Constructing Robots for Undergraduate Projects Using Commodity Aluminum Build Systems

John Seng

California Polytechnic State University, San Luis Obispo, CA 93407, USA,
jseng@calpoly.edu,
WWW home page: https://www.csc.calpoly.edu/~jseng

Abstract. In this paper, we outline our experiences constructing two robots for undergraduate student projects using different commodity aluminum construction systems, Actobotics and goBilda. These building systems have gained popularity for use in high school robotics competitions. For our work, we adopt these modular build systems to construct robots used for undergraduate projects and as research robots. These building systems provide aluminum components that can be used to construct robot chassis and have the benefit of being reusable. We evaluate the benefits and drawbacks of each system. In addition to the evaluation of the construction systems used, we outline integration of embedded computers running ROS and the characteristics of each system.

Keywords: aluminum construction system, Actobotics, goBilda, undergraduate robotics projects

1 Introduction

Robotics education in the college classroom environment can take shape in many forms, including: using small robots in a class, having students participate in large scale team projects, or using virtual environment simulators. In the first example, there is much students can learn from smaller scale robots (i.e. Arduino-powered designs), but students may be missing out on larger system integration issues and may be needing more compute capability. When working on a large scale team project, such as a group of students working on an autonomous car, students may encounter system level engineering issues, but may become pigeonholed into the area of the project they are working on. In the last example of a simulation environment, students may be missing the hands-on aspect that many students appreciate when working in the field of robotics.

In our work, we focus on the area of what we categorize as medium-sized robots (i.e. microwave oven-sized) which have a single Linux computer for compute that is coupled with several other sensors (e.g. cameras, lidar). Having medium-sized robots available for undergraduate students to work on as projects can be very effective in improving student learning and can expose them to many software, mechanical, and electrical issues that they may encounter when working on an engineering project in their future careers.

Commercial research robots in the university environment can often be expensive and not very configurable if research needs change over time. In this work, we discuss the use of commodity aluminum build systems (ones that are often marketed towards high school robotics competitions) and our experience in utilizing such systems for undergraduate projects, along with the computer systems used in the robots.

We have used these modern aluminum build systems to construct two generations of project robots that we call Herbie 1 and Herbie 2. These robots are used at our university as a foundation for student projects and for undergraduate research. The robots use different build systems and we outline the differences between the systems.

In this paper, we will describe the robot designs in parallel and cover the various design aspects of each robot. This work focuses on robots that are not intended to be duplicated for multiple student groups in a classroom setting. That is completely possible with our work, but it is currently not viable in our university's educational environment and budget. Instead, our robots are used as development platforms for senior design projects where a few students work on particular aspect of the robot at a time.

This paper is organized as follows: Section 2 outlines prior work that is related and relevant to this project. Section 3 outlines the construction systems used in the robot designs and covers the benefits and drawbacks of using the systems in an undergraduate student environment. Section 4 describes the compute hardware and software used on the Herbie robots. Section 5 covers the experience gained from utilizing these robots. Section 6 concludes.

2 Related Work

Aside from the construction systems that are discussed in our work, there are a number of other modular aluminum construction systems that are available on the market. Some of these include Tetrix Max[12], Rev Robotics[13] channel and extrusion, and the Andy Mark S3 system[14]. The Tetrix Max system by Pitsco Education is very similar to the construction systems that we utilize. The system consists of aluminum channel and provides flexibility in motor mounting. The channel design offered by Rev Robotics has the unique feature of having slots to allow easy slide mounting of brackets in a manner similar to a T-slot. The S3 system by Andy Mark provides a custom box aluminum extrusion for building structures. We find that all 3 related systems target FTC (FIRST Tech Challenge) contestants on their respective web sites. For our work, we selected the Actobotics[2] system and the goBilda[3] system based on their merits, academic discount pricing, and market availability.

One research robot that utilizes the Actobotics construction system is a snake robot developed by Dear et al [6]. The authors use U-channel as the body of the snake and utilize servos to actuate the locomotion of the robot. In that work, the authors studied snake robot locomotion when motion constraints are placed at each segment of the robot. Work by Ray et al. [7] uses an Actobotics gripper

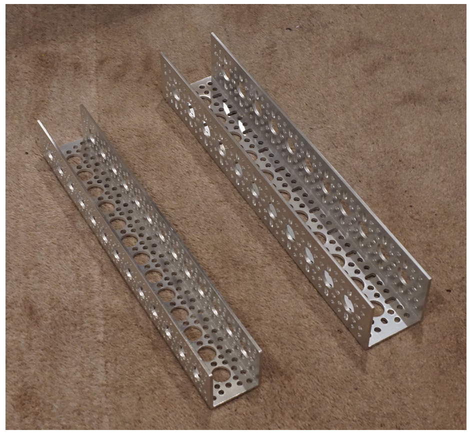

Fig. 1. Photograph of Actobotics (on the left) and goBilda channel (on the right). The channel is U-shaped with regularly spaced larger holes for mounting bearings and axles. The smaller holes can be used for fastening brackets and other connectors.

to implement techniques to efficiently detangle salad from plant material. These works focus primarily on using the Actobotics components for research work and not in the educational domain.

Ramos et al.[8] describe an open source platform that is designed for teaching legged robot control in a classroom environment. The hardware structure they present is constructed using the goBilda system.

3 Commodity Construction Systems

In recent years, reconfigurable metal construction systems have become popular in the educational robotics community especially due to their use in high school robotics competitions such as FIRST robotics[1]. Because the competition goals are different every year, high school teams competing in FIRST robotics need construction systems that allow rapid reconfiguration and in order to save cost, reusability. These competitions typically involve having the robots move and grasp objects while driving very quickly under human remote control. Several companies have emerged to cater to the needs of educators and students to support the construction of these competition robots.

The component systems that we describe in our work may seem similar to other metal-based construction systems (such as Erector[10] or VEX[11]), but we find a number of advantages with the systems we utilize, Actobotics and goBilda. The construction systems we evaluate provide some variation of metal U-shaped channel as long structural members that allow ball-bearings and axles to be placed at various locations within the channel. In Figure 1, we show Actobotics and goBilda channel side-by-side.

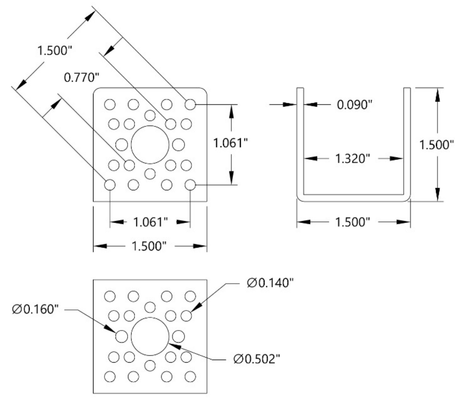

Fig. 2. Diagram of Actobotics pattern spacing. The larger center hole is for mounting ball bearings and the smaller holes can be used for brackets and connectors. Image used with permission[4].

In our work, we utilize two construction systems and discuss their suitability to building robots for university-level student projects and research. These build systems are produced by the same parent company and we outline the differences between the systems. We are not affiliated with the parent company and have selected these build systems on their merits.

3.1 Actobotics

Actobotics is a build system based on the Imperial measurement system. The structural components of the Actobotics system are fastened together using 6-32 screws. These size screws are sold in various lengths and are sufficient for the robot size we are using (approximately 10 pounds total weight).

The primary structural component of the Actobotics system is U-channel which has a 1.5" square U-shaped cross section (open on one side), with holes drilled as shown in Figure 2. The channel comes in lengths based on the number of holes in the channel (e.g. 3 hole, 5 hole, 7 hole).

Figure 2 shows the layout of holes in Actobotics channel. In the Actobotics build system, the main holes are .502" in diameter and are intended to house 0.5" flanged ball bearings and allow axles (commonly sized to 1/4" diameter) to pass through. One significant feature of both of these build systems is the ability to utilize ball bearings in various locations of a robot build. The flange on the ball bearing allows it to be easily fitted from one side of the channel while having the flange prevent the bearing from falling through.

Surrounding the 0.502" primary hole are 8 smaller holes that allow a 6-32 bolt to pass through. These 8 holes are not threaded and allow beams and bracket to be connected when the connecting holes are spaced .770" apart. The 8 holes allow mounting items conveniently at a 45 degree angle to the U-channel. U-

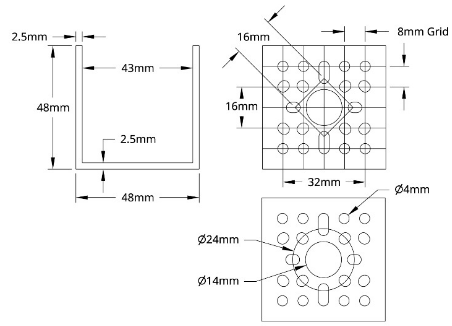

Fig. 3. Diagram of goBilda pattern spacing. Holes are drilled on an 8mm grid pattern. Image used with permission[5].

channel on its own, does not provide the strength that an equivalently sized square tubing provides. To create a strong channel similar to square tubing, spacers can be installed to close the end of the U-channel. One item that we observed is that the corners of Actobotics channel has a chamfered radius which removes the sharp corner of the aluminum. This radiused corner is not present in the goBilda system described in the next section.

In addition to the U-channel, another structural member that we find very convenient to use are the Actobotics structural beams. Beams are a straight aluminum component with regularly spaced drilled holes. These beams can easily be fastened to U-channel and provide a way to support loose cables and mount other types of cabling strain relief.

For the drivetrain, we use a direct drive system using 37mm 12V gearmotors. The Actobotics system has a few different mounting options for this diameter motor and we select a mount that clamped around the motor. There were no issues with motors slipping in this clamping mount.

The Herbie 1 wheels are 6” wheels with a rubberized tread and they connect to the 6mm motor shaft using an Actobotics hub for 6mm D-shafting. The primary drive surface is outdoor concrete sidewalk. The motors provide approximately 300 oz-in of torque and there was no problem in moving the robot using these motors.

3.2 goBilda

The Herbie 1 robot is constructed entirely using the Actobotics build system and there was a significant investment in the system. At the time of the design of Herbie 2, the goBilda system had just become available and there were a number of advantages to the build system and those advantages were significant enough to consider investment in the newer system.

One of the main differentiators of the goBilda build system is that the system is completely metric. All bolt lengths, channel lengths, and hole spacings are specified in millimeters. Although this fact in itself was not a primary reason to move to the build system, one benefit is that the system was designed to use M3 metric screws. The larger diameter M3 screws were a better design choice for the size of the Herbie 2 robot to be constructed.

A second advantage of the goBilda system is that the standard channel is larger. The exterior dimensions of the square U-channel is 48mm with the interior dimensions being 43mm. This increased size allows motors to fit inside the channel to produce a very compact right-angle drivetrain. Because Herbie 1 and Herbie 2 needed to pass through doorways, robot width was always an important design constraint. The right angle drivetrain allows the robot width to not be limited by the length of the drive motors. The goBilda system provides many different wheel options, but for Herbie 2 it was determined that a larger wheel diameter was required. 8" pneumatic kick-scooter wheels were found to be suitable and they worked with an 8mm axle that is available in goBilda.

As shown in Figure 3, the main center hole for bearings in 14mm. This hole is surrounded by 4mm holes arranged on an 8mm grid. The grid allows components to be connected in several locations and the holes at the corners surround the 14mm hole are enlarged to match a 16mm grid spacing when connecting items at 45 degrees.

3.3 Comparison

While both build systems provide similar functionality, the ability to place drive motors inside U-channel provided a significant advantage for our application in Herbie 2. If there were no width requirement for our particular application, Actobotics would have served just as well in terms of drivetrain capabilities for the second generation design.

The standard grid spacing of goBilda was very useful when designing the sensor mounts for Herbie 2. Several of the sensor brackets are 3-D printed with 8mm holes spaced to match goBilda and this allowed the sensor positions to be easily modified on the robot when necessary. We have found that because some of our sensors and components are sourced from international companies, the metric spacing of the goBilda has proven to be advantageous.

Both Actobotics and goBilda provide a variety of mounts and channel connectors. There are various mounts to hold DC motors to U-channel and also various patterned mounts which have drilled out holes to match the spacing pattern of the channel.

In terms of additional structural components, both systems provide extruded aluminum rail (similar to 80/20 aluminum extrusion[15], but matching the respective channel hole spacing). This extruded railing allows infinite adjustment of bracket mounting positions. Additionally, both systems provide timing belts and chain for power transmission. At this time, we have not utilized these components for drivetrain design.

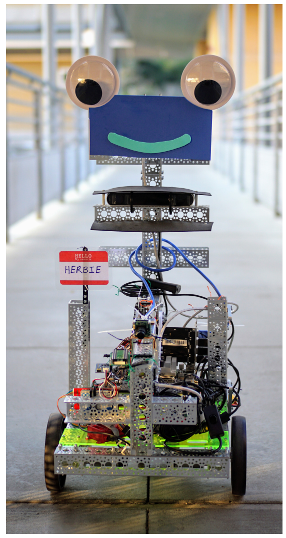

Fig. 4. Photograph of Herbie 1. Herbie 1 is constructed using Actobotics components and uses an NVIDIA TX2 board for compute. The robot is 15" (380mm) wide and 32" (812mm) tall.

4 Compute Hardware and Sensors

In this section, we describe the compute hardware on the robots as well as the sensor systems.

4.1 Embedded Computers

For both robots, it was important to be able use the ROS operating system running on top of a standard Linux distribution. We selected two computer boards from the NVIDIA Jetson line of boards. These boards have multiple ARM cores along with an NVIDIA GPU for neural network inference. Power consumption is a very important metric and the boards we use can run while using approximately 10-15 watts of power. This allows the robots to be powered with a 4S Lipo 6000mAh battery that is commonly available.

For Herbie 1, we use the NVIDIA Jetson TX2, which comes in a Mini-ITX motherboard form factor. Because the Mini-ITX hole spacing does not align with the Actobotics standard hole spacing, we use a lasercut acrylic sheet as an adapter plate to mount the Jetson TX2 to the Actobotics frame. We use an external SSD for data storage.

In terms of support electronics, we use an Arduino Uno for reading motor encoder counts and an additional USB dual motor controller to handle driving the two drive motors. A picture of a completed Herbie 1 is shown in Figure 4.

On Herbie 2, we looked to use an upgraded computer and selected the NVIDIA Jetson AGX Xavier which also comes in a smaller 105mm x 105mm

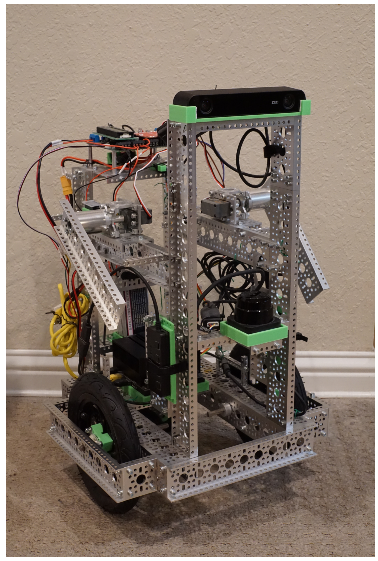

Fig. 5. Photograph of Herbie 2. Herbie 2 is constructed using components from the goBilda construction system. The robot is 15” (380mm) wide and 23” (585mm) tall.

square footprint. Because of the smaller footprint, we use a 3-D printed mounting bracket to hold the AGX Xavier board. The Jetson Xavier provides support for an M.2 SSD and that is used to hold additional data and record video. For low level control, the Arduino Uno is replaced by a Sparkfun Redboard Turbo[16]. A picture of Herbie 2 under development is shown in Figure 5.

4.2 Sensors and Software

The sensor set for both robots is similar with some slight upgrades as available. Because the batteries of both robots are relatively small (4S Lipo 6000mAh), there is a limitation on the number of sensors that can be on-board.

For camera input, both robots use the ZED stereo camera with Herbie 1 using the original ZED camera and Herbie 2 using the ZED 2. These cameras provide a depth map which is computed using the on-board GPU of the NVIDIA boards.

For Herbie 2, we add an additional 2-D laser scanner for obstacle detection and for building maps. For both robots, we have used the RTABMAP SLAM system [17]. This SLAM system allows for map building using visual input as well as with laser scanner input. RTABMAP has built-in support for ROS and supports several feature detection and matching techniques.

5 Experience

In this section, we outline two types of experience that we have obtained through the Herbie 1 and Herbie 2 projects. The first is our experience in using the modular construction systems. The second section describes student involvement in the projects.

5.1 Build System Experience

Our primary observation in using these build systems is that the ability to reconfigure the structure of a robot has provided a tremendous advantage. The determination of the appropriate width and height of the robot has been a trial and error process and the ability to quickly rebuild the chassis has saved time on a number of construction iterations. In addition, because of the large number of holes drilled into each segment of U-channel, it is easy to quickly adjust the position of a sensor or to adjust the position of a motor to change weight distribution.

One our the initial concerns when running the robots was the problem of fasteners coming loose during the testing and operation of these undergraduate project robots. We have found that this has not been an issue even during our outdoor operation of these robots on concrete sidewalks. The strength of our robot structures has not been a concern either. Even though the U-channel of both systems is not inherently as strong as a boxed square tube, with the addition of the correct type of standoffs and spacers, the structure can be just as rigid.

A primary reason for using these build systems to construct our robots has been the potential to save on costs over the long term when rebuilding robots from one design to the next. Because the robots are built using two different construction systems, we were not able to see cost savings in transitioning from Herbie 1 to Herbie 2, but we believe that for future robot designs, we will not need to invest in a new construction system. We think that this is the greatest benefit of using a modular system for an undergraduate project robot.

5.2 Student Experience

Initially, the preliminary robot was designed by a faculty member and one computer engineering student as part of an independent study project. This preliminary design of a robot involved selecting the construction system and it was through this process that the Actobotics build system was selected. During this initial design phase, an NVIDIA embedded controller board was chosen and the design required a custom mounting plate for the controller. It was at this point that it was decided that the robot project as a whole would make a good platform for undergraduate students. During this process, the student was exposed to the overall design process involving selecting components, budgeting, and software development. Although this was a greatly beneficial educational experience limited to a student, this type of experience would be difficult to duplicate in a classroom environment.

A second set of undergraduate students who worked on Herbie 1 were focused on adding audio capabilities to the robot. Instead of using the on board audio of the computer, the project revolved around making an external audio interface that could be remotely activated even when the main computer was not active. This exposed the students to the challenges of low power electronics and wireless communication.

Because of the reconfigurable nature of the robots, we found that students were inclined to make suggestions on the design of the robot in terms of drivetrain and sensor placement. We believe that if we had used a pre-built robot design students would possibly have felt more restricted during their development process.

For the Herbie 2 design, one of the advantages of the upgraded computer was that groups of students could develop machine learning models in order to classify various obstacles that the robot may encounter. Students have developed a process infrastructure to manage training images and to use that data to develop machine learning models built around the Efficientnet architecture[18]. This infrastructure will be greatly beneficial to the groups of future students who will be working on building additional machine learning models.

Overall, we have observed that the construction of the two robots has been a successful approach to providing upper level undergraduate students with platforms that serve as a basis for their design work. Although the robots are not completely suitable for use in a classroom environment because we are not able to construct several in parallel, there is enough engineering work required that small student teams can work on implementing various capabilities. This does require more coordination and management in terms of faculty involvement, but robotics projects such as these requires close involvement in order to maintain continuity through the lifespan of the robot design.

6 Conclusion

In this work, we describe the construction of two robots for undergraduate student projects: Herbie 1 and Herbie 2. Instead of purchasing pre-built robot chassis designs, the structures for these robots are constructed using Actobotics and goBilda. These are two commodity aluminum build systems that are commonly used in high school FIRST robotics competitions. We find these build systems to be robust, reconfigurable, and reusable - all characteristics needed for developing robots for undergraduate student projects and research. The build systems provide the ability to quickly construct a stable platform for carrying embedded computers, sensors, and batteries.

Throughout the development of these robots, we have incorporated undergraduate student work through various projects. Some students have been involved in designing the chassis itself while other students have been a part of adding various features (mechanical, electrical, and software) to the robots. In addition, students have been involved in developing software infrastructure to enable future groups to develop machine learning models to enhance robot capabilities.

References

1. Burack, C., Melchior, A., Hoover, M.: Do After-School Robotics Programs Expand the Pipeline into STEM Majors in College? Journal of Pre-College Engineering Education Research 9:2 (2019) pp 1-13
2. Actobotics. https://www.servocity.com/actobotics
3. goBilda. https://www.gobilda.com
4. Actobotics Pattern. https://cdn11.bigcommerce.com/s-tnsp6i3ma6/images/stencil/original/products/3671/21044/585440-Schematic__02283.1583537050.png?c=2
5. goBilda Pattern. https://cdn11.bigcommerce.com/s-eem7ijc77k/images/stencil/original/products/846/27263/1120-0001-0048-Schematic__02571.1605298181.png?c=2
6. Dear, T., Buchanan, B., Abrajan-Guerrero, R., Kelly, S., Travers, M., Choset, H.: Locomotion of a multi-link non-holonomic snake robot with passive joints. International Journal of Robotics Research (January 2020), Vol.39, Issue 5, pp 598-616
7. Ray, P., Howard, M.: Robotic Untangling of Herbs and Salads with Parallel Grippers. International Conference on Intelligent Robots and Systems (2020)
8. Ramos, J., Ding, Y., Sim, Y., Murphy, K., Block, D.: HOPPY: An open-source and low-cost kit for dynamic robotics education, https://arxiv.org/pdf/2010.14580.pdf
9. NVIDIA Robotics Teaching Kit. https://developer.nvidia.com/teaching-kits
10. Erector by Meccano. http://www.meccano.com/products
11. VEX Robotics. https://vexrobotics.com
12. Tetrix Robotics. https://www.pitsco.com/Shop/TETRIX-Robotics
13. REV Robotics. https://www.revrobotics.com/
14. Andy Mark S3 Tubing. https://www.andymark.com/products/s3-tubing-options
15. 80/20 T-Slot Aluminum Building System. https://8020.net/
16. Sparkfun Redboard Turbo. https://www.sparkfun.com/products/14812
17. Labbe, M., Michaud, F.: RTAB-Map as an Open-Source Lidar and Visual SLAM Library for Large-Scale and Long-Term Online Operation, in Journal of Field Robotics, vol. 36, no. 2, pp. 416-446, 2019.
18. Tan, M., Le, Q.: EfficientNet: Rethinking Model Scaling for Convolutional Neural Networks, In International Conference on Machine Learning 2019