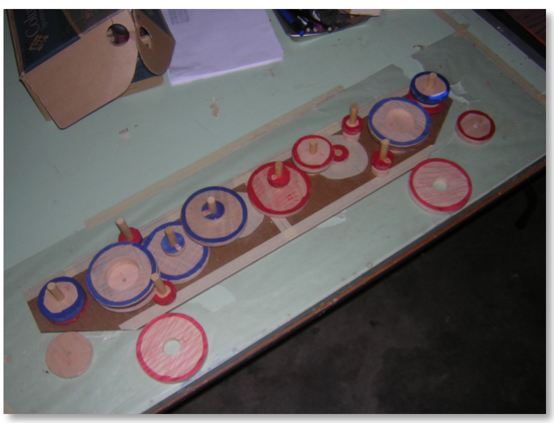


Image of Mock up Gear System

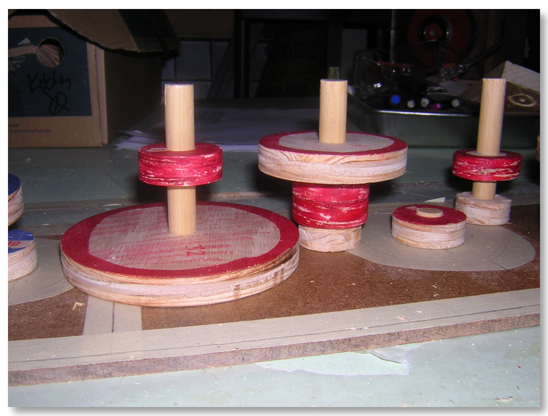


Image of multi-level Gear System

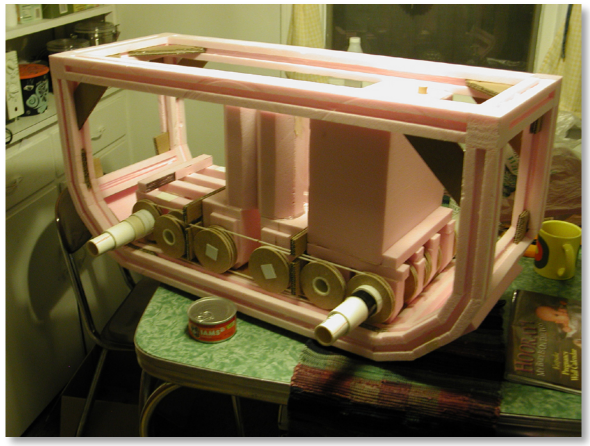
Once the mockup was created, I used it as a test piece by which to implement design changes which became obvious at this phase of gestation. For example, the mocked up design would weigh approximately 500 pounds when completed and so, using the “test” Bruce, I eliminated the top “flatbed” section (originally intended to provide more surface for carrying items, but I felt that extensions could be added after-market to assist with that goal) and began a second mockup.

Second Mockup

Bruce's second mockup focused on details of maximizing effectiveness for mission-critical components and physical size. Bruce's dimensions were critical to maximizing effectiveness of the robotic technology for the user; large enough to properly house the necessary electronics and mechanical parts while, at the same time, small enough to maneuver through a typical home and also able to carry large objects.

Where the motor is concerned, I found that two motors from an electric wheelchair gave me the power I needed to effectively move Bruce while, at the same time, conserving space. During creation of the mockup, however, it became clear that space was still an issue internally due to the gear box (which was too large for the body). I then worked on adapting to a motor design without a gearbox, as the design of the housing demanded the gear system to be spread throughout the internal space.

Height is an important consideration, as it's important to keep the height as low as possible in order to afford storage under a desk, table, workbench, whatever. At the same time, Bruce's battery was an issue, as sealed cell batteries need to be kept upright in order to avoid problems with leaking or spilling harmful acid. This required Bruce's height to remain at 22". The height could have been lowered if I had changed the size of the wheels, but I preferred to leave them at 16" for optimal performance. Bruce's length was less restricted by technological limitations, but I preferred to keep it shorter at 36" (whereas a wheelchair is typically 48") to ease turning and maneuverability.



Model of layout, position of motors, battery, gears.

Revisions

Further exploration uncovered a NPC brand 24v 2,000 rpm, 6amp motor, which fit the requirements and specs for Bruce's operation and physical design, had the same torque ratio as the wheelchair motor while, at the same time, not using a gearbox. This brought another issue to the fore: While the motor itself was ideal, the pre-made gear system was prohibitively expensive, and so after much research I discovered that most robot designers employ a roller chain and sprocket system instead of gears (due to low cost and availability). This resulted in a much better solution which was spread throughout the internal space and accommodated all the other parts. Four of these motors were included in the final Bruce design.

Custom-Made Materials

Much of Bruce's components were custom-made or modified. Among these were the double-axles, braces for the aluminum extrusions, and both the internal and external body.

Double Axles: The double axles were created from mild steel. Though stainless steel is better for preventing rust (especially if Bruce is exposed to the elements), the cost was prohibitive.

Braces for Aluminum Extrusion: After conducting extensive research, it became clear that [that] the aluminum extrusion manufacturing companies I could order from did not have exactly what I was hoping to purchase. Bruce's design requires a block on the end of each extrusion to easily screw extensions in, rather than the commonly-used manufacturer design which involves drilling through the bar and screwing in an "L" bracket. For Bruce, I did not want any holes that would be created by drilling to be exposed; again, to prevent any moisture from seeping in. I created a block that would hold the extrusion bars (as depicted).

Internal Body: The internal body is somewhat complex due to the specific requirements of the motor system within, and so this part was built with uncut metal that had been purchased off the shelf. Small adjustments in the design were made to accommodate the sort of metal that's available on the market, but nothing that had impact on the functionality or external design.

External Body: The issue with standard, off-the-shelf T-slot materials is that they are typically in a single row and rarely available with more than a few slots in a grouping. No manufacturing companies offer T-slots with enough niches in a single group so, therefore, I created the body with multiple rows of T-slots from scratch.

Predictably, the customized manufacturing of these materials was time consuming but necessary.

Assembly

Assembly took place in phases, beginning with the construction of Bruce's aluminum frame and followed by the motor and gear assemblies. These, in particular, took a lot of time. The double axles were attached after, and the aluminum plates planned for the body were replaced with wood (for cost reasons). The control system was finally installed at the rear of the body.

Bruce: The Multi-Purpose, Personal Robot

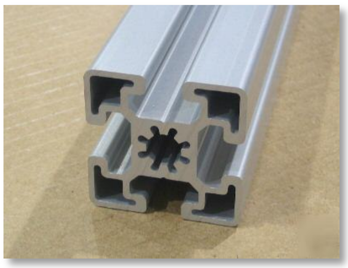
Image of Bruce, Final Stage of the Thesis Project

Design and Function

In this section, I will explain in some detail about the functionality of each of Bruce's components and explain the reasoning behind the design choices.

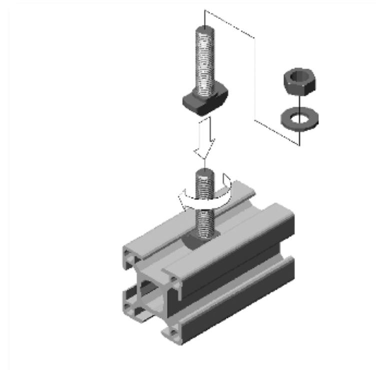
T-Slot system

According to the website Tooling (www.toolingu.com), a T-Slot is "a T-shaped opening that runs the length of a machine table. T-slots enable machinists to clamp vises and other work-holding components onto the table". Essentially, T-Slots are niches (recessed slots) that are designed to "receive the square head of a T-slot bolt" (www.answers.com).



T-slot niche
(www.parts-recycling.com)

Bolt fastened into the T-slot
(www.darlex.com)



How to attach a bolt
to the T-slot
(www.infraredheaters.com)

Bruce's design uses a modified T-slot system. Niches, shaped like upside down "Ts" (depicted above) are in evenly spaced parallel lines along the top and sides of the robot. This allows the head of a bolt to anchor into the niche at the desired area, providing a way to fasten an object to the bolt. The multiple T-slots will provide the user with the flexibility of mounting an object almost anywhere on Bruce's surface.

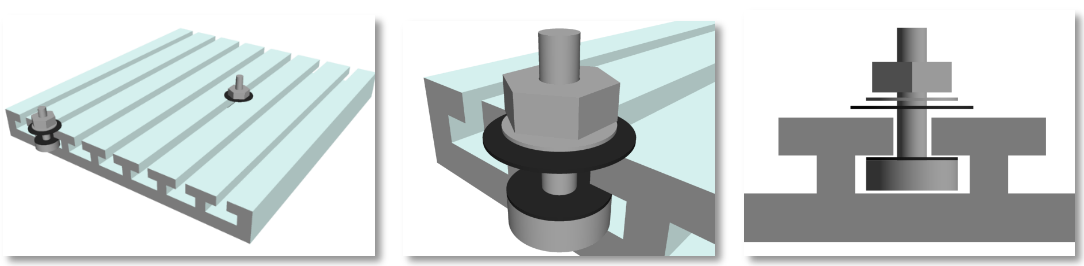


Image of T-Slot Plate

Double Axles

Double axles are made of a set of 2 axles: one narrow axle which protrudes from another, larger axle in the same direction. As one is nested in the other, this allows them to move independently of each other.

Bruce's double axles are designed to allow a wide range of objects to be mounted to them. The wheels are typically attached to the inner axles, leaving the second axle free for attachments and extensions. (see drawing below)

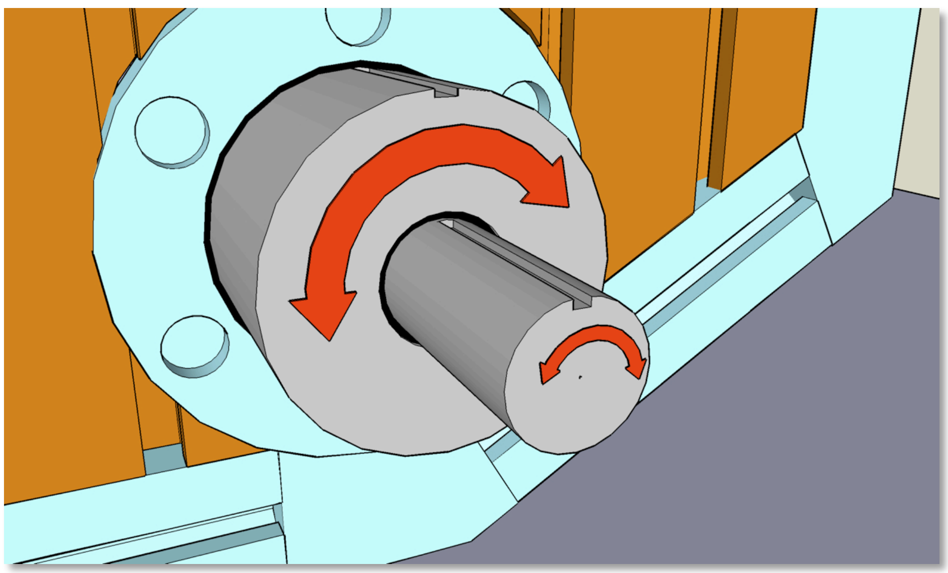


Image of double axles

There are endless possibilities of attachment functions, including:

- Lift or lower
- Optional steering wheel system
- Pull or push
- Act as a winch

Some examples of attachments and their applications:

- Extra wheels (extra control for difficult maneuvering)
    - Bulldozer
        - Use double axles to control bucket
    - Snow blower
        - Use double axles to turn the plow
        - Use double axles to lift and lower the plow
    - Fork lift
        - Use double axles to lift and lower the fork
        - Use double axles to tilt the lift backward

Control System

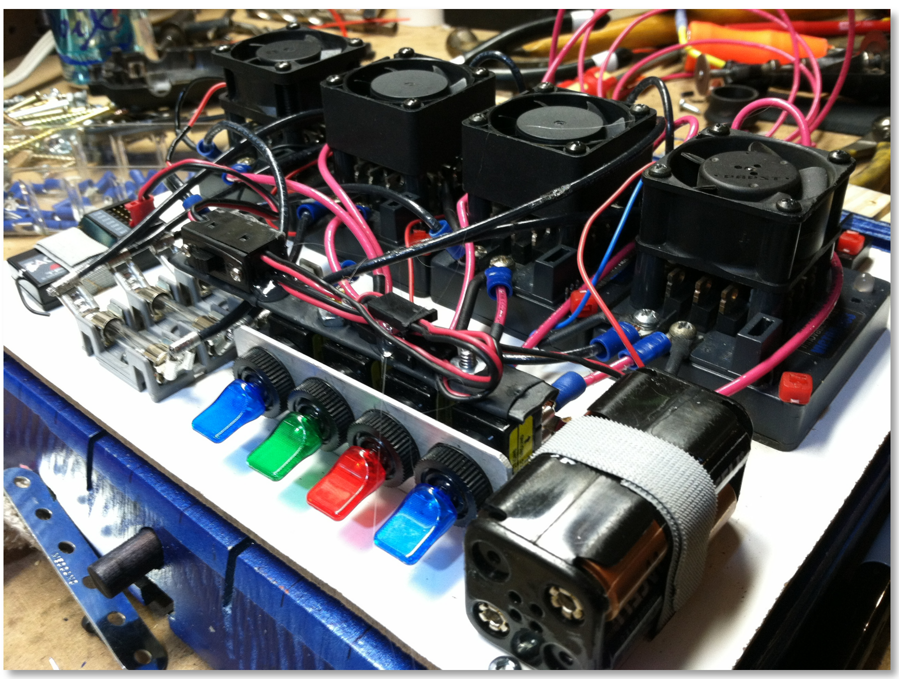
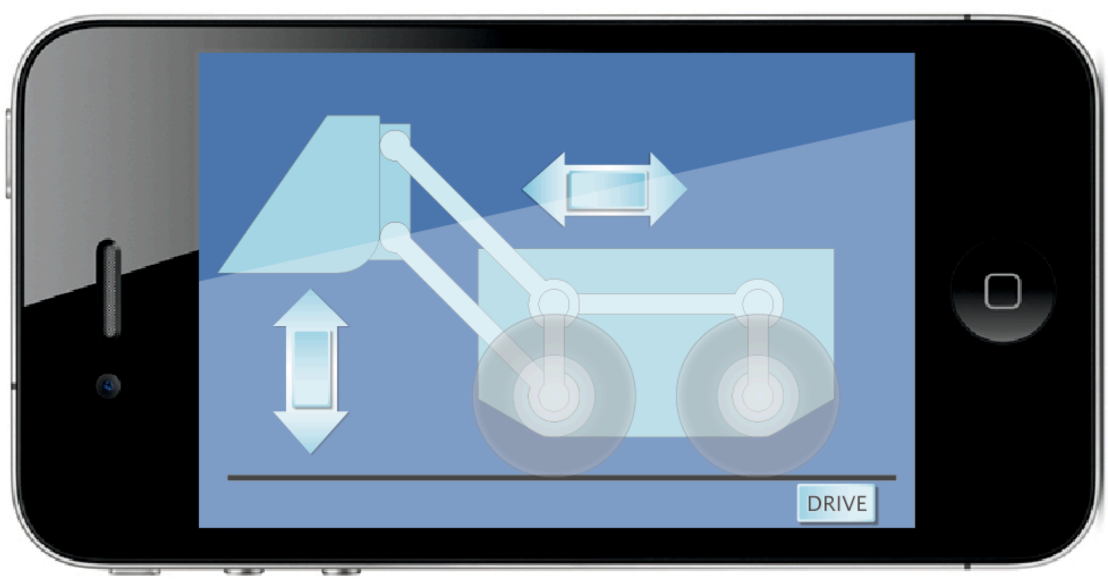


Image of Control Circuit

As mentioned elsewhere, Bruce's control system is electronic and allows the user to customize the behavior of the robot based on manipulation of software code. There are a variety of ways to have Bruce follow tasks assigned by the user:

- Remote control with a dedicated controller device akin to those hobbyists use for remote model cars and airplanes
- Automatic decision-making, i.e. goes forward until meeting an inanimate object and then turns, or stops at the edge of a stair or curb
- Pre-programmed paths, i.e. forward 10', turn left 45º, forward 15, stop, etc.
- Control from a dedicated app on a mobile device such as an iPhone, which can be done over Wifi. The device can also potentially monitor a camera that's been installed on Bruce while, at the same time, directing its movement.



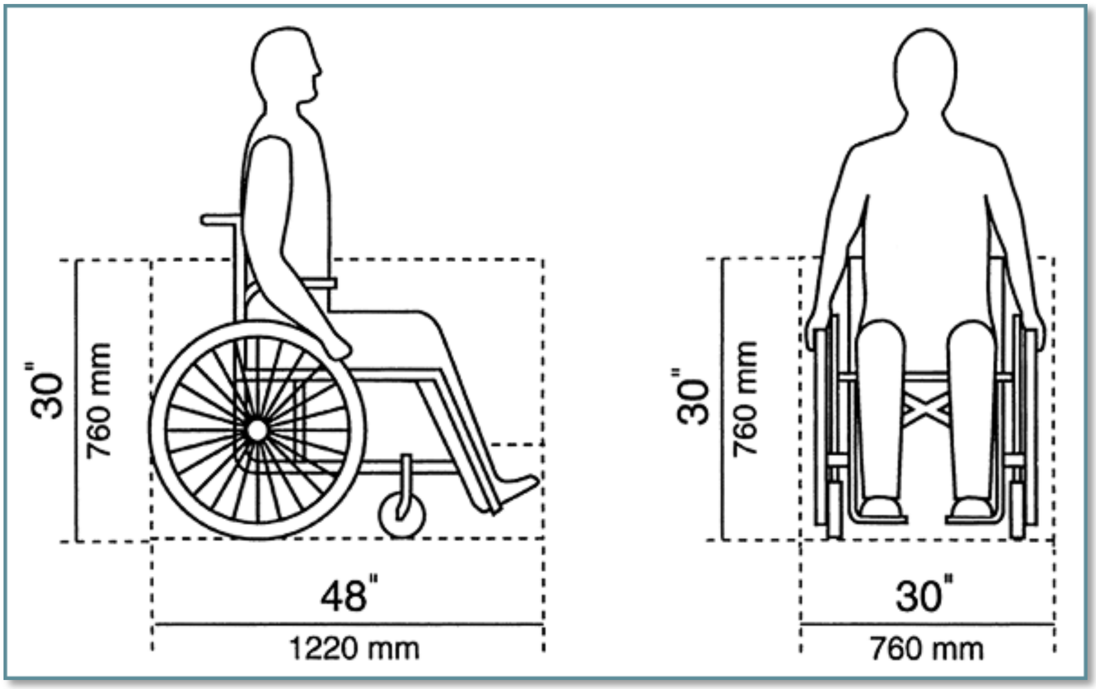
Concept Image of iPhone Intuitive Control

www.wirc.dension.com

- Long distance control via PC on an internet connection can be helpful for performing certain tasks from a distance such as pet care and feeding or monitoring home security.
- There’s even potential for more advanced control mechanisms such as integration with assistive devices used by quadriplegic consumers.

Dimensions

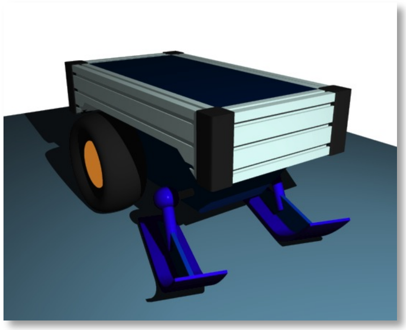
Dimensions similar to those of a wheelchair, easy access (ramp, doorway, elevator, van/car)



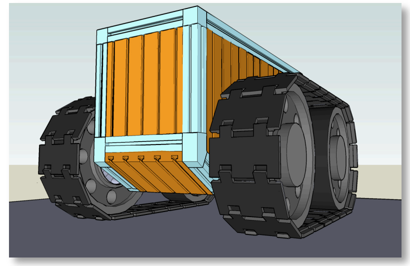
- Geometrically basic body for attachments purpose

Wheels

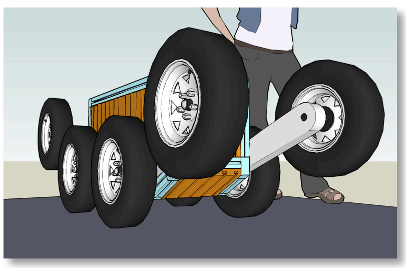
- 16" maximum size on the standard robot
- Options for different types of wheels for different uses



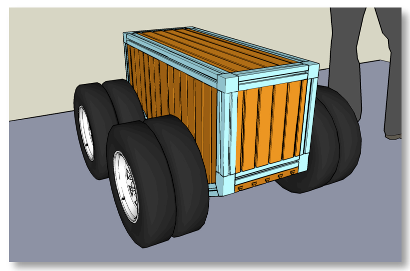
Ski, with option of using rear track drive



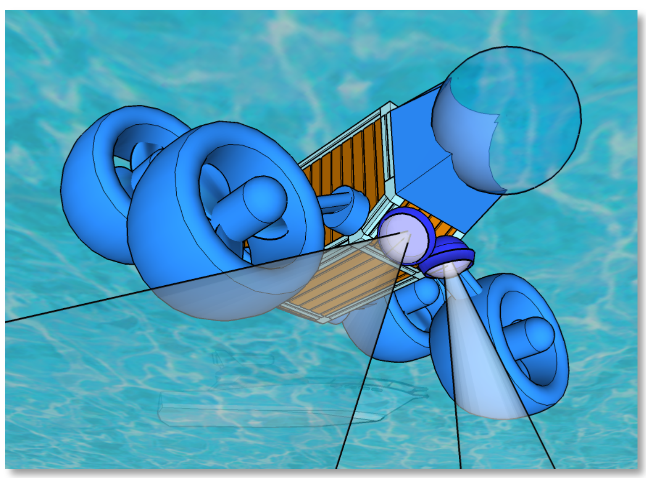
Simple Track Drive



With pivot arms
(ideal for climbing up and down stairs)



Double wheels for reduced traction surface

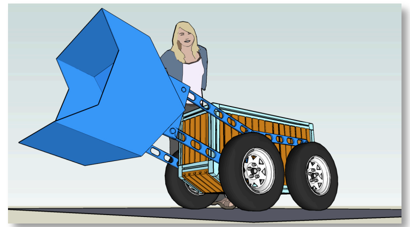


For experimental purposes

Underwater propulsion. Use narrow axle to turn the propeller, large axle to steer

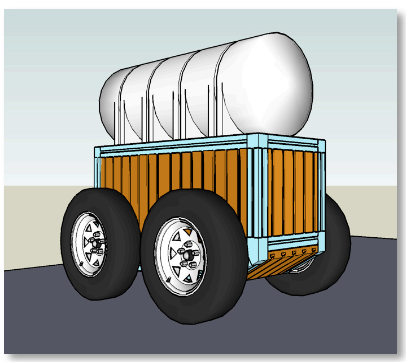
<u>Attachments</u>

- Flatbed surface
- Carry hay bales
- Shovel Bucket



Carry loads of small objects

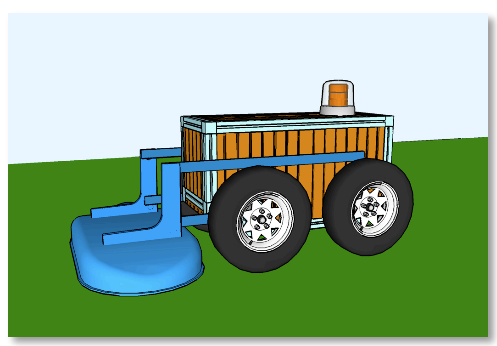
- Soil
- Sand
- Rocks
- Tools
- Fork Lift for lifting furniture



Liquid Tank

- Carry water
- Carry sprayed liquids (e.g. pesticides for farm)

Lawn Mower



Marketing

Due to its flexibility and customization, Bruce's target audience is potentially quite broad. Though few consumers have exactly the same list of needs and tasks that require doing, almost every consumer has a use for this sort of robotic technology.

The Elderly: As physical mobility diminishes with age, the elderly often face a distinct challenge in completing simple tasks that they need to do in order to live comfortably and safely. A fear of losing pride and dignity can sometimes result in seniors trying to attempt physically demanding jobs which are beyond them, often resulting in injury. Bruce can take away the burden of carrying heavy items or having to perform tasks such as clearing snow or moving soil as well as simple home security for which Bruce can be used to check locked doors and windows.

Farmers: Farmers typically require heavy work to be done all year long, and the work often is comprised of repetitive and demanding physical labor. Despite the archetype of the farming family still being a reality in much of the world, many farmers have to work completely alone. Again, Bruce's ability to move heavy items as well as its adaptability to outdoor terrain could potentially make it an ideal choice to aid in these kinds of work:

- Caring for crops
    - Weeding
    - Planting
    - Watering
    - Spraying pesticides
- Caring for livestock
    - Feeding
    - Monitoring

- Carrying large and/or heavy loads
  - Hay bales
  - Feed
  - Seed

Urban/Suburban Residents: Those who live in cities or outlying areas often find themselves too busy to complete some of the simple home maintenance that's required for comfortable living, such as yard work or housecleaning. Having Bruce take care of these chores not only frees up time, but also helps with regard to physical exertion, as is the case for almost anyone who uses it:

- Outdoor/yard tasks
  - Lawn mowing
  - Gardening (tilling, raking)
  - Snow clearing
- Lift, push or pull heavy items
  - garden equipment (bags of soil)
  - Perform dangerous maneuver
    - Pull wild branches log
    - Go or cut through pricked plants
- Work in extremely hot or cold climates

Bruce's adaptability lends itself to almost any living situation. For example, Bruce's programming could be wirelessly integrated with thermostat/temperature sensors in a home to ascertain whether or not snow may fall. It can even be programmed to equip itself with a snow blower and undertake the task of clearing a driveway before the home owner even wakes up in the morning.

Disabled people: People who are quadriplegic, physically challenged, or blind can be empowered to live safely and comfortably on their own or to complete daily tasks with the help of robotic technologies.

With right control and customized system, almost any disabled person could design their own “chores” without needing an external party to come into their home. The blind can employ Bruce as a “seeing eye dog” that guides them through the use of programmable waypoints or GPS to a specific destination (it can even be fitted with sensors to detect things like puddles and icy patches on a sidewalk). Bruce can also carry a price scanner to assist the blind in shopping or a camera that can analyze terrain and warn the owner of what’s on the path ahead.

Accessibility to the Consumer Market

To market Bruce and associated technology will require outreach to [the] many populations (both the special demographics mentioned in this thesis, but also the typical able-bodied consumer). The cost of purchasing Bruce at this time will be very high for the average household, and perhaps prohibitive for the time being. What will help to bridge this gap will be if Bruce is accepted by a mass audience, thus allowing for the economy of scale to take hold and individual component prices to come down. To make Bruce more attractive to the target demographics, it would be vital to demonstrate that rentals or payment plans can be set up. This is very common for other types of simple technology such as snow blowers, so it’s not at all out of the question for Bruce.

It’s also possible to create a service industry around Bruce, where a business owner could rent time to operate Bruce with a specific code set to help consumers accomplish certain jobs on their property.

Future Plans

It would be interesting to see the development of a community made up of both hardware and software specialists working and discussing to exploit Bruce's potential and configure custom code sets and extension devices. The programmability of Bruce's software would be best served as an open source project, thus inviting brilliant minds world-wide to contribute to and improve upon the stock code. Clever formulas of code can be shared over the internet, thus giving users access to pre-made templates and scripts that could be modified and tweaked to suit their own needs.

Going even further, Bruce "Service Stations" could be designed to work on, maintain and extensively customize an individual's Bruce robot. This could free owners from the burden of having to upgrade, recharge, repair or replace parts. Not unlike an automobile garage/shop, equipment and licensed professionals would be on-hand to aid in the care and maintenance of the user's investment. Service could even be used as a marketing tool by including a certain amount of labor (either a time or dollar value) with the purchase of Bruce itself.

Conclusions

"Life is a journey, not a destination."— Ralph Waldo Emerson

The most exciting part of developing this concept in an academic context was the intensive learning. This is what made a large project such as this one so appealing, and it forced me into conceiving, designing and building something that I would not have been pushed to complete otherwise.

It is my hope that Bruce can serve a purpose in closing the gaps people experience in their daily lives and increases their comfort and ease.

The design and creation of Bruce has been in production for a very long time and, since the beginning, I have come to learn a great deal about other organizations and companies who offer excellent computer-controlled mechanical solutions. I have considered partnering with such an organization in order to leapfrog the step-by-step processes of experimenting and funding. I don't regret the I took, however, as the learning I've been afforded was invaluable and my intimate experience with the developing technology of robotics is a quality that distinguishes me now from the rank and file.

When Bruce was finally assembled and I saw what I'd created having started only with my dreams, I felt a great awe at the process of bringing vision to reality.

If my wishes come to pass, others will use Bruce as a springboard to make the same journey.