PRELIMINARY DESIGN AND EVALUATION OF AN OVERHEAD KITCHEN ROBOT APPLIANCE

by

Joshua Solomon Telson

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This thesis was presented

by

Joshua Solomon Telson

It was defended on

July 29, 2013

and approved by

Dr. Rory Cooper PhD, FISA/PVA, Distinguished Professor and Chair, Department of Rehabilitation Science and Technology

Dr. Jonathan Pearlman PhD, Assistant Professor, Department of Rehabilitation Science and Technology

Annmarie Kelleher MS, OTR/L, ATP, CCRC, Clinical Instructor, Department of Rehabilitation Science and Technology

Thesis Director: Dr. Dan Ding PhD, Assistant Professor, Department of Rehabilitation Science and Technology

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Joshua Solomon Telson, MS

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Many older adults and individuals with disabilities have difficulty with reaching, grasping, and carrying items that are a necessity to perform independent activities of daily living, including meal preparation in the kitchen. Assistive robotic manipulators are starting to show potential for independent assistance through their use on wheelchairs or mobile bases, but continue to lack many of the autonomous features readily available with fixed environment manipulators. The KitchenBot design described here provides the details and approach to providing an assistive robotic manipulator access to an entire kitchen workspace by utilizing a multi-degree track. Numerous focus groups were conducted in conjunction with the design and major features like heavy payload ability, tablet control interface, and user feedback was extracted. With further development, the KitchenBot could perform an even longer list of routine autonomous tasks in a product viable for everyone to use.

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PREFACE

I would like to thank the University of Pittsburgh and the wonderful study participants, faculty, staff, and students at the Human Engineering Research Laboratories (HERL) for their support during this research. I would especially like to acknowledge my advisor Dr. Dan Ding for her guidance and support during my years. I would like to thank Emily Teodorski, Annmarie Kelleher, and Stacy Eckstein for their assistance with the many focus groups. Also, I would like to recognize the shop staff at HERL, which includes Mark McCartney, Josh Brown, Garrett Grindle, Zach Mason, Ben Gebrosky, and Dalton “Roadhouse” Relich for their effort and support during numerous roadblocks. Many thanks to Dr. Rory Cooper and Dr. Jonathan Pearlman who provided instrumental design input throughout the project and Mary Goldberg who exposed me this wonderful program and opportunity. Thank you to my parents, Lynn and Stan, and wonderful girlfriend Chelsea, for all the love and support. It’s been quite a ride.

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1.0 INTRODUCTION

Individuals with upper limb impairments due to injury, neuromuscular disease, or other severely physically disabling conditions often have difficulties in performing activities of daily living (ADLs) that require object handling and manipulation. Assistive robotic manipulators have emerged as a potential solution to mitigate the difficulties, frustration, and loss of independence experienced by these individuals (Allin, Eckel, Markham, & Brewer, 2010; Romer, Stuyt, & Peters, 2005). Assistive robotic manipulators today are usually wheelchair-mounted or on a mobile platform. While the wheelchair mounted assistive robotic manipulators have the capacity to accommodate unstructured environments and a large range of tasks, it increases the footprint of the wheelchair and is only suitable for those who use powered wheelchairs for mobility (Stanger, Anglin, Harwin, & Romilly, 1994). Mobile manipulators are flexible and could perform tasks independent from the user, but require complex sensing and planning, limiting their practical use (Srinivasa, Ferguson, & Vande, 2008). The third option involves mounting a manipulator into a fixed environment. The following will outline the design process and evaluation of an assistive robotic manipulator embedded into a living space with a dynamic track to broaden its work envelope. A kitchen was chosen because it is often referred to as the "*heart of the house*." Likewise, a survey of 42 individuals who had either limited or no upper limb ability showed that the kitchen was considered the best site for accommodating an assistive robotic manipulator (Stanger et al., 1994).

The project shows initial development of a robotic kitchen appliance (AKA: KitchenBot) for people with upper limb impairments by following a product design and development process. The KitchenBot is an assistive robotic manipulator that operates along an overhead track built into the kitchen. The known position of the assistive robotic manipulator with respect to various kitchen components, such as cabinets and appliances, makes it easy to control the manipulator manually and autonomously.

1.1 ASSISTIVE ROBOTS FOR MANIPULATION

1.1.1 Target population

In the 2010 U.S. Census, over 12.3 million (4.4 percent) people needed assistance with one or more activities of daily living or instrumental activities of daily living (IADLs), 19.9 million people (8.2 percent) had difficulty with tasks related to upper body function, and 17.2 million people (7.1 percent) reported difficulty lifting a 10-pound object like a bag of groceries (Brault, 2012). Also, about 1 in 10 adults aged 55 years and over have difficulty reaching (11%) or grasping (9.4%) with rates tripling between the ages of 55-64 years and 85 years and over (Schoenborn & Heyman, 2009). Likewise, about 1.1 million Americans have experienced serious upper extremity impairments, including those with quadriplegia, hemiplegia, and hemiparesis. Approximately half of those individuals with hemiplegia have a non-functional arm and hand even four years after a stroke (Broeks, Lankhorst, Rumping, & Prevo, 1999). Such functional limitations, which are required for interacting within a kitchen environment, can be caused by the natural progression of aging, a medical condition, or trauma. In a survey of 89 wheelchair users and 52 health care professionals, the ability to adequately reach for objects was rated as the most important concern (Holliday, Mihailidis, Rolfson, & Fernie, 2005).

Those individuals with upper limb impairments, or those who need assistance with ADLs or IADLs, generally require assistance from caregivers to complete common daily tasks. The world is intensely paying attention to the rise in population and growing population of older adults and people with disabilities (Kwang-hyun, Lee, & Bien, 2008). However, attendants and caregivers suffer from a shortage of resources while demand continues to increase, causing individuals to leave their homes for costly institutional settings simply for the benefit of receiving basic care (Feinberg, Wolkwitz, & Goldstein, 2006). In order to provide this basic care, improve privacy, and quality of life, without the need of an increased human caregiver workforce, assistive robotic manipulators are evolving to best serve individuals and ensure their current and future independence.

1.1.2 Forms of assistive manipulators

In the past 50 years, nearly a dozen manipulators have been advanced and considered for their performance in usability and functionality but only few commercialized assistive robotic manipulators are on the market (Chung, Wang, & Cooper, 2013). Moreover, the advancement of robotic manipulators and hands have made applications such as telerobotics or upper limb prosthetics possible (Pons, Ceres, & Pfeiffer, 1999). Numerous research endeavors seek to improve this market for assistive robotic manipulators by demonstrating varied design solutions. Traditionally, these robotic manipulators have been placed on a mobile base, mounted on power wheelchairs, or installed in fixed environment locations.

1.1.2.1 Mobile-based assistive manipulators

Several research initiatives seek to provide a mobile assistive robotic solution. One example is the Home Exploring Robotic Butler (HERB) developed at Carnegie Mellon University, which focuses on providing mobile-based dual manipulators with intelligent control software capable of detecting objects, planning grasp methods, and navigating environments (Srinivasa et al., 2009). Development of the system is still progressing but HERB can already perform tasks such as carrying pitchers, getting a pack of chips, sorting dishes, and fetching drinks. User evaluations are still to be conducted as the development continues to advance. Another research group proposed a service robot which acts as an agent between a user and their complex home environment by providing basic interaction and repeatable learning ability via its dual robotic arms and mobile base (Z. Z. Bien et al., 2007; Kwang-hyun et al., 2008). It provides interaction and learning by recognizing key emotion words on which to operate. Although untested with users, a different team has developed a service robot that learns from a sensor equipped kitchen, such as RFID tags, light and temperature sensors, and capacitive sensors, to perform tasks with its dual robotic arms (Rusu, Gerkey, & Beetz, 2008). A system such as these could grip and transport a cup of tea, milk, and coffee and could supplement for some deprived functions (Stoian, Nitulescu, & Pana, 2009). The robot EL-E is an assistive mobile manipulator developed at Georgia Tech that aims to help people with motor impairments to retrieve lightweight items from ground level to 90 [cm] above the ground. Users can control the EL-E using either a laser pointer or touch screen for object retrieval and the test was able to successfully demonstrate retrieval of 21/25 objects ranked most important by ALS patients (Jain & Kemp, 2009). Even humanoid robots would fall into this category of mobile-based robots, such as ASIMO, PR2, or HRP-2, which are mainly for demonstration purposes but could eventually assist the elderly or wheelchair users (Graf & Staab, 2009). The Personal Robot 2 (PR2) developed by Willow Garage was used in a study of independent living seniors to gain information regarding their preference of tasks performed by a robot or human. The study results showed the highest preferred robot tasks should be maintaining the lawn, fetching objects from the floor, moving heavy items, cleaning the kitchen, and reaching for items. Additionally, their data suggests that older adults would be most accepting of a mobile robot if it was performing household or manual labor tasks (Mitzner et al., n.d.).

The benefit of mobile manipulators is the their ability to go in different environments. While the potential benefits of these devices are impressive, the drawbacks to mobile robotic systems is the complexity needed to perform navigation, mapping, and sophisticated trajectory planning in an environment that is unstructured and constantly changing (Srinivasa et al., 2009). Moreover, they require large amounts of valuable floor space, can only reach or interact with things at mid-level height, are usually bulky, and limited in the ability to handle heavy objects.

1.1.2.2 Wheelchair-mounted manipulators

A wheelchair mounted robotic arm (WMRA) can serve many functions and a few companies are active in the market. For example, the Manus Assistive Robotic Manipulator (ARM) is a 7 degree of freedom (DOF) manipulator designed for mounting on power wheelchairs with a built-in programmable work envelope to protect the nearby user (Rosier et al., 1991). An example application of the ARM is the Personal Mobility and Manipulation Appliance (PerMMA), which is an advanced wheelchair equipped with dual ARMs on a curved track with local or remote controlled task execution (Cooper et al., 2012). The initial testing of 15 participants found that although cooperative control took less time to execute five different tasks, individuals reported they preferred independent control via the touch interface (Xu et al., 2010). The ARM has also been shown to provide economic benefits with return on the investment occurring 1-1.5 years after purchase by greatly reducing the need of a caregiver (Romer et al., 2005). StrongArm is also an example of a chair mounted manipulator that aids individuals with transferring by providing direct interaction control and an increase in payload ability (Cooper et al., 2012). Similarly, the JACO is a lightweight carbon fiber robotic manipulator, intended as a WMRA, which has been controlled through a three-axis joystick and has shown potential to reduce caregiver time by up to 41% (Maheu, Archambault, Frappier, & Routhier, 2011). An earlier study reported greater than 79% success rate for completion of simple tasks with the JACO among 11 spinal cord injury, 5 dystrophy, and 7 other neurological disabled participants (Routhier & Archambault, 2010). Additionally, other popular WMRA's include the KARES I, FRIEND, and Raptor (Z. Bien et al., 2004; Mahoney, 2001; Ruchel, Lang, & Ivlev, 2001). ASIBOT, is a unique robotic arm but needs only a docking station and power to operate in numerous locations including a wheelchair, table, wall, or ceiling. The arm changes location by docking and undocking via a unique interlocking mechanism, however this has yet to be clinically tested or developed with a human-machine interface (Jardón, González, Stoelen, Martínez, & Balaguer, 2009).

In general, a WMRA has shown great potential to improve function ability and independence of people who use powered wheelchairs for mobility in different everyday environments. However, it may not be a practical solution for those who do not use powered wheelchairs. In addition, difficulties arise with the control methods of a WMRA that often require complex sequences or numerous steps to complete an independent task (Kim, Wang, & Behal, 2012). Additionally, it continues to be technically challenging to perform a reliable autonomous task.

1.1.2.3 Fixed environment manipulators

Assistive robotic manipulators that are fixed to a particular environment are an alternative solution to the two aforementioned methods of assistance. An early example of a fixed environment system is the Desktop Vocational Assistant Robot (DeVAR), which is an example of a manipulator mounted in a fixed location on an overhead track for assistance in the workplace and is controlled using discrete voice commands, shown in Figure 1 (Taylor, Cupo, & Sheredos, 1993). A later version, called the Professional Vocational Assistant Robot (ProVAR) included force sensors and different training modes via a physical or graphical interface.

Figure 1: ProVAR system

Ultimately, they showed training with the graphical interface was not time effective but training was effective when working with the physical manipulator (Wagner & Van der Loos, 2004). Another example of a vocational robotic workstation showed participants using an UMI-RTX manipulator and computer access device performing different occupational therapy (OT) assessment tests, such as the Minnesota Rate of Manipulation Test, to measure manipulation skill of a person operating a robot. They suggest someone with severe manipulation deficiencies could have a wider range of vocational opportunities with a mounted manipulator (Schuyler & Mahoney, 2000).

Figure 2: CAPDI kitchen overhead arm

Taking this fixed environment installation one step further, the CAPDI kitchen (Adapted Kitchen for the Disabled) utilized an overhead linear Cartesian track with a telescoping vertical arm to grasp items on a height-adjustable countertop, shown in Figure 2 (Casals, Merchan, Portell, Cufi, & Contijoch, 1999). The CAPDI adapted kitchen, which relies on an object database and record of user routines, is now being studied and an experimental prototype is being developed with aim at personal autonomy (Aranda, Vinagre, Martin, Casamitjana, & Casals, 2010).

Figure 3: “RoboticRoom” long reach manipulator

Although not intended for task completion, the “RoboticRoom” shown in Figure 3 is an interactive environment that utilizes a ceiling-mounted long reach manipulator and a height changing kitchen counter to research the benefits of human and robot symbiosis. Ultimately, the main advantage presented by the authors is the constantly changing and adapting environment that can best suit any user’s need (Sato, Harada, & Mori, 2004).

The proposed KitchenBot is aimed at furthering the development left behind by these previous initiatives. The overall goal is to reduce caregiver needs, by implementing a quickly feasible and simple design, so individuals may perform activities of daily living independently, improve self-confidence, and increase their quality of life. In comparison to past and present work, KitchenBot aims to provide universal accessibility to all individuals with upper limp impairments regardless of their mobility status, provide autonomous control of daily routine tasks without the complexity of object recognition development, and present opportunities for handling heavy payload items.

2.0 EARLY STAGE DESIGN PROCESS

We followed a traditional product design and development process with an emphasis on involving potential lead users, project managers, clinicians, and engineers who would contribute to the development. The initial meeting with the potential stakeholders resulted in a list of needs and a mission statement, which were used to guide the subsequent design process. Numerous meetings of similar nature were followed as the design of the KitchenBot evolved.

2.1 MISSION STATEMENT

A mission statement encompasses the idea, motivation, and belief of a potential future product. It is used to direct the intentions of designers and engineers as the process continues. The mission statement derived from the initial meeting became, "Design an overhead mounting system for a dynamic robotic manipulator to assist individuals with physical disabilities for tasks associated within a kitchen environment." This statement was the basis on which each concept design would be compared. The bounding envelope allowed a free range of ideas the possibility of becoming reality without constraining creativity or uniqueness.

2.2 DESIGN CRITERIA

The criteria, resulted from questions such as, "What is the end goal of this research?" and "What types of tasks should a robotic arm in the kitchen be able to accomplish?" and "Is there a minimum work space?" From these and similar questions, the following list of criteria was extracted:

Table 1: The KitchenBot design criteria

Is safe to be within close proximity of when operational
Has built in dead stops and limit switches
Aesthetically pleasing
Has low noise (<60dB)
Able to accommodate a payload up to (25lbs)
Has minimal track deflection (< 0.1 in)
Freedom to move within the kitchen footprint
Incorporates fail-safe braking
Is motor controlled
Provide position feedback (~ ± 0.5 in)
Can accommodate two arms at once
Can be installed into a standard home kitchen

The idea behind listing these design criteria was to "create a high-quality information channel that runs directly between customers in the target market and the developers of the product" (Ulrich & Eppinger, 2012). These simple criteria allow the concept designs to be narrowed for further refinement and evaluation in the concept selection process.

Furthermore, the concepts must also adhere to criteria specific to the kitchen space available at the Human Engineering Research Laboratories. This kitchen, seen in Figure 4, has a ceiling far above the cabinets, concrete floors, an electrical box directly above the cabinets, and is part of a much larger space that must retain an open feel.

Figure 4: HERL kitchen prototyping space

2.3 CONCEPT SKETCHES

After the user needs were identified, a wide range of ideas was generated as possible solutions. These ideas ranged from a simple gantry style overhead track to a three-point wire suspension system, like those seen in football stadiums for camera suspension. The three most viable concepts, which can be seen in Appendix A, included the gantry style, crane style, and hybrid style concepts that are explained in detail later. The gantry style concept required mounting of two parallel tracks and one perpendicular track above the kitchen with a carriage able to move along both. The crane concept was simply modeled after a jib-style crane with a cantilever arm and carriage that could rotate and translate. Lastly, the hybrid concept was a simply supported beam with a carriage and articulating cantilever for which the robotic arm could be mounted. Sketches of these concepts can be seen in.

2.4 INITIAL CONCEPT SELECTION

The top ideas generated during the concept phase were selected to be further evaluated using a selection matrix, a tool for ranking concepts based on how well they meet each criteria (Ulrich & Eppinger, 2012). Furthermore, a weight is applied to each criterion to level the importance and ensure, for example, that one does not have the same importance as another. The following selection matrix was used and evaluated early during the design process.

Table 2: Selection matrix

		Gantry		Crane		Hybrid	
Criteria	Weight [1-5]	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Low Deflection	4	0	0	0	0	0	0
Kitchen Safety	5	0	0	0	0	0	0
Aesthetically Pleasing	4	0	0	1	4	1	4
Easily Hidden	3	0	0	1	3	0	0
Quieter than an EPW	2	0	0	0	0	0	0
High Payload Capabilities	4	0	0	0	0	0	0
Covers Required Work Space	5	0	0	0	0	0	0
Control System Simplicity	3	0	0	-1	-3	0	0
Self-Locking Capability	5	0	0	0	0	0	0
Ease of Installation	4	0	0	1	4	1	4

Table 2 (continued)

Ease of Manufacturing	4	0	0	1	4	1	4
Ease of Design	4	0	0	-1	-4	-1	-4
Low Cost	3	0	0	1	3	0	0
	Total Score:	0	0	3	11	2	8
	Rank:		3		1		2

From this table, it was shown the crane concept would be the best course of action but this was only an initial method for evaluation. The selection matrix is not a definitive method for choosing a design solution and thus further consideration required making a pros and cons list of the top two concepts. After reviewing the following Table 3, the single mounting point for the crane could pose structural problems for the building floor. In comparison to the hybrid system though, this structural problem would be less of a concern and ultimately became the next course of action.

Table 3: Pros and cons of top two initial designs

Crane		**Hybrid**	
Pros	**Cons**	**Pros**	**Cons**
One mounting point	Counter weight clearance issues	Two mounting points	Large but awkward work envelope
Self contained system	Large bending moment	Self contained system	Requires more components (cost)
2 DOF (w/o Z control)	Large beam torsion	2 DOF (w/o Z control)	
	Requires tension cables	Half the bending moment	
	Pie shaped work envelope		

2.5 EARLY CONCEPT ITERATIONS

Of the three concepts that underwent analysis in the previous section, only the hybrid concept was chosen for further advancement. As one will read, the hybrid concept fell short of meeting the criteria as it was being developed. However, two new ideas emerged, the telescoping and bookshelf ladder concepts, are subsequently detailed below. Each concept was compared to the previous solution and criteria.

2.5.1 Hybrid crane concept

The following figures show the hybrid crane concept in true scale. The StrongArm, previously mentioned, was inverted and was considered the best manipulator to create a prototype. Furthermore, reused components from an old gantry crane were incorporated so they would not need to be purchased.

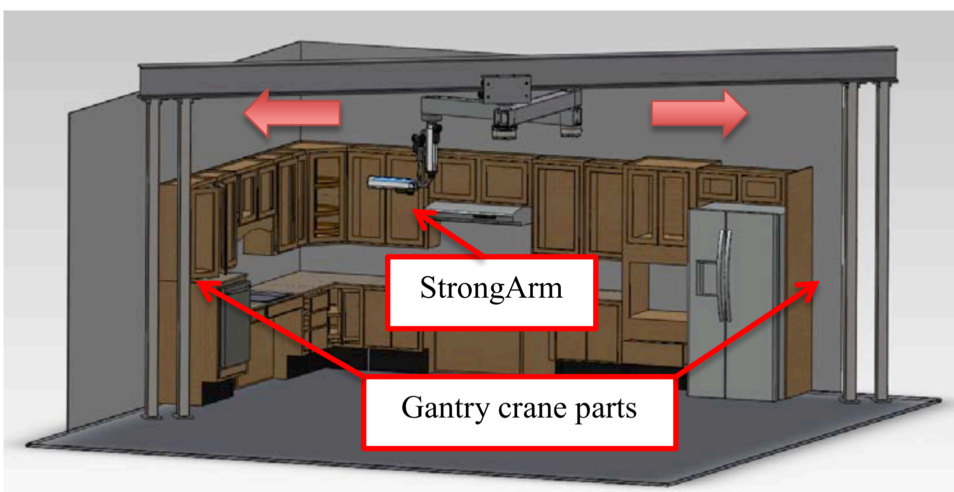


Figure 5: Isometric SolidWorks model of the hybrid crane concept

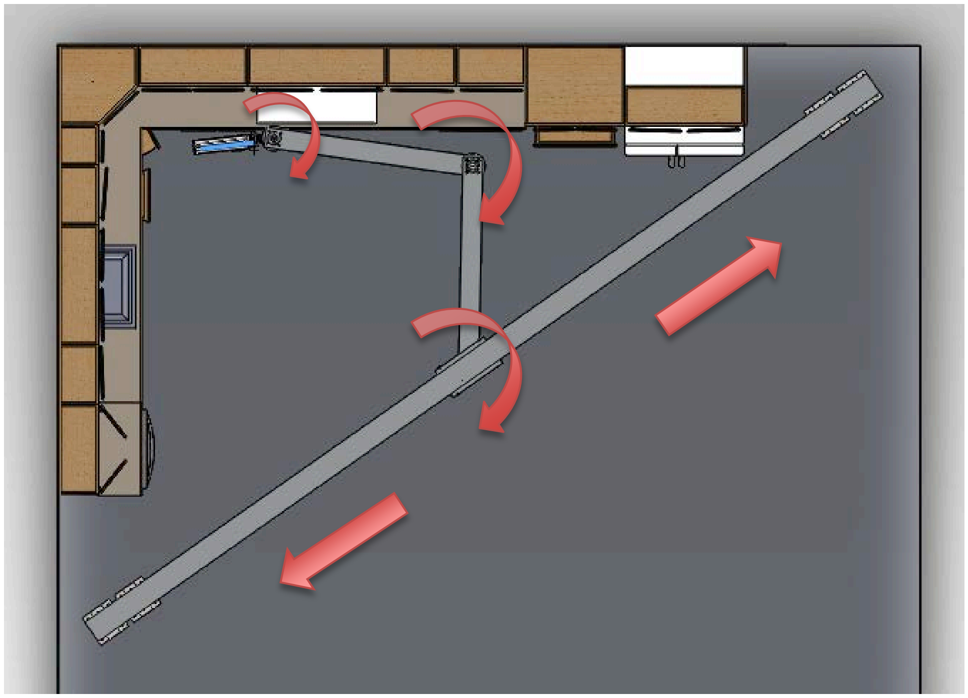


Figure 6: Top view of hybrid crane SolidWorks model concept

Figure 7: Side view of hybrid crane SolidWorks model concept

Although the above detailed design was ready for prototyping, it presented two major problems. First, it was initially designed without gear motor inputs because of the added complexity. That is to say, it would rely on the users force to drive the arm into position and brakes would automatically lock everything into place. Second, it would not be able to reach the entire workspace (i.e. the lower cabinets and floor). In addition, the idea of having an overhead-swinging beam in one's kitchen could make an individual feel uneasy based on our meetings with stakeholders. Due to these issues, the design was reconsidered to better fill the needs of the end users.

2.5.2 Telescoping concept

The idea of a wall mounted telescoping track came up as an improved solution over the hybrid crane concept. The "StrongArm", developed at HERL, utilized an easy to manufacture and ridged telescoping mechanism (Cooper et al., 2012). This telescoping design was mimicked in the telescoping concept to create one longer so a new manufacturing scheme would not need to be considered. Furthermore, having an ominous overhead beam from the previous hybrid crane concept was resolved by moving to a wall-mounted track. The idea being that a curved track would follow any kitchen design and be suspended from the wall studs. Although the track's shape and mounting was yet to be determined, a design was put into place to keep the project moving forward. The JACO arm was chosen, although its payload ability is less than originally desired, because it weighs a mere 6 [kg], has a reach of 90 [cm], and can lift objects up to 1.5 [kg], (Maheu et al., 2011).

Figure 8 below shows an early rendering of the first telescoping concept. It utilized an extra long linear actuator and a carriage system that could drive straight and around a curve. The JACO would have been mounted upside-down to optimize the work envelope, though this later became a problem upon testing.

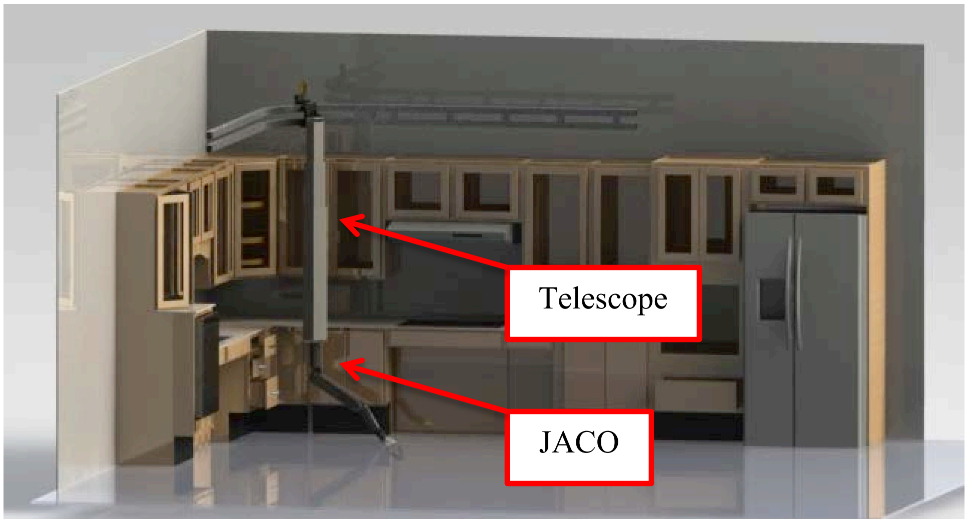


Figure 8: Preliminary wall-mounted telescoping concept

Further improvement and design refinement led to the next iteration of this concept. Improvements were made to simplify the track's cross section, define the overall contour, specify the mounting locations and style, and reduce the length of telescoping to limit deflection. Brackets would be hidden between the cracks of each cabinet and would incorporate a newly designed "French Cleat" mounting style. An aluminum rectangular tube was selected because of it sharp corners produced during the extrusion process and ability to withstand a high degree of torsion.

The track was expanded to wrap around any shape of cabinetry by turning both left and right. This would ensure the manipulator could work in any area of the kitchen and allow the manipulator to be stored on the side when unused. Subsequently, this required a carriage that could travel around an inside and outside curve. This carriage concept utilized two contact points on the top and bottom to pivot when turning a corner and is later discussed in more detail.

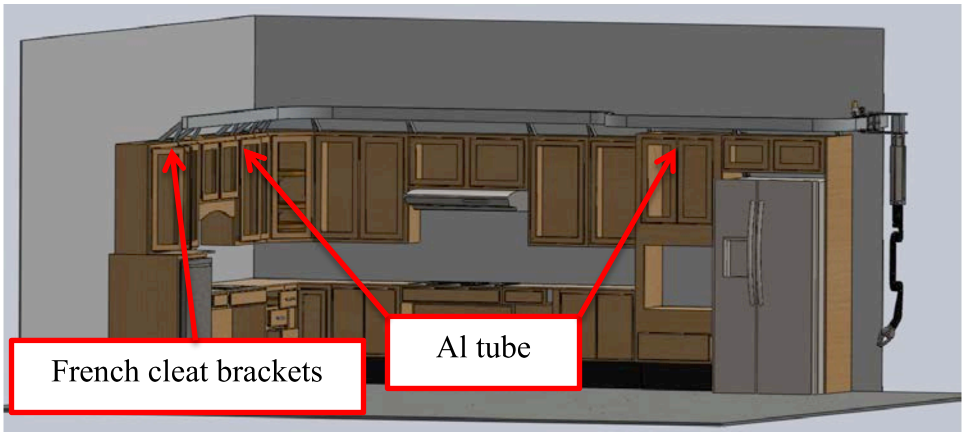


Figure 9: Secondary wall-mounted telescoping concept with brackets at stored position

Figure 10: Secondary wall-mounted telescoping concept with brackets opening drawer

This concept was a dramatic improvement in practicality and feasibility from the previous but some issues were initially overlooked. First, the JACO was not designed for inverse mounting. Bench top testing of the arm revealed the motors inability to operate under inverse gravity. This again created a false need for a longer telescope so the correctly mounted arm could still reach the bottom cabinets. Second, the unsupported arm would have much deflection if the track and carriage tolerances were not manufactured to high standards. This would also be magnified if the telescope length were to increase. The concept was again reassessed due to the better understanding of the JACO's abilities and the practicality of manufacturing tight tolerances over a long track length.

2.5.3 Bookshelf ladder concept

Large libraries have rolling bookshelf ladders that glide around the room on a curved track and roll on the floor for an individual to use. The next concept is a modification of the previous, which is derived from these rolling ladder products. Though, instead of a ladder with rungs, the track would utilize a motorized linear column to raise and lower the attached arm. Furthermore, the carriage above would drive the column around the room to position it for a new task. The support given from the ground also meant the column would not sway with dynamic motion. The JACO no longer needed to be mounted upside-down because the vertical carriage could reach close to the ground. This support on the ground would provide a reaction force that would decrease the torque on the track and walls and increase the payload ability.

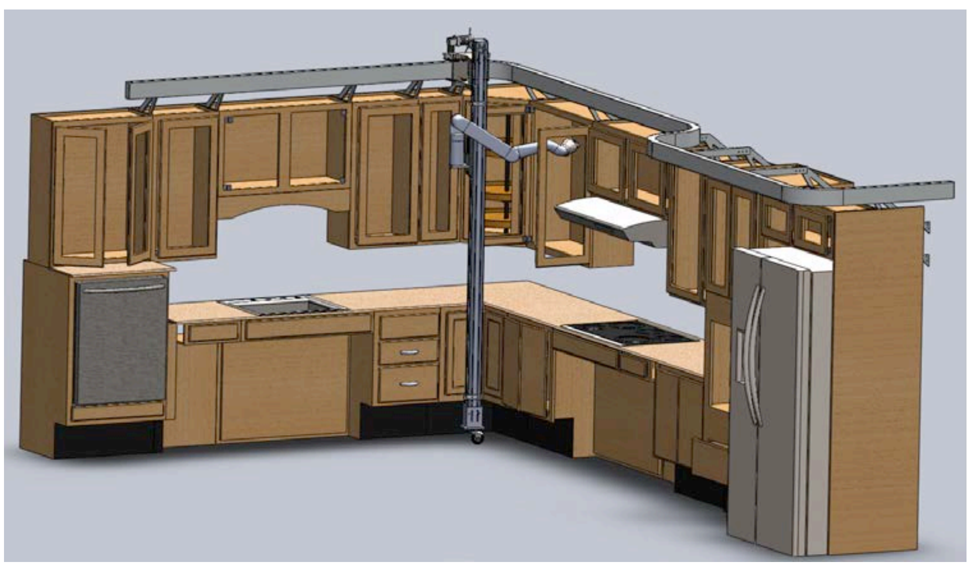


Figure 11: Bookshelf ladder style design with JACO reaching into upper cabinet

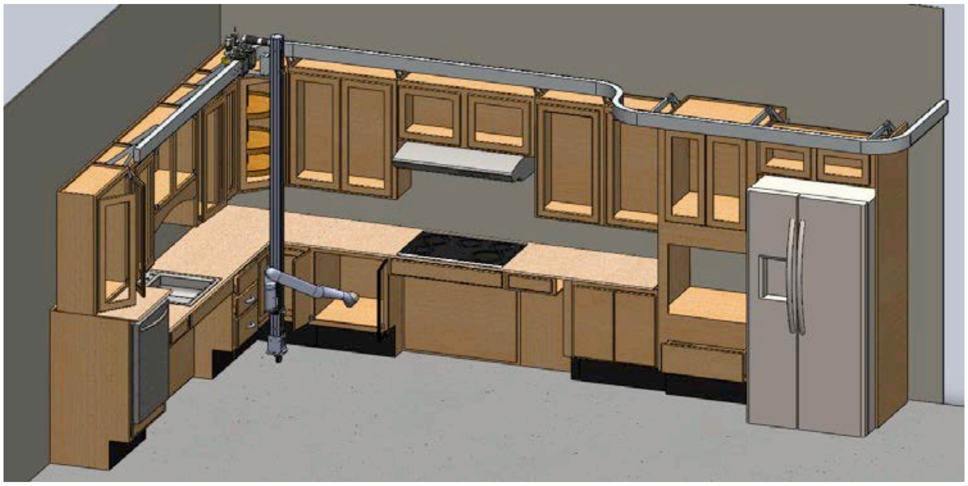


Figure 12: Bookshelf ladder style design with JACO reaching into lower cabinet

At this stage, the concept began to take shape and form into a feasible KitchenBot. The design would allow an individual to relocate a manipulator throughout the entire kitchen envelope, is discrete when unused, has built-in dead-stops, is motor controlled, could provide position feedback, and could be installed into a standard style kitchen. Of course, the concept was still merely a concept. In the next chapter, the details of overcoming concerns and design issues will be explained. Some of the concerns included:

- The uneven floor
- The wear on the floor
- Strength of the walls, brackets, and track
- Ability to manufacture the track
- Wear on the track
- Risk of the column tilting
- Carriage mechanics
- Electronics and control software

Though many concerns still existed, the design seemed feasible and had potential to satisfy all, if not most, of the design criteria. It was at this point that an evaluation was deemed necessary to formally seek feedback from potential users of KitchenBot before further development work is conducted.

2.6 FOCUS GROUP CONCEPT EVALUATION

A focus group is a form of qualitative research to extract user ideas, opinions, and perceptions about a particular product or technology (Denzin & Lincoln, 2005). The VA Pittsburgh Healthcare System's Institutional Review Board (IRB) approved the protocol titled "Participatory Evaluation of Assistive Technologies". The protocol allows for numerous technologies to be presented and discussed with a group of users for soliciting feedback and advice. The KitchenBot was discussed using the approved protocol during the 2012 National Veterans Wheelchair Games in Richmond, VA.

2.6.1 Methodology

Subjects were recruited if they were over the age of 18, have a physical disability, and could comprehend English. All subjects provided informed consent before participation in the focus groups.

Participants first completed a questionnaire about general demographics and their current and past experience with assistive technology. They then participated in a round-robin group discussion moderated by one of the investigators. Each focus group consisted no more than 15 participants and lasted no more than 2.5 hours. During the focus group, subjects were presented with enlarged wireframe photos of the conceptual KitchenBot design and incorporated a hand-sketched wheelchair user interacting with it. These images can be seen in Appendix B. The discussions were audio recorded and later transcribed for content analysis. After the focus group discussion, subjects were also asked to complete a questionnaire on kitchen area difficulties, amount of use, and potential features they would like the KitchenBot to have. A copy of this questionnaire can be found in Appendix B.1.

Descriptive statistics were used to summarize the data from the questionnaires. Context analysis was performed to extract common discussion themes based on audio transcriptions.

2.6.2 Quantitative results

A total of 25 subjects were recruited at the 2012 National Veterans Wheelchair Games (NVWG) to participate in 3 focus groups. Of those 25, 24 reported their disability of either a Spinal Cord Injury (15), Multiple Sclerosis (4), Hemiplegia (1), Paralysis (1), Stenosis (1), Arthrogryposis (1), or having a bone disease (1). They were recruited due to physical limitations with their upper limbs. Of those 25 individuals, 12 have manual wheelchairs, 12 have power wheelchairs, and 1 has a scooter for their independent mobility. The average number of years with a disability was 22.4 ± 13.4 years. There were 18 males, 5 females, and 2 with missing information on gender.

Of the participants, 9 said they live in an urban location, 11 live in a suburban location, 5 live in a rural location, and 1 was unknown. Furthermore, 22 indicated they live in an apartment, home, or condominium with only 1 living in a relative's home, and 2 unknown others. The participants highest education level is well mixed with 9 indicating they have received a high school diploma or GED, 8 have an associates or vocational degree, 6 have a bachelors degree, and 2 have a masters degree. Total household income was also diverse with 5 (20%) participants earning less than $10k per year, 1 (4%) participants earning $10-$15k per year, 2 (8%) earning $15-$20k per year, 2 (8%) earning $20-25k per year, 2 (8%) earning $25-$35k per year, 5 (20%) earning $35-$50k per year, 7 (28%) earning $50-$75k per year, and 1 (4%) who is earning more than $75k per year. Current work status indicated 1 participant is working full-time outside the home, 2 working part-time outside the home, 1 working part-time inside the home, 11 unable to work because of disability, and 10 retirees. Participants were also allowed to indicate more than one answer in regards to health insurance which showed that 1 pays out-of-pocket for expenses, 13 are covered by Medicare or Medicaid, 3 are covered by their employer, spouse's/parent's employer, or previous employer, 9 are covered by the Veterans Affairs, and 2 have missing information.

Information related to the health and experience with technology was also gauged to better understand the background of each individual. In regards to self-care, 6 participants (24%) indicated they have some problems washing and dressing and 3 participants (12%) indicated they are unable to wash or dress themselves. Fourteen participants (56%) also stated they have some problems with performing usual activates (work, study, housework, etc.) and 1 (4%) said they are unable to perform these activates. Additionally, 4 (16%) participants said they built an assistive device to meet their needs, 9 (37.5%) modified some existing technology to meet their needs, and 8 (32%) considered themselves as technology savvy. The median response to questions pertaining to technology in general is shown in Table 4 with 1 indicating "Not At All" or 7 indicating "Completely". Moreover, the median response to phrases about the participant is also listed below in Table 5 with a 1 indicating "Not At All Accurate" or 7 indicating "Extremely

Accurate". Lastly, the median responses to factors for choosing technology, which vary between "Not At All Important" to "Extremely Important" are detailed in Table 6 below.

Table 4: Median response of technology in general on a seven-point Likert scale

Phrase	Median Response
Makes life easy and convenient:	6.0
Makes life complicated:	2.0
Gives people control over their daily lives:	7.0
Makes people dependent:	5.0
Makes life comfortable:	7.0
Makes life stressful:	2.0
Brings people together:	6.0
Makes people isolated:	2.0
Increases personal safety and security:	6.0
Reduces privacy:	2.0

Table 5: Median response of phrases on a seven-point Likert scale

Phrase	Median Response
I like to keep up with the latest technology:	6.0
I generally wait to adopt a new technology until all the bugs have been worked out:	4.0
I enjoy the challenge of figuring out high tech gadgets:	6.0
I feel confident that I have the ability to learn to use technology:	6.0
Technology makes me nervous:	1.0
If a human can accomplish a task as well as technology, I prefer to interact with a person:	6.0
I like the idea of using technology to reduce my dependence on other people:	7.0

Table 6: Median response of factors for choosing technology on a seven-point Likert scale

Factor	Median Response
How well it meets your needs:	7.0
Ease of use:	7.0
Cost:	7.0
Attractiveness:	5.0
How visible it is to others:	4.0
How it affects your privacy:	6.0
How safe it is to use:	7.0

Table 7 shows the variation in meal preparation activity conducted by each participant on an average basis. The majority (72%) of the participants prepare a meal less than once per day at home and 56% of participants said they receive assistance with meal preparation more than five times per week.

Table 7: Concept focus group's percentage of participants who prepare meals at home

20%	Do not cook at home
16%	Cook 0-1 times per week
24%	Cook 2-4 times per week
12%	Cook 5-7 times per week
16%	Cook 8-14 times per week
12%	Cook greater than 14 times per week

Furthermore, Table 8 represents the percentage of participants who scored each appliance or activity on a seven-point Likert scale between "No Difficulty" and "Much Difficulty". It revealed 28% and 29% of individuals have the most difficulty using the oven and putting away groceries. Additionally, 40% said they do not use a dishwasher at all, but this could be explained because they may not own one.

Table 8: Percentage of responses regarding level of difficulty with each activity

Appliance/Activity	Total answers	"I do not use at all"	Scored as (1,2,3)	Scored as (5,6,7)
Microwave:	25	4%	88%	8%
Sink:	25	4%	76%	8%
Refrigerator:	25	0%	88%	8%
Stove-top:	25	16%	52%	24%
Oven:	25	16%	52%	28%
Dishwasher:	25	40%	44%	16%
Counter-top appliances (Coffee maker, blender, toaster oven):	25	16%	60%	24%
Putting away groceries:	24	8%	58%	29%

Moreover, Table 9 shows the participants frequency of usage for each of those common kitchen appliances. Using the oven or dishwasher is the most commonly neglected appliance, with 52% of participants saying they use it less than once per week or not at all. In regards to the dishwasher, this high percentage of non-use could be due to the lack of individuals not owning one.

Table 9: Percentage of responses showing frequency of appliance usage

Appliance/Activity	Total answers	"I do not use at all"	Less than once per week	Greater than once per week
Use the Microwave:	25	4%	36%	60%
Use the Sink:	25	0%	24%	76%
Use the Refrigerator:	25	0%	12%	88%
Use the Stovetop:	25	24%	40%	36%
Use the Oven:	25	28%	52%	20%
Use the Dishwasher:	25	52%	32%	16%

A list of potential features were also asked to be scaled from “Less likely to want it” to “More likely to want it” by the participants. The results showed the top three most important features of the conceptual KitchenBot should be unloading the groceries, handling hot objects, and reaching for items in the upper cabinets.

Table 10: Percentage of responses showing rank of potential KitchenBot features

Feature	Total answers	"No Difference"	Scored as (5)	Scored as (6)	Scored as (7)	Scored as (5,6,7)
Opening cabinet doors, drawers, and appliances:	25	20%	4%	20%	44%	68%
Reaching items from the upper cabinets:	25	4%	0%	28%	60%	88%
Reaching items from the lower cabinets:	25	28%	8%	12%	36%	56%
Reaching items from the floor:	25	24%	8%	16%	28%	52%
Stabilizing items:	25	12%	24%	24%	28%	76%
Unloading the groceries:	25	4%	8%	20%	52%	80%
Unloading the dishwasher:	23	30%	4%	17%	22%	43%

Table 10 (Continued)

Handling hot objects:	25	4%	4%	24%	60%	88%
Handling heavy objects:	25	8%	0%	8%	68%	76%
Easily Hidden:	25	24%	12%	12%	40%	64%

Finally, the participants were also asked to rank, on the same Likert scale as above, their preference with the three types of presented interface. Table 11 shows three quarters of the participants would prefer the tablet interface.

Table 11: Percentage of responses showing rank of potential control interfaces

Feature	Total answers	"No Difference"	Scored as (5)	Scored as (6)	Scored as (7)	Scored as (5,6,7)
Control via "touch to move" interaction:	25	20%	20%	12%	20%	52%
Control with a joystick:	25	8%	4%	16%	40%	60%
Control with a tablet PC:	24	13%	0%	21%	54%	75%

2.6.3 Qualitative results

Major themes emerged during discussion of the KitchenBot concept including the feasibility of home installation, the areas of the kitchen that pose the most difficulty, and the desired features. Moreover, the participants, in regards to the concept KitchenBot, also made some suggestions, which were not included in the discussion.

Much of the discussion time was spent gauging the general thoughts of the design and the level of difficulty individuals face in the kitchen. Participants, in general, had mixed reviews of the concept feasibility. More specifically, some concerns were related to the KitchenBot's track mounting style. When asked if they have about 12 [in] above their cabinets, a mixed response was given briefly.

Related to areas of difficulty, all the participants seemed to agree that reaching into or using the upper cabinets was a difficult challenge. Although, utilizing the bottom cabinets was also explained to be not a simple task and reaching into the back is even more challenging. Moreover, many expressed difficulty with fine motor tasks like stirring a cup of coffee. Some supporting statements by participants said:

"Even with a reacher, when you try to get something that is high or too heavy, it falls."

"Pots and pans are down low and I have to get on my knees, but I have a hard time getting back up."

"My hands shake, so I can't cut anything or stir my coffee."

"For most of my cabinets, I cannot get anything out of the back."

The moderator also explained, through the use of enlarged photos, some of the potential features of the concept, such as joystick control, reaching ability, or stirring assistance. In terms of control methods, the majority of groups seemed to favor the tablet out of the three possible options. Some supporting statements were:

"Its gatta do the mundane work in the kitchen."

"I would like it to work with me because you're normally doing many things…to have help with some of the other tasks."

Some suggestions made during the discussions included the addition of a voice control interface and cleaning ability. Moreover, others wanted it simply for the manual labor tasks.

"Tablet, if it was voice controlled."

"It would be a good idea if it could sweep or something"

3.0 FINAL PROTOTYPE DESIGN

The conceptual KitchenBot received an overall positive feedback from the end users who also provided suggestions for the design features that are considered in the following prototyping phase. Figure 13 shows the final concept model of the KitchenBot with labeled design sections.

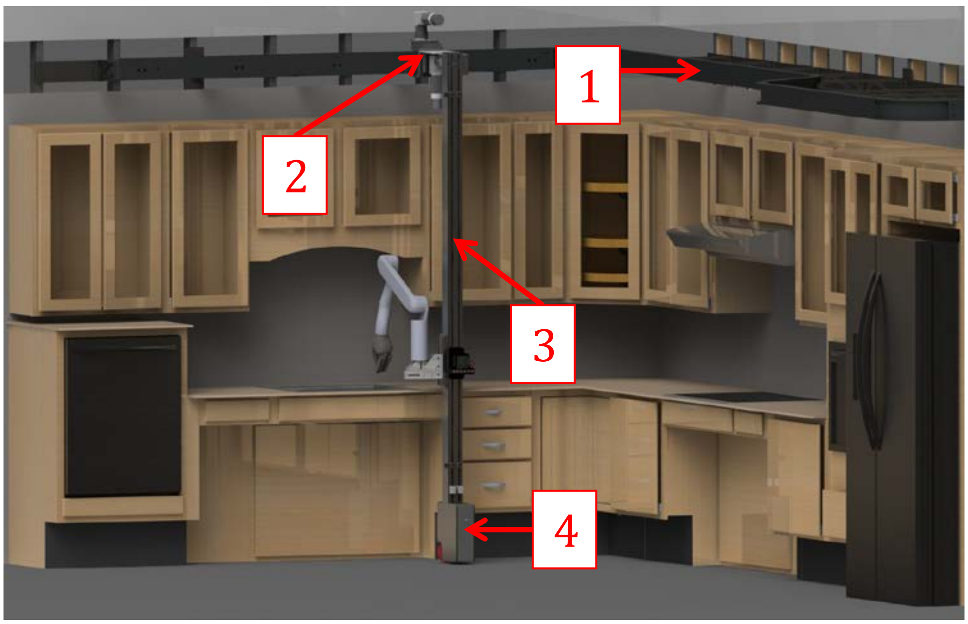


Figure 13: KitchenBot design component sections diagram

This concept model is broken into four main design components:

1. Curved horizontal s-curve track that surrounds the overhead cabinets
2. Horizontal carriage that drives the column left or right
3. Vertical column that drives the manipulator up and down
4. Bottom carriage that maintains stability

Each was a challenge of its own to refine, strengthen, and simplify. In this chapter, each section of the KitchenBot will be discussed and explained to further understand the challenges and capabilities of the final prototype.

3.1 KITCHENBOT DESIGN COMPONENTS

3.1.1 Horizontal track

A wall-mounted overhead track was a main focus for improvement to ensure safety and reliability. The idea of designing an s-curved track would open possibilities for traversing any area of the kitchen or home but created more manufacturing and testing challenges. This meant devising a ridged curved segment connection method and creating a carriage that could navigate a curve from far left to far right. The carriage will be discussed in section (3.1.2), but the method for connecting and manufacturing the curved segments, protecting the track surface, and ensuring strength of the brackets, studs, and track will be further explained in this section.

The wall-mounted track model shown in earlier concepts had one solid curved extrusion that was for proof-of-concept but was impractical to manufacture. The first track revision involved two pairs of quarter circle solid aluminum blocks with square billets on each side that would press inside of purchased aluminum rectangle tube extrusion. The two by four inch aluminum tube was readily available and large enough to build a robust carriage around. Once the solid curve was pressed into the tube, two flat head bolts would restrict it from coming out. Additionally, where the center of the 'S' joined, the curve would have a dovetail press fit with two bolts across (dashed line below). A small-scale example is shown in Figure 14.

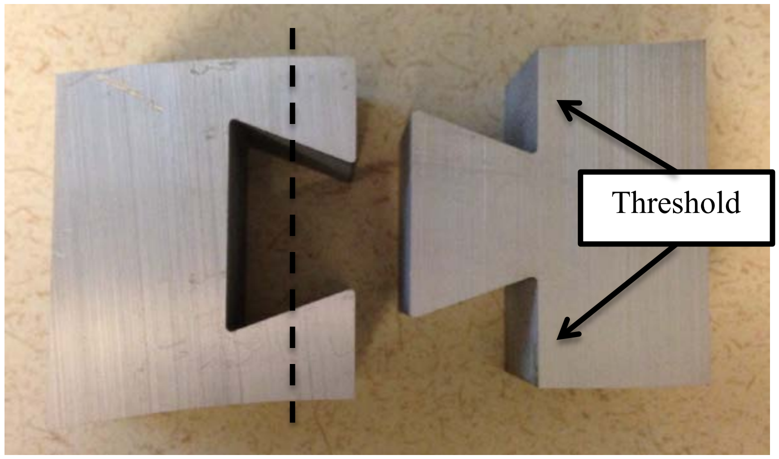


Figure 14: Curved dovetail example

The downfall to this concept, which was close to becoming a reality, was the excess solid weight and the large tolerance variation on the tubes inner dimensions. Furthermore, if the holes for bolting did not meet exact specified distance from the edge, a gap would present itself across the threshold.

To make manufacturing practical, the next revision needed curved sections with low weight and a method for pulling the curve tight against the tube. Sandwiching and bolting curved aluminum plates on top of a thin center aluminum piece created lightweight but strong curves. At the end, a loose fit billet, similar to the one earlier discussed, would provide access for four bolts to be inserted parallel to the track and thread into a block previously inserted into the tube a few inches deep. Although this design required a tube between each curve, the weight of each segment was reduced by over 50%. To make this design work on the ‘S’ turn, two smaller semi circles, with the same contour were used with a short tube in between. This maintained the ‘S’ concept but was a more gradual change. An image of the tracks assembly and short segment is shown in Figure 15. All the mechanical drawings of the track components can be seen in Appendix C.1.

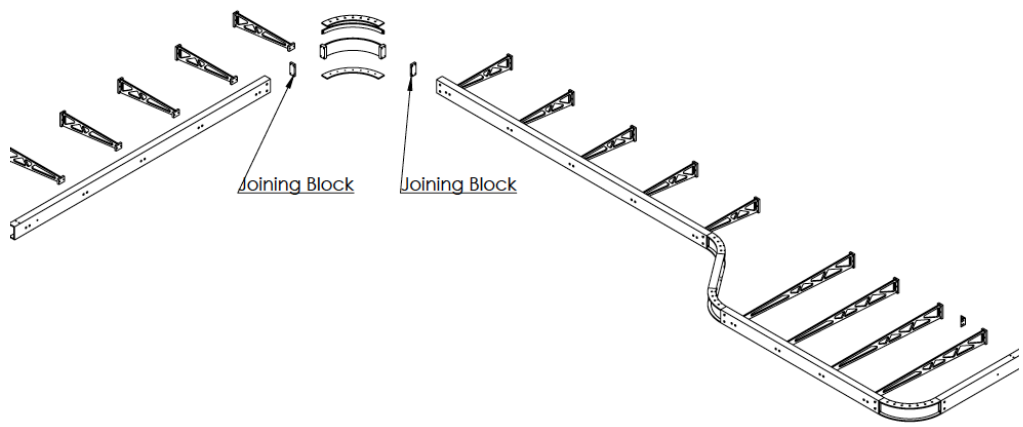


Figure 15: Horizontal track assembly and joining blocks

With track design nearing the final form, the next check was for durability of the track and rolling surface. Aluminum was chosen because of its low weight to strength ratio and ease of manufacturing. However, when steel rollers are used against an aluminum track the surface will begin to wear quickly. Steel rollers were required because of their high radial load capabilities but the aluminum tube and curve assemblies had to be protected. Ideas for inlaying steel strips or having a steel track came to light but the best method to withstand wear on aluminum was to have the entire assembly hard anodized. A black hard-coat anodize process, though it added 0.002 [inches] of thickness, was the perfect solution to ensure the track would last repeated use.

The final concern for track design was to confirm wall mounting would achieve the required load-carrying capacity and safety margins. Concerns existed regarding the rigidity of the building studs, brackets, and track when subjected to load. The brackets were redesigned to make the track more accessible to cabinets without gaps and it required using shorter but thicker steel plates that would be tied to a unified mounting plate connected to each stud. These brackets can also be seen in Appendix C.2. To evaluate the strength of the new bracket design, we conducted Finite Element Analysis (FEA) on the assembly. The FEA analysis was performed using SolidWorks Simulation Tool. A small-scale simulation and bench-top test was performed on the longest bracket with wood reinforced steel studs, shown in Figure 16 and Figure 17.

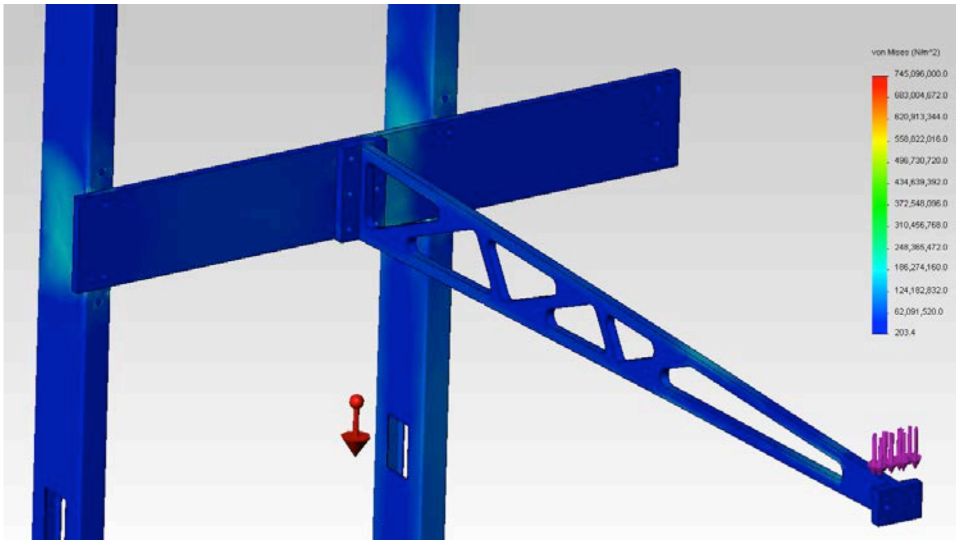


Figure 16: SolidWorks small-scale FEA on a long track bracket

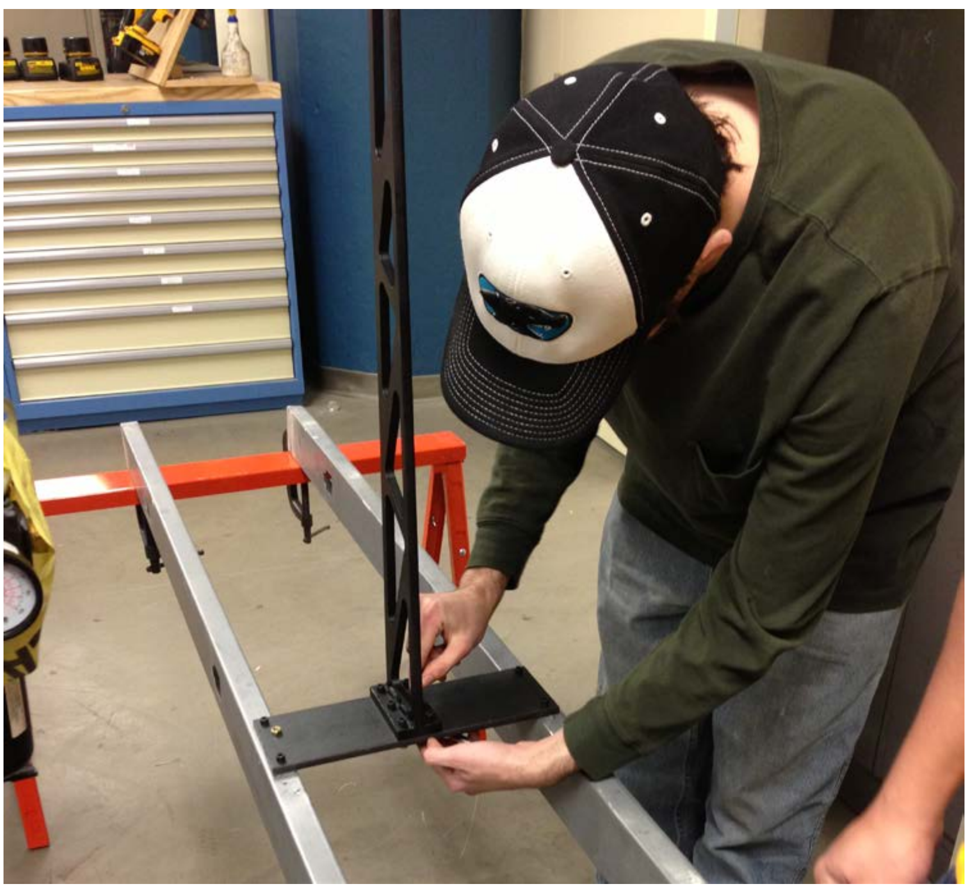


Figure 17: Bench-top testing of a long bracket under load

A load test was conducted using two recycled steel studs and a long bracket to bench test the attachment system. Each stud was fixed to a sawhorse at the standard 16 [in] center-to-center distance and bolted together using a steel connecting plate. A load cell was then used to apply the same 150 [lbs] of load as in the simulation. The deformation of the bench test, when under the same loading as the FEA model, were comparatively minimal. A large-scale simulation was then conducted on the entire assembly. The input simulation parameters required defining each individual part's material properties (i.e. yield strength, density, elastic modulus, etc.), the fixed-in-space faces of the wall studs, all bolt connections (including their torque, mass, and surface contact area), all non-penetrating surface contact pairs, and the applied loading (including gravity, torque, and payload). The highlighted input parameters can be seen in the following four figures.

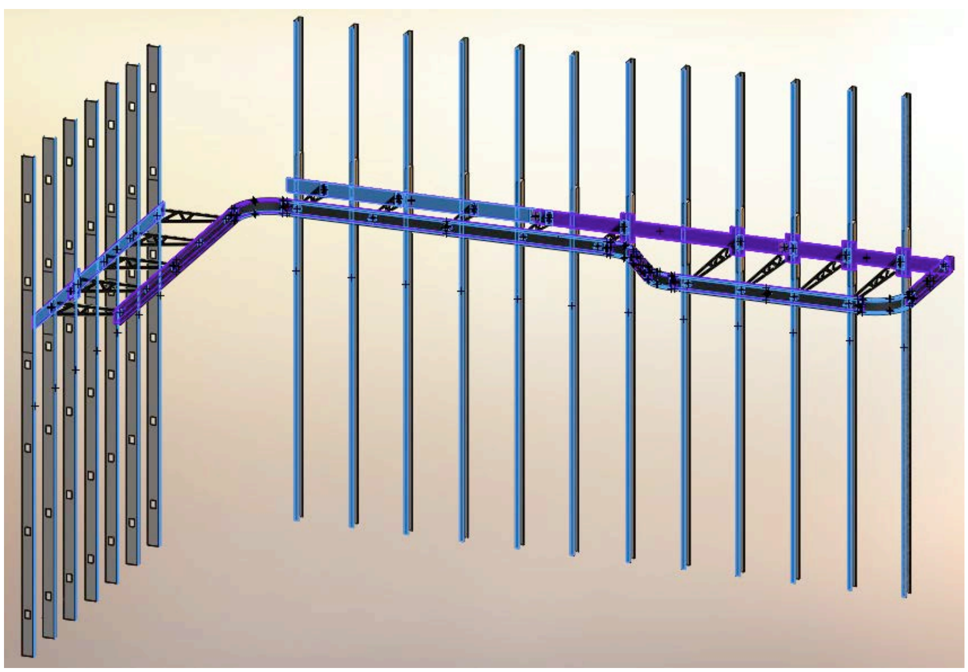


Figure 18: SolidWorks FEA track assembly's contact sets

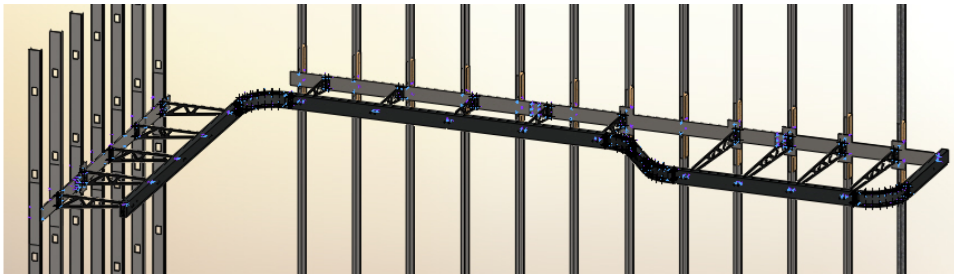


Figure 19: SolidWorks FEA track assembly's bolted connections

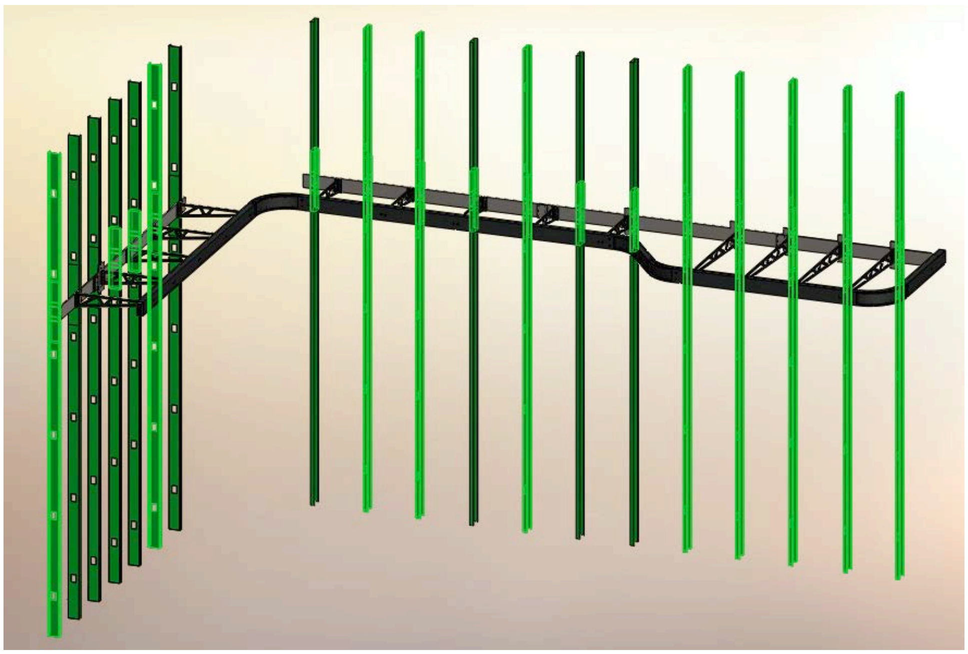


Figure 20: SolidWorks FEA track assembly of the building stud bonded connections

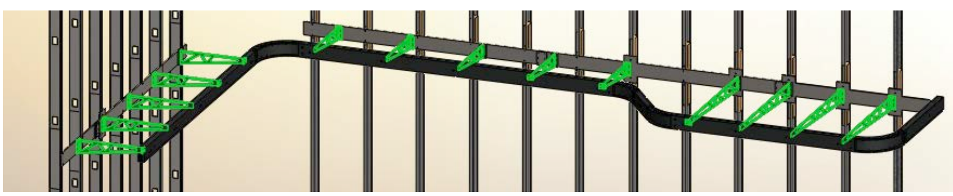


Figure 21: SolidWorks FEA track assembly of the brackets welded connections

To test this assembly, an applied load on the track's most unsupported point was 50 [lbf], derived from the criteria, and a torque of 100 [ft-lbf]. What resulted was a stress level induced in the track between 27 [Mpa] and 200 [kpa], the brackets between 12 [Mpa] and 2.5 [Mpa], and the studs between 207 [Mpa] and 76 [Mpa]. All static stress values, as well as the negligible strain level, are well below the respective material's yield point and indicative of a safe track.

The maximum deflection of the track was 0.059 [in]. This is an acceptable deformation because it does not exceed the elastic region of the material's properties. The lowest Factor of Safety (FOS) in the studs, which is a term used for describing the structural capacity of a system beyond the load, was found to be 2.5. These results show the track and building studs are safe when operating within the design criteria limits set by the earlier design process.

The output of the simulation provided a visual representation of stress, strain, deformation, and the FOS. This can be seen in the following four figures.

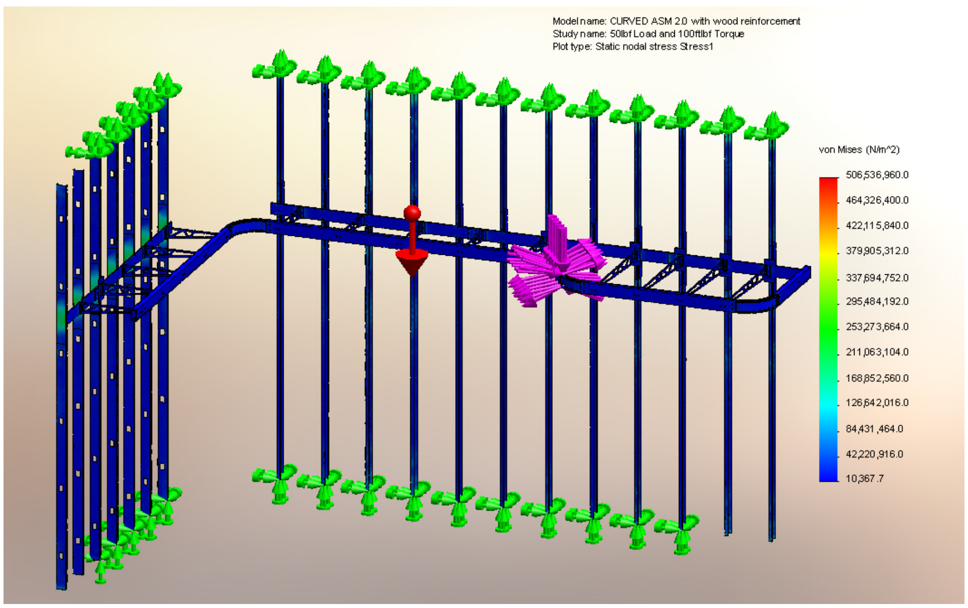


Figure 22: SolidWorks FEA track assembly Von Mises stress result

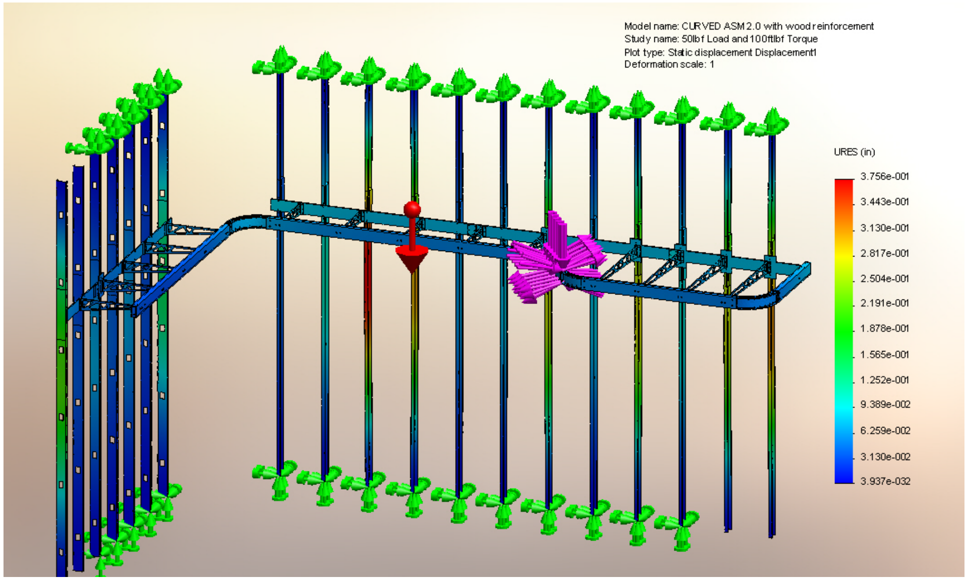


Figure 23: SolidWorks FEA track assembly deflection result

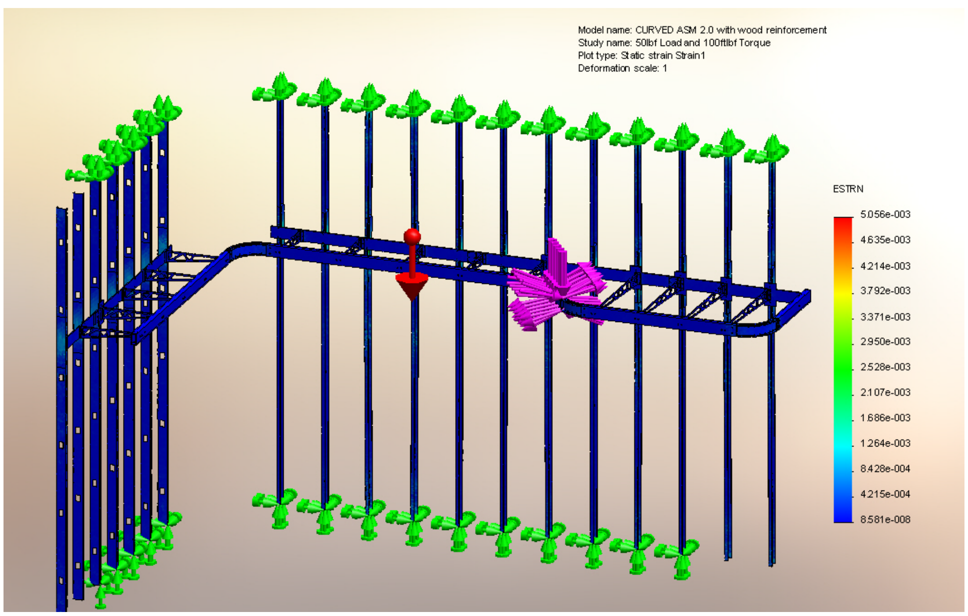


Figure 24: SolidWorks FEA track assembly strain result

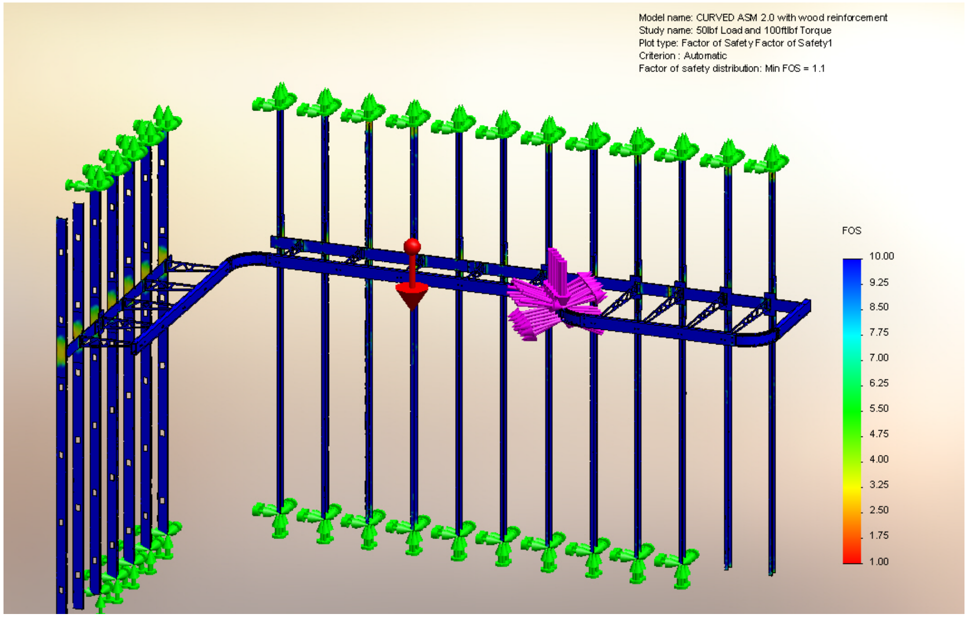


Figure 25: SolidWorks FEA track assembly FOS result

3.1.2 Horizontal drive carriage

The overhead carriage assembly is a vital component that must be able to resist torque, remain rigid, and drive the lower assemblies in a controlled manor. Many iterations of this design took place before the final version was reached. Initially, this carriage comprised many segments but was quickly simplified. The three major developments that will be discussed in this section include the dual drive carriage prototype, the three-point contact prototype, and the refined aluminum prototype.

The initial concept for a driven carriage evolved from the idea of two separate but connected carriages. Each would capture the track with one roller on either side, allowing it to pivot about its center axis in both directions. One would provide the power input while the other would track position (not shown) in Figure 26 below. The vertical column would have been attached to the cantilever arm connecting the two carriages.

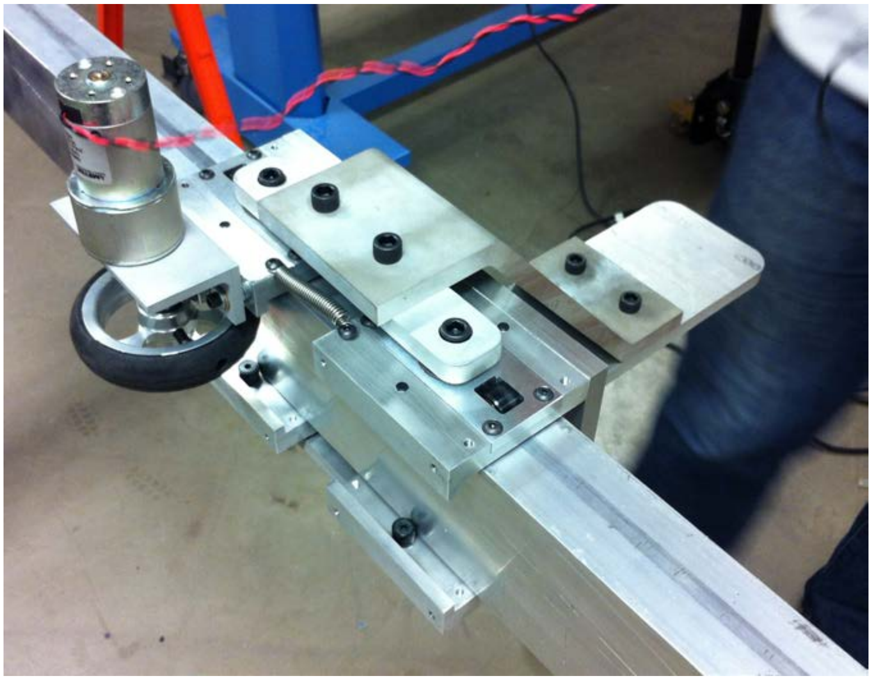


Figure 26: Dual drive carriage concept

The downfall to this concept, which was discovered after developing a working prototype, was the inability for the carriages to remain parallel when traveling along a straight path. Once this twisting occurred, as outlined by the two red lines, it causes the motion to be hindered and would have to be manually corrected, as shown in Figure 27 below. Springs were added to correct the unwanted motion but the entire assembly was flawed and a better method had to be derived.

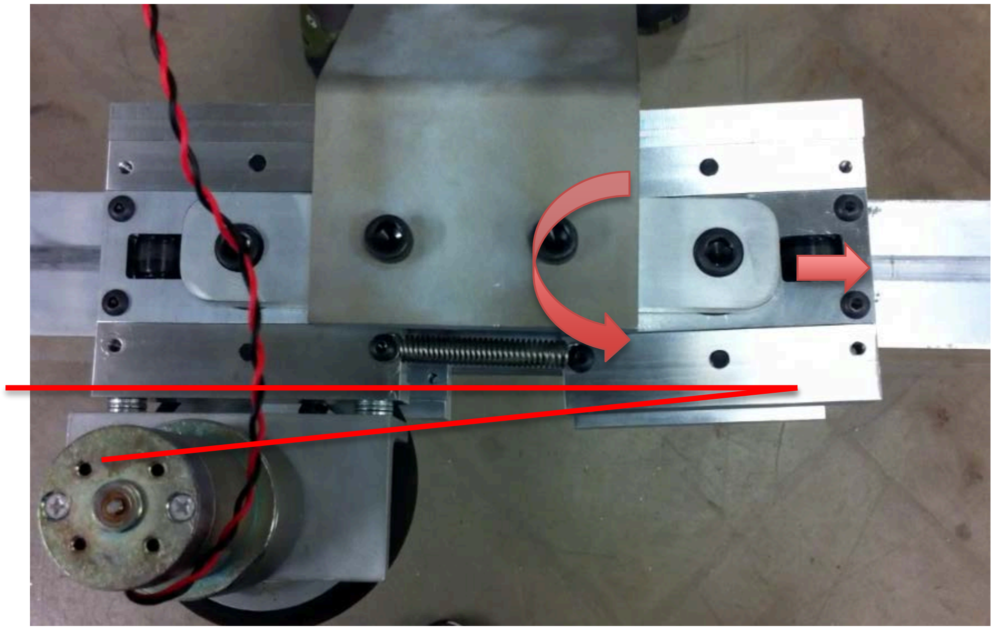


Figure 27: Dual drive carriage failure mode caused by unwanted twisting at the pivot points

The second major revision to the drive carriage was to eliminate the second carriage, but devise a spring loaded method that could change the perpendicular width of three track rollers. This would allow the carriage to move around both types of curve without the loss of torsional resistance. The amount of motion was determined via a SolidWorks sketch shown in Figure 28. The distance between the 0.5 [in] rollers is clearly shown to vary between 2.444 [in] and 2.573 [in] when turning through a 10 [in] curve. This 10 [in] radius was kept on each curved segment but modified to the required arc length.

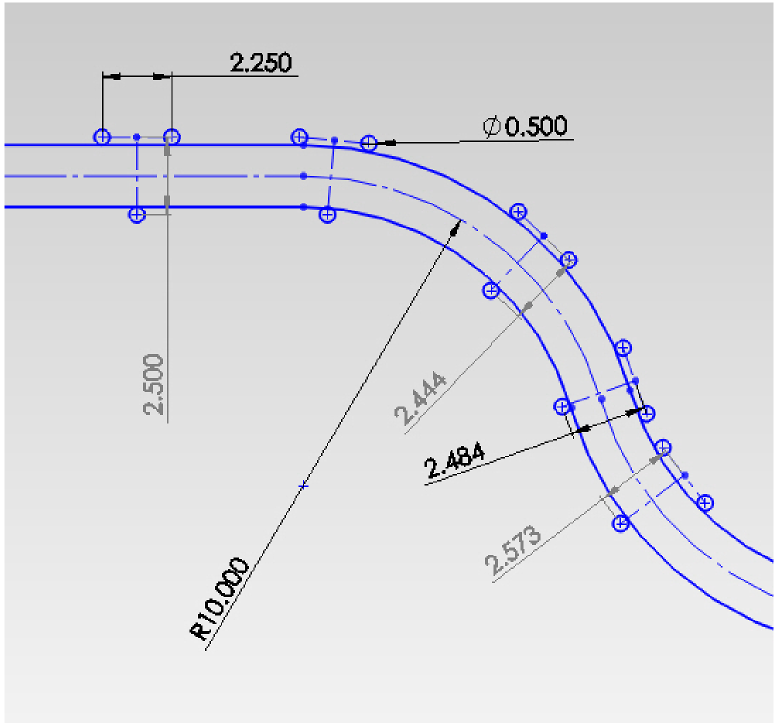


Figure 28: Three-point contact state diagram showing variation in roller width

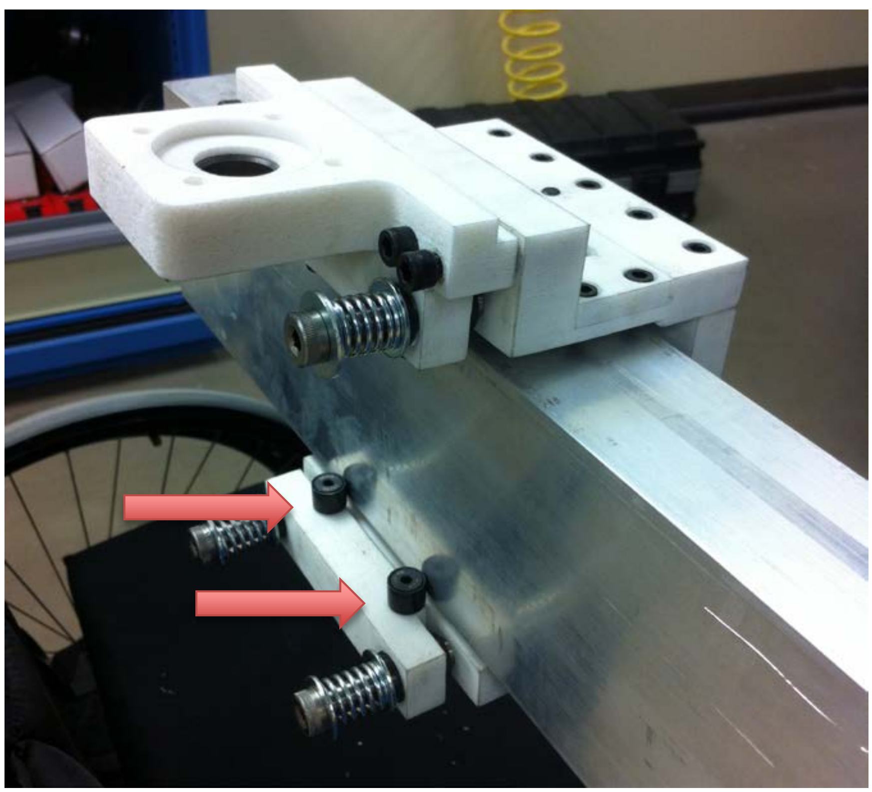


Figure 29: Three-point horizontal contact plastic drive carriage with two adjusting rollers

These two rollers would move along parallel shoulder bolts via a sleeve bearing and be under compression of a steel spring. Further refinement of this 3D printed prototype revealed the need for spring-loaded track rollers on the bottom to account for variations in the track's vertical height (highlighted in green on Figure 30), added mounting holes (highlighted in red), and added bolting points for the drive wheel housing to withstand deflection (highlighted in orange).

The final prototype of the drive carriage was machined from aluminum and is shown in Figure 30 below. As previously discussed, the bottom two track roller axles were given four compression springs, the thickness of the assembly was increased, and bolting points were added for the motor assembly. Furthermore, the lone track roller was moved to the adjustable side as testing showed this to be a more refined method, a solid L-piece replaced the need for two column-mounting parts, and the top section was reduced from two to one parts.

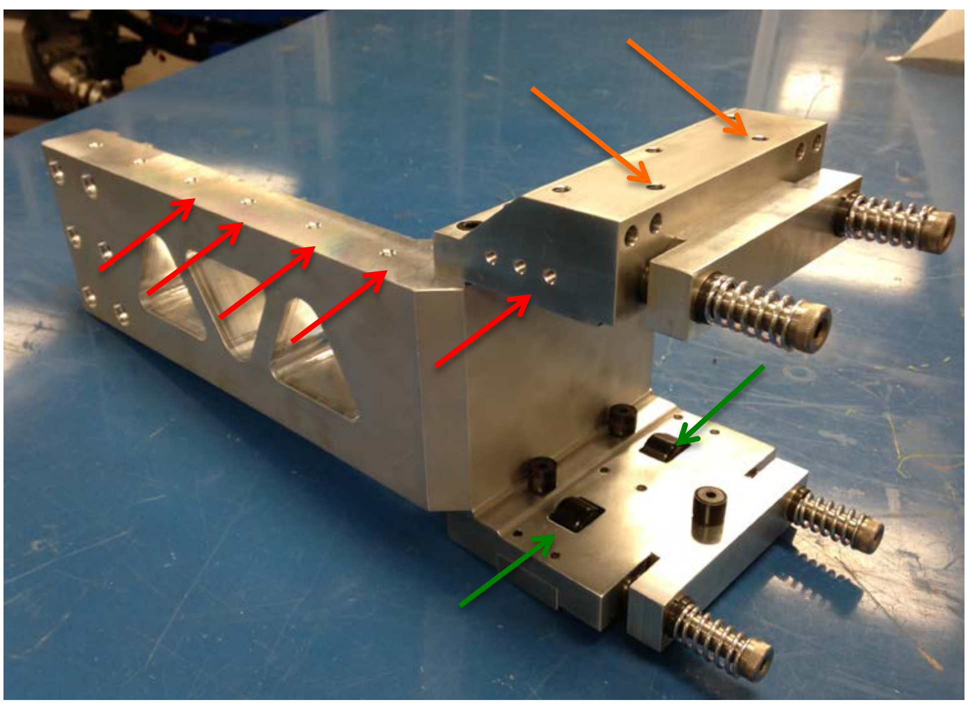


Figure 30: Final aluminum prototype drive carriage without motor assembly

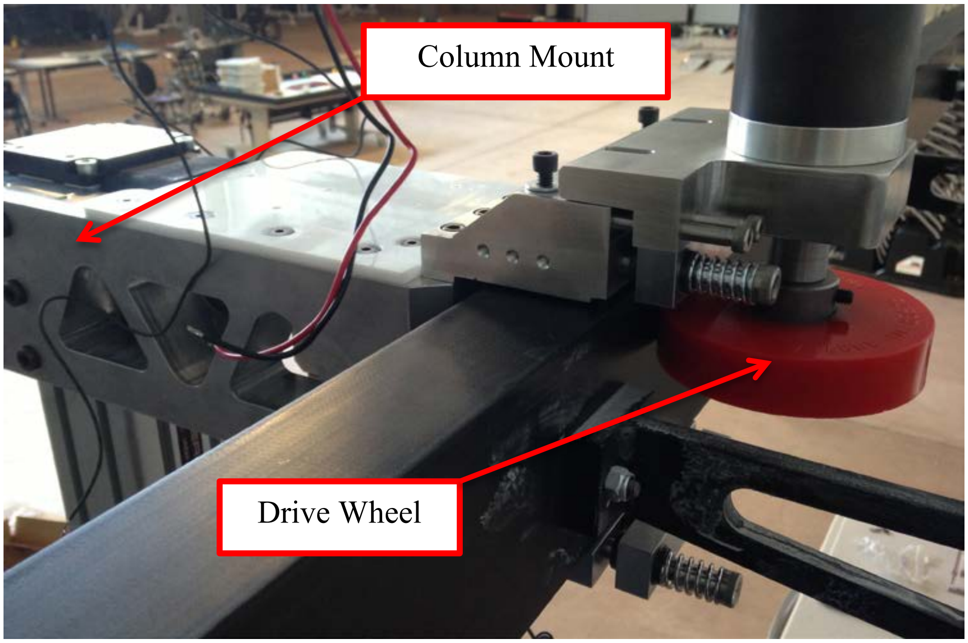


Figure 31: Final aluminum prototype drive carriage with motor assembly and vertical column

The torque and speed of the drive carriage motor was determined by assuming the maximum horizontal velocity should be no greater than 9 [in/sec], friction could be ignored because of the low resistance track rollers, and the mass of the entire assembly, with payload, would not exceed 200 [lbs]. Overall, the final motor that was chosen incorporated an encoder, fail-safe electromagnetic brake, 220 [in-lbs] of torque, and a maximum speed of 53 [rpm] to achieve the required speed ("Midwest Motion Products," 2013). These specifications were enough to satisfy the designs needed capabilities.

3.1.3 Vertical column

The vertical column in the KitchenBot is a key aspect in the design but was difficult to develop. The major challenges in the design of the vertical column include finding a carriage capable of withstanding torque in three dimensions and specifying a capable motor. Initially, early concepts of this linear motorized carriage were developed using 80/20 aluminum extrusion and a lead screw. However, it was quickly realized that a lead screw would be heavy, noisy, and difficult to acquire or machine at a length just over six feet.

An engineered linear actuator was sought-after so that further carriage design would not be required to determine the torque limits. We purchased a belt driven linear actuator (motor not included) with an aluminum body and carriage from Pacific Bearing Company (Rockford, IL). The actuator and carriage could withstand force between 370 and 1011 [lbf] and torque between 708 and 3982 [lbf-in] ("PBC Linear MTB080 Linear Actuator," 2013). For the particular axis, which the arm will be loading and torqueing, this carriage would be able to withstand the maximum required. The motor for this linear actuator had to provide enough power to lift the arm and payload at a reasonable safe speed of about 3.5 [in/sec]. At this speed, the carriage could traverse from top to bottom in 18 [sec]. The track constants, variables, and outputs can be seen in Table 12 and Table 13.

Table 12: Vertical motor speed and torque calculation inputs

Constants:	
L_stroke [in]:	63.00
L_body [in]:	74.02
m_trolley[lbs]:	5.13
m_load[lbs]:	125.00
D_pulley [in]:	1.95
Pulley_ratio [in/rev]:	6.30

Variables:	
V_linear [in/sec]:	3.50
t_full_stroke [sec]:	18.00
t_to_V_constant [sec]:	0.50
a_trolley [in/sec/sec]:	7.00
a_trolley [ft/sec/sec]:	0.58
FS	2.00

Table 13: Vertical motor speed and torque calculation outputs

Speed Output	
W [rpm]:	**33.3**
Where:	
W [rpm] = V_linear/Pulley_ratio*60	

Torque Output	
T_total_req [in-lbs]:	**327.8**
T_static_req [in-lbs]:	253.7
T_inertial_req [in-lbs]	74.0
Where:	
T_total_req = T_static_req + T_inertial_req	
T_static_req = FS*r_pulley*m_total	
T_inertial_req = m_total*a_trolley*r_pulley	

Furthermore, it also needed to incorporate an encoder and electromagnetic brake for tracking position and locking when power is lost. The motor chosen to satisfy these requirements came from Midwest Motion (Watertown, MN) and supplied 33 [rpm] and 352 [in-lbs] of torque ("Midwest Motion Products," 2013). The next challenge was to keep the column vertical at all times.

3.1.4 Bottom carriage

The bottom carriage is the assembly that contacts the floor and is mounted to the vertical column. The purpose of this assembly is to ensure the column remains vertical when translating, provide a vertical reaction force from the ground, and prevent the column from swaying when stationary.

This carriage had numerous criteria to follow that included being spring loaded, power driven, lockable, able to turn through a corner, and maintain a small footprint. Compression springs were needed to ensure the assembly would always be contacting the uneven floor. Measurements showed an entire half-inch of variation in the HERL kitchen floor. Furthermore, the bottom carriage had to compensate for column tilt, via a driving wheel, when it deviates from the vertical. Most importantly; however, the assembly had to remain smaller than a power wheelchair base because the floor is considered valuable space.

To satisfy these criteria, a single driven rubber wheel mounted on small linear ball bearings was the best working solution. The design simply repurposed a duplicate horizontal drive motor that incorporated an EM brake and encoder. The rubber wheel, as shown in Figure

32, is a hard polymer that provided good friction on the floor and could scrub around turns easily.

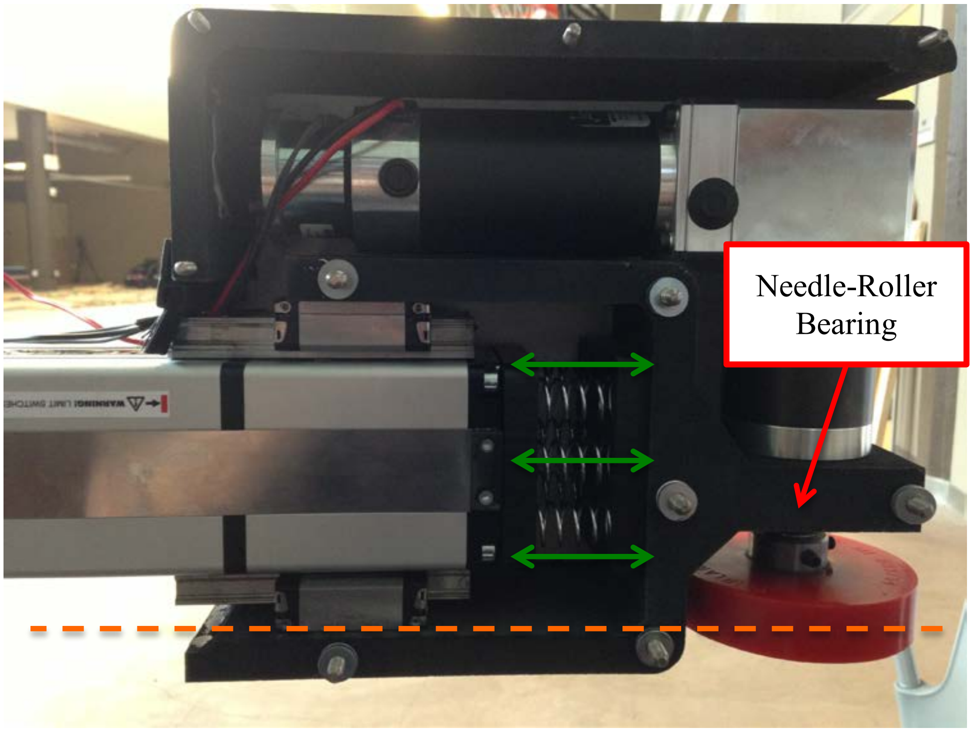


Figure 32: Final bottom carriage assembly cross-section view

The axis of rotation (shown in orange on Figure 32) was placed directly over the wheel so that scrubbing occurs on its center-point when moving horizontally through a curve. Moreover, a needle roller bearing was included to distribute the radial loading. The entire assembly could also move up or down depending on the distance to the floor and was under spring force (shown in green on Figure 32) to ensure enough friction was created to withstand the arm's torque. This friction created by the lower and upper drive wheels provide the reaction forces, which vary depending on the position of the column and manipulator height, are necessary to keep the body ridged when loaded by the manipulator. The 6 compression springs delivers between 38 [lbs] and 82 [lbs] of force depending on the position and deflect a maximum of 0.5 [in].

A simple static load test was conducted to demonstrate the bottom carriage would not slip when torque is applied in different dimensions by a manipulator. The test was done by clamping steel bar stock onto the manipulator's mounting point to serve as a lever. The column was positioned to an approximate point along the track with the least amount of spring force. Weight was then gradual added with a load cell 2 [ft] from the mounting point to simulate a torque away, towards, and about the cabinets. The assembly held a maximum torque of 80 [ft-lbs] in each of the three directions, which is indicative of a plausible payload ability of 26 [lbs] at 3 [ft] from the vertical carriage. This test and result indicate proper design feasibility.

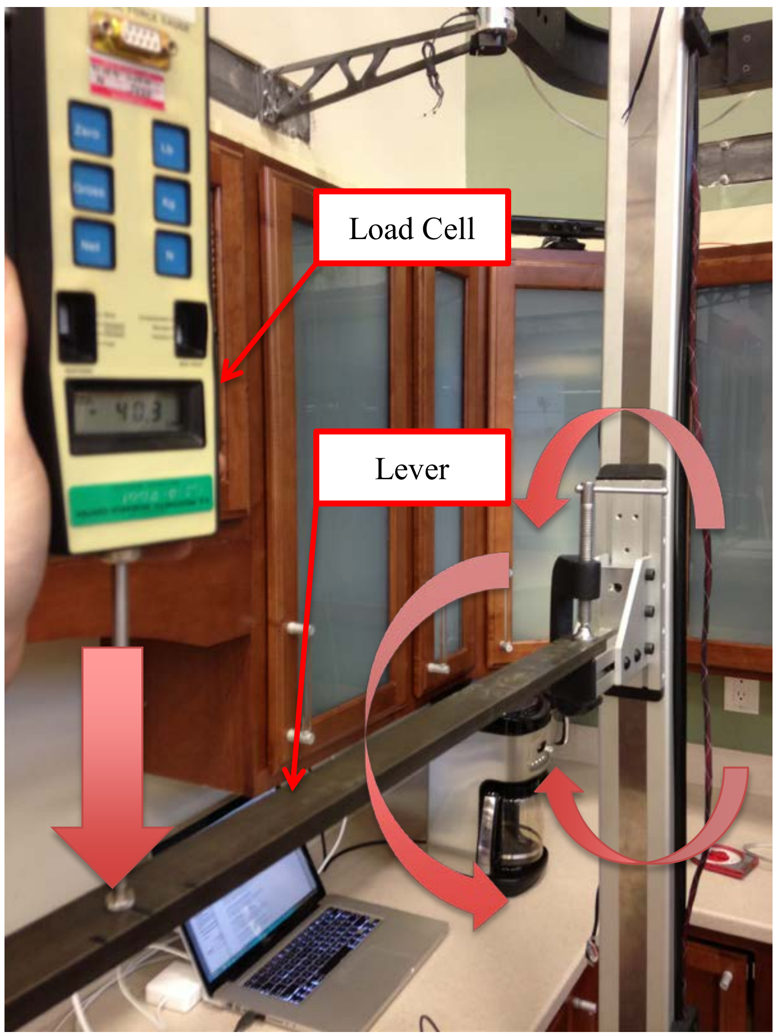


Figure 33: Robotic manipulator static load test on the mounting point in one dimension

Additionally, the bottom carriage responds in the same way as an inverse pendulum. As the column begins to tilt, the driving wheel compensates its speed, based on an accelerometer, to ensure the column remains vertical. A proportional accelerometer signal is averaged and converted into an angle with respect to the pull of gravity. The motor speed is proportional to the angle, up to an arbitrary 10 [degrees], resulting in a faster correction.

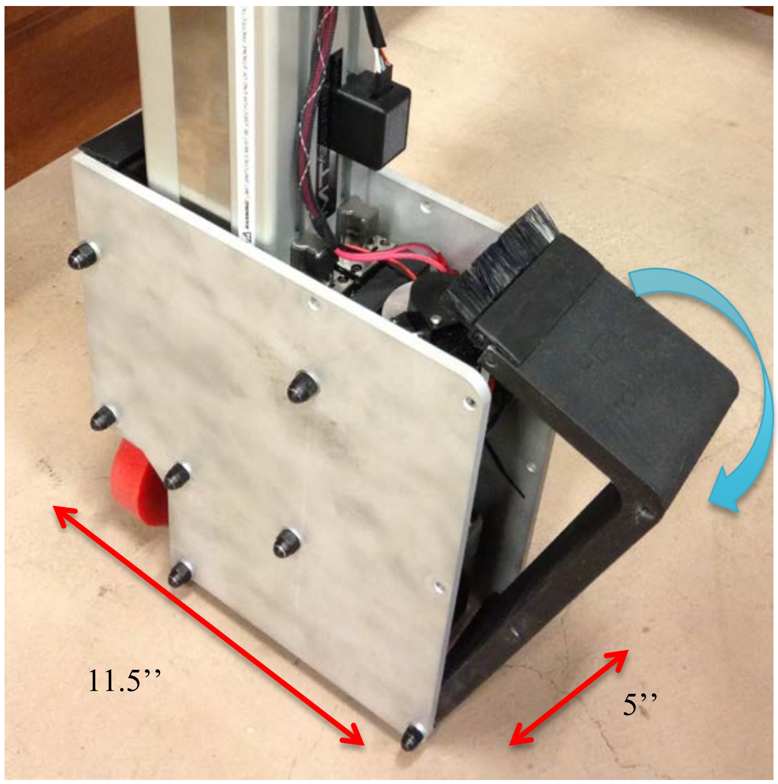


Figure 34: Final bottom carriage footprint and easy access window

3.1.5 Electronics and control

The programming and electrical components were written in Arduino C-complier and put together on a breadboard for quick functionality. The entire assembly and electronics were designed for use with an Arduino Mega 2560 for its numerous inputs and outputs. These inputs initially included the three motor encoders, joystick controller, limit switches, accelerometers, and wireless xBee transmitter for limit-switch information transfer between the kitchen and robot. The main pulse width modulation (PWM) outputs were for the motor controllers that would subsequently drive the motors via a speed and directional signal and digital outputs would control the simple electromagnetic brake solenoid. A schematic of the electronics can be seen in Appendix D.

The control code to operate these electronics was created in numerous stages to avoid problems. Initially, only a single motor and brake was driven with gradual complexity added. Next, the other two motors were added with functions created to read from the accelerometers and compensate for column tilting. Further capabilities were then created to read from on-board limit switches and from external wirelessly transmitted limit switches. Encoders were then incorporated to track position down to a tenth of an inch and the data was saved via the Arduino's internal memory. The final version of the prototyped code allowed for input from a column-mounted joystick or from a computer's serial interface to autonomously move the track to a given X, Y position within 0.1 [inches]. It was at this point a demo could be generated and a prototype focus group evaluation could be conducted. The final working version of Arduino-based code can be seen in Appendix D. The finished prototype can be seen in Figure 35 below.

Figure 35: Final prototyped KitchenBot

4.0 FOCUS GROUP PROTOTYPE EVALUATION

The second iteration of the "Participatory Evaluation of Assistive Technologies" protocol was conducted with a modified questionnaire and a working prototype for demonstration. This evaluation would provide some user insight to assist with the next stage of development. The KitchenBot was discussed in three different focus groups at the Human Engineering Research Laboratories in Pittsburgh, PA.

4.1 METHODOLOGY

Similar to the previous focus groups, subjects were recruited if they were over the age of 18, have a physical disability, and can comprehend English. All subjects provided informed consent before participation in the focus group.

Participants first completed a questionnaire about general demographics, their current and past experience with assistive technology, meal preparation task importance, and frequency of assistance. They then participated in a round-robin group discussion with each group consisting of no more than 5 participants and lasting no more than 1.5 hours. Although the participants were not allowed to directly interact with the KitchenBot, they were able to see a demonstration of the KitchenBot autonomously opening kitchen cabinets, appliances, and the sink faucet. Towards the end of the discussion, the group was asked to rank the priority of topics discussed which were outlined on a whiteboard. These images can be seen in Appendix E. The discussions were audio recorded and later transcribed for content analysis. After the focus group discussion, subjects were asked to complete the end of the questionnaire related to frequency of meal preparation, frequency of meal preparation assistance, perceived KitchenBot usefulness, and perceived KitchenBot ease-of-use. Likert-Type scale response anchors were used to aid individual responses for varying levels of agreement, importance, and concern (Vagias, 2006). A copy of this questionnaire can be found in Appendix E.1.

4.2 RESULTS

4.2.1 Quantitative data

A total of 11 subjects were recruited to participate in three focus groups. Of those 11, six reported their disability as a Spinal Cord Injury, two as having Cerebral Palsy, one as having Polio, one as a double amputee, and one as having orthopedic impairments. There were 5 who use manual wheelchairs, 5 who use power wheelchairs, and 1 who uses a scooter for independent mobility. The average number of years with a disability was 24.9 ± 24.4 years. There were 7 males and 4 females with an average age of 44 ± 21 years.

Of the participants, 7 said they live in an urban location, 3 live in a suburban location, and 1 lives in a rural location. Furthermore, 10 indicated they live in an apartment, home, or condominium with only 1 living in a residence hall or collage dormitory. The participants highest education level is well mixed with 3 indicating they have received a high school diploma or GED, 3 have an associates or vocational degree, 3 have a bachelors degree, and 2 have a masters degree. Total household income was also diverse with 2 participants earning $10-$15k per year, 3 earning $15-$20k per year, 1 earning $20-25k per year, 1 earning $25-$35k per year, 2 earning $35-$50k per year, and 2 who elected not to answer. Current work status indicated 3 participants are students, 1 working full-time outside the home, 3 working part-time outside the home, 1 working part-time inside the home, 1 unable to work because of disability, 1 retiree, and 1 with missing information. Participants were also allowed to indicate more than one answer in regards to health insurance which showed that 7 are covered by Medicare or Medicaid, 4 are covered by their employer, spouse's/parent's employer, or previous employer, and 2 pay out-of-pocket for coverage.

Information related to the health and experience with technology was also gauged to better understand the background of each individual. In regards to self-care, 4 participants (36.4%) indicated they have some problems washing and dressing and 1 participant (9.1%) indicated they are unable to wash or dress themselves. Seven participants (63.6%) also stated they have some problems with performing usual activates (work, study, housework, etc.). Additionally, 4 (36.4%) participants said they built an assistive device to meet their needs, 7 (63.6%) modified some existing technology to meet their needs, and 4 (36.4%) considered themselves as technology savvy. The median response to questions pertaining to technology in general is shown in Table 14 with 1 indicating "Not At All" or 7 indicating "Completely". Moreover, the median response to phrases about the participant is also listed below in Table 15 with a 1 indicating "Not At All Accurate" or 7 indicating "Extremely Accurate". Lastly, the median responses to factors for choosing technology, which vary between "Not At All Important" to "Extremely Important" are detailed in Table 16 below.

Table 14: Median response of technology in general on a seven-point Likert scale

Phrase	Median Response
Makes life easy and convenient:	6.0
Makes life complicated:	2.0
Gives people control over their daily lives:	6.0
Makes people dependent:	5.0
Makes life comfortable:	6.0
Makes life stressful:	2.0
Brings people together:	5.0
Makes people isolated:	4.0
Increases personal safety and security:	6.0
Reduces privacy:	3.0

Table 15: Median response of phrases on a seven-point Likert scale

Phrase	Median Response
I like to keep up with the latest technology:	6.0
I generally wait to adopt a new technology until all the bugs have been worked out:	5.0
I enjoy the challenge of figuring out high tech gadgets:	5.0
I feel confident that I have the ability to learn to use technology:	6.0
Technology makes me nervous:	1.0
If a human can accomplish a task as well as technology, I prefer to interact with a person:	4.0
I like the idea of using technology to reduce my dependence on other people:	6.5

Table 16: Median response of factors for choosing technology on a seven-point Likert scale

Factor	Median Response
How well it meets your needs:	7.0
Ease of use:	5.5
Cost:	5.0
Attractiveness:	5.0
How visible it is to others:	4.0
How it affects your privacy:	3.0
How safe it is to use:	6.0

Before the group discussion, each participant was asked to respond to a list of kitchen related tasks using a seven-point Likert scale from "Very Unimportant" to "Very Important" and the frequency they receive assistance with each of those tasks from "Never" to "Every Time". The percentage of participants who said the most important tasks, those ranked between "Slightly Important" and "Very Important", were found to be opening/closing/reaching into a cabinet above the countertop (90%), moving hot objects from the stove and oven (90%), moving hot objects from the microwave (91%), and putting in/taking out heavy objects (91%). In addition, participants also reported they needed assistance "Frequently", "Usually", or "Every Time" with stabilizing pots on the stove (55%), opening/closing/reaching a cabinet above the countertop (55%), moving hot objects from the stove (60%), moving hot objects from the oven (64%), putting in/taking out heavy objects (64%), and carrying heavy objects (64%).

After the group discussion, participants then responded to questions of meal preparation frequency and assistance. Results showed 10% do not cook at home, 40% cook 0-4 times per week, 20% cook 5-7 times per week, and only 30% of participants prepare a meal more than once per week at home. Moreover, 70% of the group reported they receive assistance with meal preparation more than once per week, 20% receive assistance 2-4 times per week, and only 10% reported being completely independent with meal preparation. The following Table 17 compares the concept and prototype focus group meal preparation frequency responses.

Table 17: Comparison of focus group meal preparation frequency responses

Concept Focus Group	Prototype Focus Group	Average	Question
20%	10%	15%	Do not cook at home
16%	20%	18%	Cook 0-1 times per week
24%	20%	22%	Cook 2-4 times per week
12%	20%	16%	Cook 5-7 times per week
16%	10%	13%	Cook 8-14 times per week
12%	20%	16%	Cook greater than 14 times per week

The final tables of the questionnaire also gauged the participants perceived ease-of-use and usefulness of the KitchenBot. These ease-of-use and usefulness tables were modeled after an established questionnaire (Sauro, 2011). From the results, 90.9% of participants believed it would be easy for them to remember how to operate the KitchenBot and 72.7% reported that interacting with KitchenBot would be understandable, as shown in Table 18. Moreover, almost two thirds of the participants (63.6%) believed the KitchenBot would be easy to use and 81.8% believed using the KitchenBot would allow them to complete tasks they currently could not do independently, as shown in Table 19.

Table 18: Percentage of responses in regard to perceived KitchenBot ease-of-use

Statement	Neither Agree or Disagree (4)	Somewhat Agree (5)	Agree (6)	Strongly Agree (7)	Somewhat to Strongly Agree (5,6,7)
KitchenBot would be cumbersome to use	0.0%	36.4%	9.1%	0.0%	45.5%
Learning to operate KitchenBot would be easy for me	10.0%	9.1%	36.4%	18.2%	70.0%
Interacting with KitchenBot would be frustrating	18.2%	18.2%	0.0%	9.1%	27.3%
It would be easy to get KitchenBot to do what I want it to do	0.0%	18.2%	36.4%	9.1%	63.6%
It would be easy for me to remember how to operate KitchenBot	0.0%	18.2%	45.5%	27.3%	90.9%
Interacting with KitchenBot would require a lot of mental effort	9.1%	18.2%	27.3%	0.0%	45.5%
Interacting with KitchenBot would be understandable	0.0%	18.2%	54.5%	0.0%	72.7%
It would take a lot of effort to become skillful as using KitchenBot	18.2%	18.2%	18.2%	9.1%	45.5%
It would be easier to just get another person to help rather than use KitchenBot	20.0%	9.1%	27.3%	9.1%	50.0%
I would be anxious about using KitchenBot	27.3%	27.3%	18.2%	0.0%	45.5%
KitchenBot would be easy to use	9.1%	9.1%	54.5%	0.0%	63.6%

Table 19: Percentage of responses in regard to perceived KitchenBot usability

Statement	Neither Agree or Disagree (4)	Somewhat Agree (5)	Agree (6)	Strongly Agree (7)	Somewhat to Strongly Agree (5,6,7)
Using KitchenBot would allow me to complete kitchen tasks that I cannot do independently	9.1%	18.2%	36.4%	27.3%	81.8%
KitchenBot would enable me to complete kitchen tasks more quickly	18.2%	27.3%	27.3%	0.0%	54.5%
Using KitchenBot would improve my performance with kitchen tasks	20.0%	18.2%	27.3%	0.0%	50.0%
Using KitchenBot would allow me to complete more kitchen tasks than would otherwise be possible	10.0%	18.2%	36.4%	9.1%	70.0%
Using KitchenBot would enhance my effectiveness with kitchen tasks	20.0%	18.2%	18.2%	9.1%	50.0%
Using KitchenBot would make my life easier	20.0%	27.3%	27.3%	9.1%	70.0%
It would be embarrassing to be seen using KitchenBot	9.1%	0.0%	0.0%	18.2%	18.2%
Overall, KitchenBot would be useful in my daily routine	9.1%	18.2%	27.3%	27.3%	72.7%
The government should invest resources to develop KitchenBot	0.0%	27.3%	27.3%	45.5%	100.0%

This is congruent with the earlier concept focus group findings, which leads us to better understand the numerous challenges individuals with disabilities face with meal preparation. With 45.5% of the participants saying they would either “Likely”, “Very Likely”, or “Definitely” be willing to have the KitchenBot in their home, this robot could prove to be a viable solution.

4.2.2 Qualitative data

Discussion topics included the types of interface and control method, feasibility, safety, and development priority. Varying amounts of time were spent on each topic and were dictated by the demeanor of the group.

The early portion of the discussion was spent considering the different types of interface and control method. The three types of interface included the joystick, tablet, and voice control. The joystick method was demonstrated utilizing a column-mounted horizontal two-degree of freedom joystick for the track and a separate tethered joystick for controlling the arm, shown in Figure 36. The tablet was demonstrated next with the majority of individuals stating that direct use of the tablet would be the only way they could really critique its layout and features, shown in Figure 37. Voice control was examined last with an explanation of its potential architecture, such as manual motion or task type commands. Some common interface and control method themes can be explained when some said:

"The problem I see, especially if you are using a manual chair, is to follow [the joystick's] movement through the environment."

"It seems like the joystick would be easier instead of like talking."

"That's what's nice about this screen, because if it's on a computer, you can use adapted equipment to control it, like a track ball, or dragon, or a head pointer."

"If you have any background noise, [voice control] is very sensitive. So, it would have to be really quiet for it to be accurate."

Figure 36: Joystick track control interface

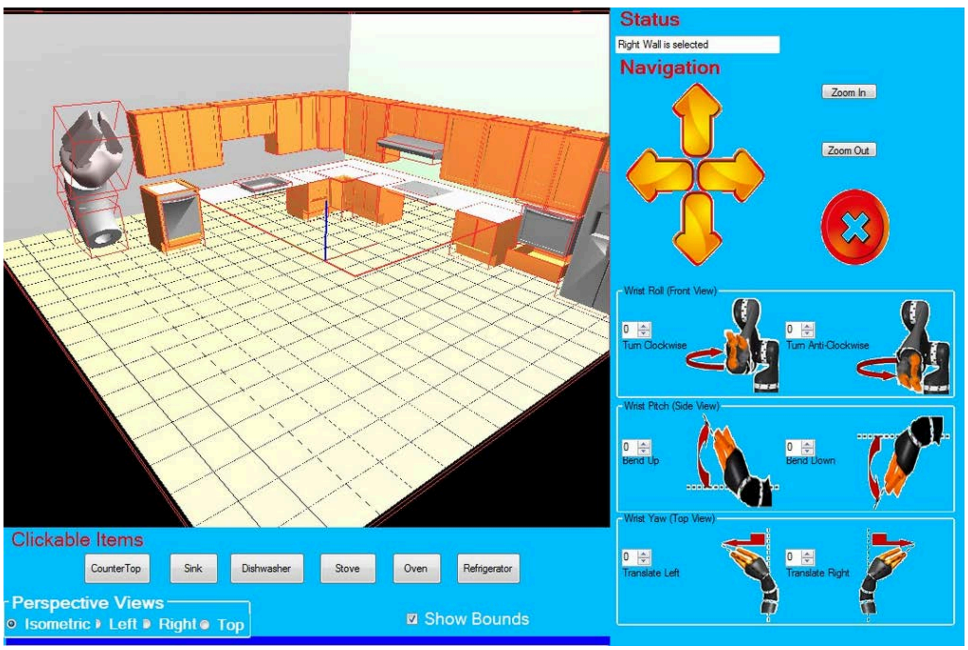


Figure 37: Tablet control interface

In response to the varied types of track interface, the tablet was ranked the favorite more times than the joystick or voice control. Moreover, in response to the gripper control, the favorite method was tied between the tablet and voice method. Autonomous vs. manual control was also discussed with an explanation that a hybrid of both methods could exist, such as performing semi-autonomous tasks. The idea of KitchenBot performing automated or semi-automated tasks was widely liked and could be summarized by one participant which said:

"I would think automated tasks, because that could greatly reduce the time and effort to get something."

The KitchenBot feasibility was the next major discussion topic with areas including the level of noise, track installation, footprint, adapted kitchen equipment/organization, and dual arms. In general, the response to the level of noise was neutral, but all the participants agreed that noise would not hinder their willingness to use the KitchenBot. As with the earlier concept focus group, participants were well mixed in the likelihood of installing this type of track above their cabinets. Similarly, in regards to the footprint, some had concerns with maneuvering around the KitchenBot because of their small apartment style kitchen while others thought it should not be a problem. Discussion also delved into the idea of robot adapted kitchen equipment or item organization to further improve the manipulator's capabilities. Many adapted equipment suggestions were made in regards to pickup up items, but generally the groups had no issues with using custom equipment or sticking to a particular organizational scheme as long as items could be replaced, if needed. Lastly, responses regarding adding another arm revolved around which types of tasks would benefit, particularly opening containers or taking out heavy items from the oven. Some comments related to these discussion themes were:

"If you have friends over or something else, then [the noise] might get annoying when you're trying to do something at the same time."

"This looks like [KitchenBot] would cater to a more modern home type of kitchen. You know, spacious."

"My kitchen does have room where the track could be put."

"I would prefer [footprint] to be less, but if it came like that I would just deal with it."

"You can make [footprint size] reductions, but in my case, I could make it work."

"The only time I think you would need two arms is if you're stirring something and you need to hold the bowl with one."

"You would really only use two arms for opening containers, unless you had something else that could grip it."

Safety was discussed briefly among participants. The emergency stop button on the joystick and current-limiting manipulator were explained to the group and opinions and suggestions were heard. The groups thought an emergency button should be located somewhere other than the column, but preferably two groups thought it should just stop on its own.

The whiteboard development priority ranking was the last discussion topic. As the groups discussed the previously mentioned aspects, they were written onto a whiteboard for prioritizing. These three whiteboard images can be seen in Appendix E. Each of the three groups picked "automating tasks" as the most important priority for the next stage of development. Moreover, "safety features" was chosen among all the groups as the second most or third most important development priority. Group one and three thought customizing the track and footprint to fit smaller sized kitchens should be the third most important development priority. Lastly, group 2 thought working on item organization and adapted kitchen equipment should be the third most important development priority.

Some design and development suggestions emerged from the groups as well. These comments varied from topic to topic but are shown here:

"Maybe you could have a wireless [joystick] device."

"I think two [arms] would make it complicated."

“*You should have like an automatic safety stop.*”

“*An emergency button to call [for help].*”

5.0 CONCLUSION

The KitchenBot prototype and focus group evaluations were a stepping-stone for further improvement. The design of the KitchenBot was not truly a technological advancement, but merely a unique combination of existing technology. A series of practical autonomous capabilities, such as opening doors, opening the faucet, or pulling out drawers have already been quickly developed. Further refinement of such tasks can provide a viable product for the end user without long development time. This refinement must be systematically evaluated using the design criteria. The final section will outline the future work of the KitchenBot.

5.1 FUTURE WORK

The KitchenBot prototype possesses the potential to improve the functional capabilities of an individual with manipulation, mobility, reach, and or strength deficiencies by successfully completing the criteria. Design criteria previously discussed, such as having the freedom to move within the entire kitchen, being motor controlled, providing position feedback, incorporating fail-safe brakes, having limit switches, able to accommodate two arms, having limited track deflection, and theoretically being able to lift a 25 [lbs] turkey from the oven have been achieved. These were verified through the use of control software, FEA, and static load testing.

From those results, it was determined the track would deflect less than 0.1 [in], the current prototype could provide position feedback to within 0.1 [in], and the carriage for the arm could withstand torque of 80 [ft-lbs]. However, not all criteria were achieved.

Some criteria which have been previously unsatisfied can be evaluated by bench-top testing. These would include the level of noise, the ability to install the system into a standard residential home, and the safety of the system. The criterion related to noise can easily be tested with a decibel meter and if necessary, the motors can be replaced with comparable planetary gear motors that generate far less noise. The criteria for allowing residential home installation would need to be further analyzed using FEA and common building material properties and standards. Finally, safety could be demonstrated by running continuous testing of the system components and recording failure modes and frequency. This would give a good indication; if failure occurrence were low the system is safe. Though, safety can and should also be evaluated by the end users.

The remaining criterion, aesthetically pleasing, is a non-quantified criterion, which means that evaluation and completion must come from the consensus of the end users. This can be accomplished by testing subjects with the system to provide feedback related to the criterion. Moreover, safety could also be included in this research as added verification.

Overall, to evaluate whether the KitchenBot has achieved all the criteria and to prove its effectiveness, a single subject design could be utilized so that clinical significance could be demonstrated. Participants could be timed and asked their exertion level for completion of simple kitchen tasks before and after using the system. Before this can be successfully demonstrated, some aspects of further improvement include the design of the bottom carriage, the safety features, the type of manipulator and mounting, and the control interface.

The bottom carriage of the KitchenBot ensures the column remains vertical during horizontal motion and provides the reaction force during manipulation tasks. The prototype explained above successfully achieved these two criteria but due to the simplicity of the design, the prototype lacks a second degree of control to compensate for tilt in the perpendicular direction. A possible solution would be to implement a ball assembly that can translate in two dimensions or utilize the novel features of Omni-wheels. Moreover, this new assembly should maintain, at most, the approximate footprint of the current design and should include sensors, per the users feedback, to restrict motion if an object is in the path of travel.

Additional safety features should include an external emergency stop switch, sensors for detecting objects in its horizontal and vertical path of travel. The prototype only uses accelerometers and encoders for positioning but infrared, ultrasonic, or laser range sensors could be incorporated to restrict motion automatically. A safe-zone could also be programmed to limit the robot from entering an area that is off-limits or could cause damage to the building or individual. This would allow the KitchenBot to perform more autonomous tasks within close proximity of individuals and objects, such as cabinets and drawers, without assuming their position. Moreover, the focus groups brought to light the need for an external emergency stop switch to ensure, if the user could not be next to the robot, there would be a method of hindering motion. This switch input could even include other features of control including manual direction control or visual feedback of position and processes to inform the user of the KitchenBot's objectives. This external safety feature could even be tightly woven into the future control interface.

The focus group participants expressed interest in all of the final three types of control interface. However, the best foreseeable course of action would be to further develop a simple to use tablet-based graphical user interface (GUI). With this flexible GUI, a user could customize layout, utilize numerous autonomous or manual control features, or use computer access devices to improve accessibility. Some examples of computer access devices could be voice recognition software, such as Dragon NaturallySpeaking, to interact with different features of the GUI, a trackball or joystick to control a cursor on the screen, or a switch could even allow scanning to sequentially select items on the screen. This interface would open possibilities for single click autonomous tasks. Such tasks could be programmed into the robot as simplified sub-routines. With this database of sub-routines, a user could chain together numerous autonomous features to perform varied organizational, meal preparation, or cleanup tasks. Some examples could be retrieval of objects, opening doors, drawers, or appliances, and pushing appliance buttons.

Another potential area of investigation could be gesture control with use of a Kinect or Leap Motion sensor ("Leap Motion," 2013). Users could be able to point or directly control the track, manipulator, and hand by using their own fingers as inputs. The combination of these aforementioned interfaces could allow a user to work with the KitchenBot as though it is another human partner or sous-chef.

The JACO robotic manipulator could serve as a long-term demonstration of KitchenBot capabilities, but further improvement of the mounting and manipulator could be developed. Although the JACO is a well-researched manipulator with previously published clinical and economic implications, it lacks the ability to provide assistance with heavy payload tasks. Further development or adaptation of various manipulators could eventually provide limitless task potential. Moreover, the point used for mounting of the manipulator could be further developed to allow an individual to autonomously dock the KitchenBot manipulator on their powered wheelchair for external manual manipulation tasks. Even collaboration with smart kitchen technology, a rapidly growing market, could more easily allow the KitchenBot to recognize, locate, or organize items. With implementation of the previously suggested work and a potential system for detecting static objects, the KitchenBot could perform numerous autonomous tasks such as unloading your groceries, loading a dishwasher, retrieving items, or preparing a meal for just about anybody who needs assistance to stay home and independent.

APPENDIX A

CONCEPT SKETCHES

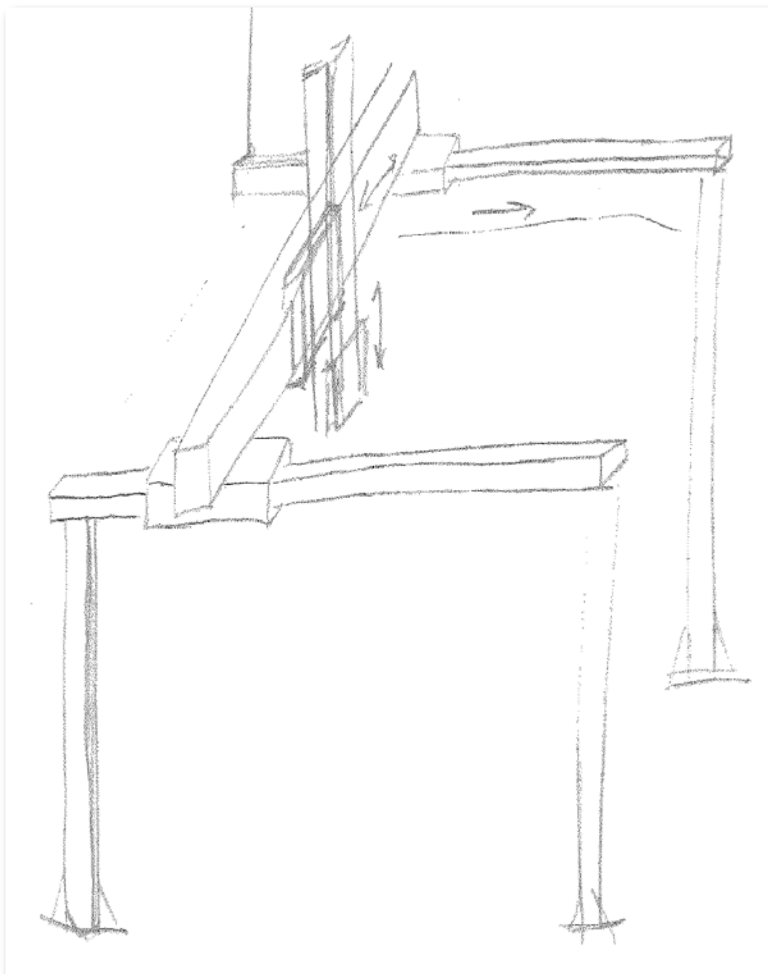


Figure 38: Gantry track style concept sketch with one corner under suspension

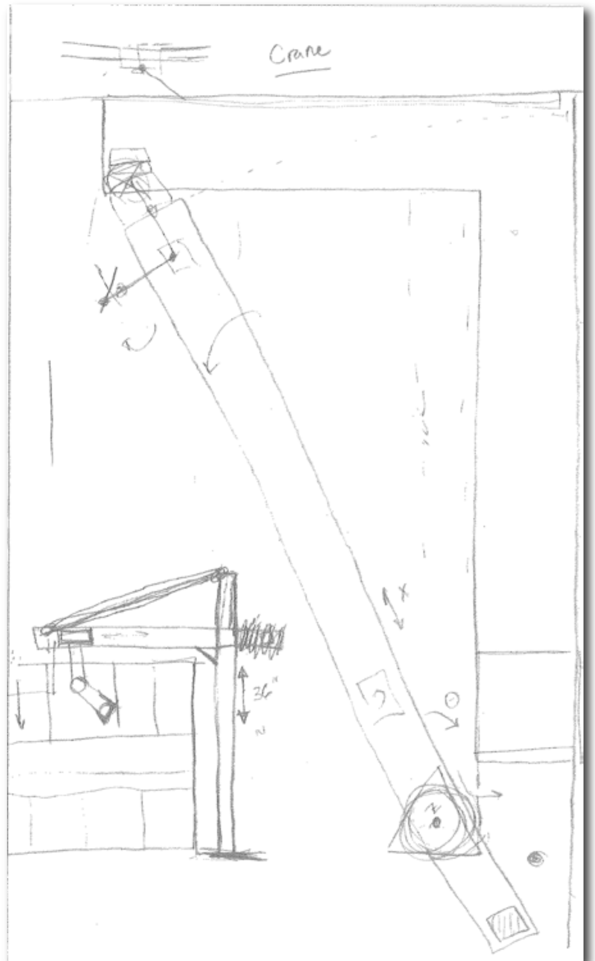


Figure 39: Jib crane style concept sketch with pie shaped work envelope

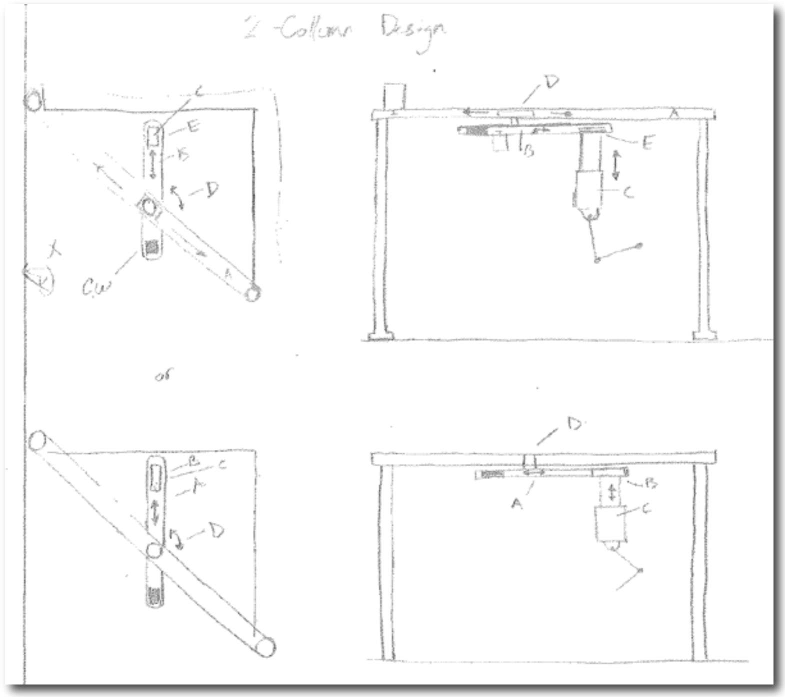


Figure 40: Hybrid concept sketch with telescoping arm and counterweight

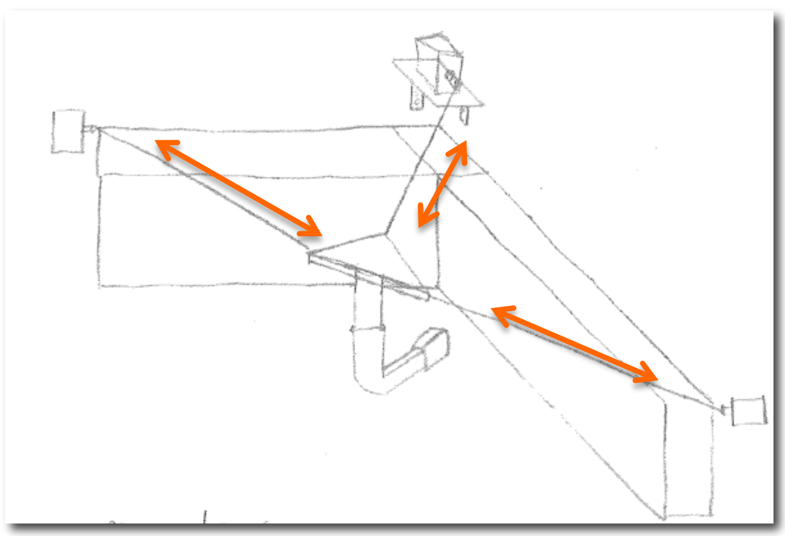


Figure 41: Stadium camera concept sketch with three fast acting winch cables

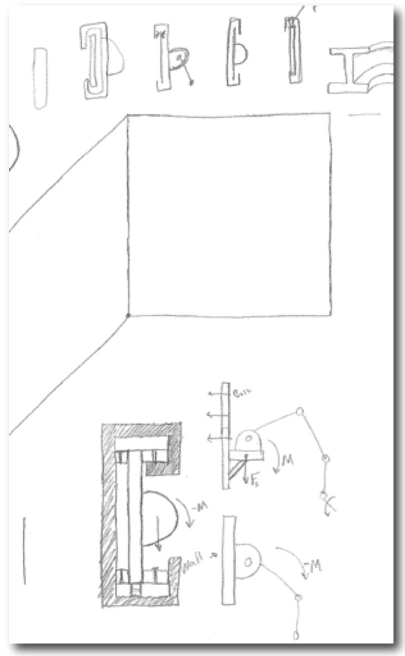


Figure 42: Early carriage cross section sketches

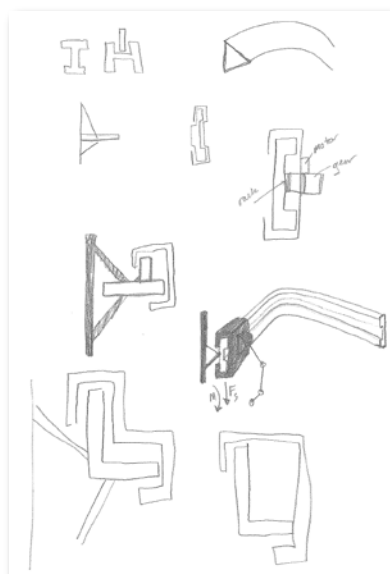


Figure 43: Early carriage cross section sketches (continued)

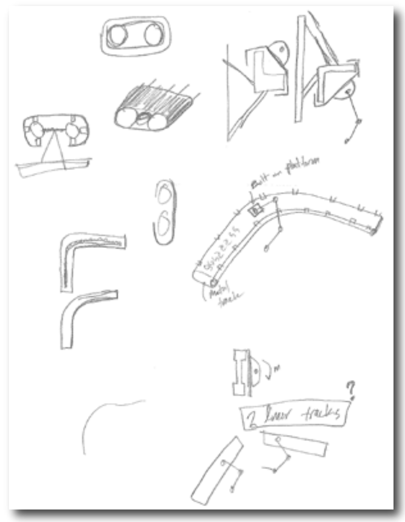


Figure 44: Early carriage cross section sketches (continued)

APPENDIX B

CONCEPT FOCUS GROUP

Figure 45: Conceptual KitchenBot reaching into a drawer

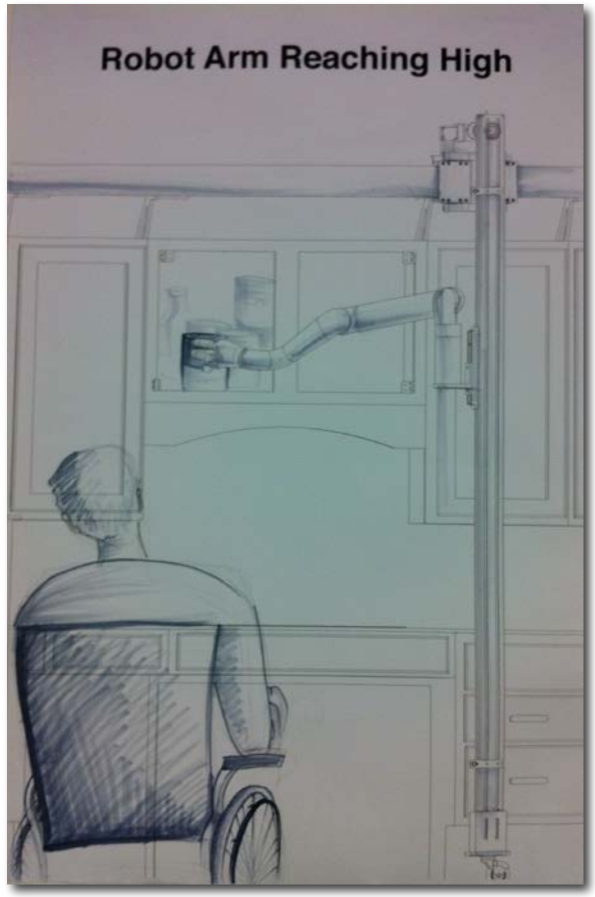


Figure 46: Conceptual KitchenBot reaching into an upper cabinet

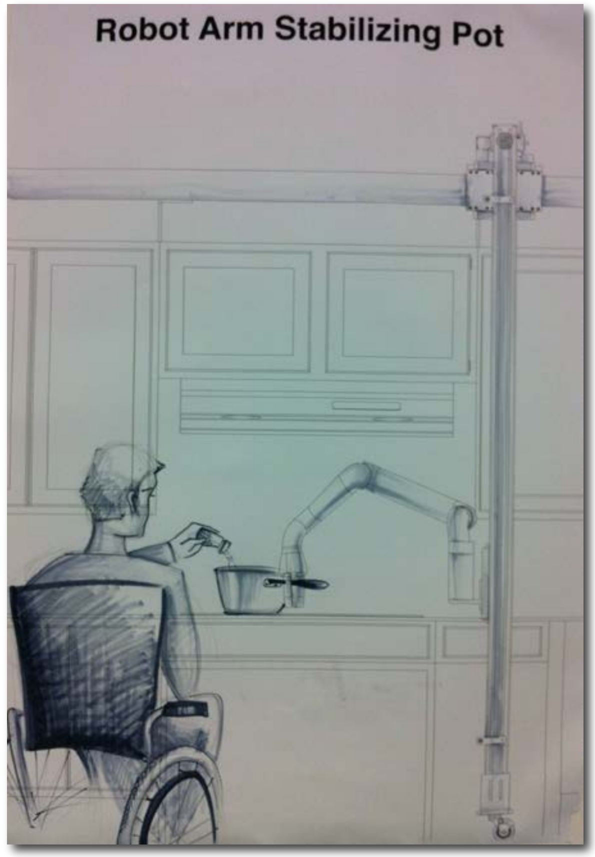


Figure 47: Conceptual KitchenBot stabilizing a pot

Figure 48: Conceptual KitchenBot full view reaching into a drawer

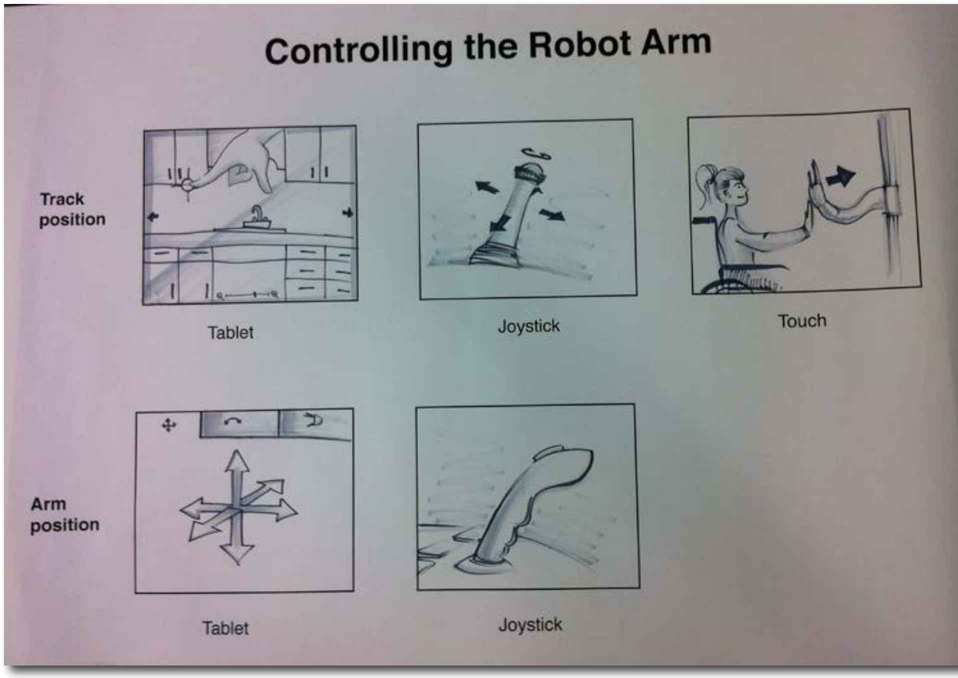


Figure 49: KitchenBot and robot arm potential interfaces

Figure 50: Focus group poster setup

B.1 CONCEPT FOCUS GROUP QUESTIONNAIRE

Subject ID: __________

Questionnaire Packet

Participatory Evaluation of Assistive Technologies

2012 National Veterans Wheelchair Games

Human Engineering Research Laboratories of the VA Pittsburgh Healthcare System and the University of Pittsburgh

COMPLETION LOG:	DATE:	INITIALS:	TIME:
Data Collection	/ /		
Data Entry	/ /		
Verification	/ /		

Prospective Technology QuestionnaireV.3 Page 1 of 11 5/23/2012

PART A: Demographics & Self-Assessment

We are interested in the relationship of disability and assistive technology to other factors in your life. The following questions deal with these factors.

1. **What is your injury or diagnosis?** ____

   ____

   Date of onset, injury, or diagnosis: _____/_____/_____

2. **Gender:** ☐ Male ☐ Female

3. **Geographic Location:**

   ☐ Rural ☐ Urban
   ☐ Suburban ☐ Unsure

4. **Race/Ethnicity**

   ☐ Black or African American
   ☐ Asian
   ☐ White or Caucasian
   ☐ Hispanic or Latino
   ☐ American Indian or Alaskan Native
   ☐ Native Hawaiian or other Pacific Islander
   ☐ Two or more races

Health Information

5. For each of the following items below, please check the statement that best describes you. Do not check more than one box in each group.

   Self-care

   ☐ I have no problems with self-care
   ☐ I have some problems washing or dressing myself
   ☐ I am unable to wash or dress myself

   Usual activities (e.g. work, study, housework, family or leisure activities)

   ☐ I have no problems with performing my usual activities
   ☐ I have some problems with performing my usual activities
   ☐ I am unable to perform my usual activities

   Pain/Discomfort

   ☐ I have no pain or discomfort
   ☐ I have moderate pain or discomfort
   ☐ I have extreme pain or discomfort

6. **In which type of housing do you live?**

   ☐ Residence hall/College dormitory
   ☐ House/Apartment/Condominium
   ☐ Senior housing (independent)
   ☐ Assisted living
   ☐ Nursing Home
   ☐ Relative's home
   ☐ Other
   (please specify):______________________

7. **What is the highest level of formal education you have completed?**

- ☐ 8th grade or less (includes pre-school)
- ☐ 9th through 11th grade
- ☐ High School Diploma or GED
- ☐ Associate Degree/Vocation/Technical School
- ☐ Bachelors Degree
- ☐ Masters Degree
- ☐ Doctorate: includes PhD, MD, JD etc.

8. **Which statement best describes your CURRENT work status?**

- ☐ Working full-time, outside the home
- ☐ Working part-time, outside the home
- ☐ Working full-time, inside the home
- ☐ Working part-time, inside the home
- ☐ Unable to work because of disability
- ☐ Unemployed: not able to find job in field that I was trained
- ☐ I choose not to be employed or am retired
- ☐ Student

9. **Please indicate which best describes your marital status:**

- ☐ Single
- ☐ Married
- ☐ Living with someone as if married
- ☐ Divorced/Separated
- ☐ Widowed

One's financial situation and health insurance can influence one's health. Please check the response that best describes you.

10. **Your current approximate total household income per year is:** (including spouse or other household income sources):

- ☐ Less than $10,000
- ☐ $10,000 – 15,000
- ☐ $15,000 – 20,000
- ☐ $20,000 – 25,000
- ☐ $25,000 – 35,000
- ☐ $35,000 – 50,000
- ☐ $50,000 – 75,000
- ☐ Greater than $75,000

11. **Do you feel that your disability has affected your income?**

- ☐ No
- ☐ Yes ➡ If yes, has your disability:
  - ☐ increased your income
  - ☐ decreased your income

12. **Are you currently on disability?**

- ☐ No
- ☐ Yes ➡ If yes, which type:
  - ☐ SSI
  - ☐ SSDI
  - ☐ Workman's Compensation
  - ☐ Other, please specify: ______________________

13. **Please check the statement(s) that best describe you regarding health insurance:**

- ☐ I do not have health insurance; I use my private money to pay for medical expenses.
- ☐ Health insurance is provided through Medicare or Medicaid.
- ☐ Health insurance is provided by my employer, my spouse's/parent's employer, or previous employer (i.e., Champus, Tri-Care).
- ☐ I have health insurance, but I pay for it through personal monies
- ☐ Other: ____

Part B: Assistive Technology

1. **On MOST DAYS which of the following assistive devices do you use?**
Check all that apply:

☐ Unassisted Walking	☐ Walker	☐ Scooter
☐ Cane	☐ Wheeled Walker	☐ Other, please specify:
☐ Quad Cane	☐ Manual Wheelchair	________________
☐ Crutches	☐ Power Wheelchair	

If you use a wheelchair….

1a. **Which type of wheelchair do you use the most?**

☐ Manual wheelchair ☐ Power wheelchair ☐ Scooter

1b. **What is the age of your current wheelchair?** _____ years

1c. **How many total years have you used a wheelchair for your mobility needs?** ______ years

5. **Are you satisfied with your current assistive technology?**

☐ Yes ☐ No ☐ Unsure

6. **Have you had a piece of assistive technology that worked especially well for you?**

☐ Yes ☐ No ☐ Unsure

⬇

6a. **If yes**, please describe: ____

____

7. **Have you had a piece of assistive technology that did not work well for you?**

☐ Yes ☐ No ☐ Unsure

⬇

7a. **If yes**, please describe: ____

____

8. **Have you ever built an assistive device to meet your needs?**

☐ Yes ☐ No ☐ Unsure

9. **Have you ever modified some existing technology to suit your needs?**

☐ Yes ☐ No ☐ Unsure

10. **Would you describe yourself as technologically savvy (i.e. you purchase the newest technology as soon as it is available)?**

☐ Yes ☐ No ☐ Unsure

In general, to what extent do you believe that technology….

	Not at all						Completely
	1	**2**	**3**	**4**	**5**	**6**	**7**
Makes life easy and convenient							
Makes life complicated							
Gives people control over their daily lives							
Makes people dependent							
Makes life comfortable							
Makes life stressful							
Brings people together							
Makes people isolated							
Increases personal safety and security							
Reduces privacy							

Subject ID: __________

How accurate are each of the following phrases about you…

Phrase	Not at all Accurate 1	2	3	4	5	6	Extremely Accurate 7
I like to keep up with the latest technology							
I generally wait to adopt a new technology until all the bugs have been worked out							
I enjoy the challenge of figuring out high tech gadgets							
I feel confident that I have the ability to learn to use technology							
Technology makes me nervous							
If a human can accomplish a task as well as technology, I prefer to interact with a person							
I like the idea of using technology to reduce my dependence on other people							

How important are each of these factors for you when choosing technology…

Factor	Not at all Important 1	2	3	4	5	6	Extremely Important 7
How well it meets your needs							
Ease of use							
Cost							
The way it looks (attractiveness)							
How visible it is to others							
How it affects your privacy							
How safe it is to use							

PLEASE STOP HERE UNTIL RESEARCHERS INDICATE TO FINISH THE QUESTIONNAIRE

Part C: Prospective Technology

PRODUCT 1: SINGLE MOTOR PROPELLED WHEELCHAIR (SIMPL-WC)

The Single Motor Propelled Wheelchair (SIMPL-WC) is a mix between a scooter and a powered wheelchair. The SIMPL-WC has a tiller like a scooter and seating system like a power wheelchair. It can be easily converted from 'manual' steering to 'powered steering' with a simple steering 'attachment', can maneuver in tight spaces like a powered wheelchair but be low-cost like a scooter and would maneuver in rough terrain like a powered wheelchair.

Statement	Strongly Disagree						Strongly Agree
	1	2	3	4	5	6	7
I would choose to use the technology							
Using this technology would make my life easier							
Learning to use this technology would be easy for me							
I would be anxious about using the technology							
It would be embarrassing to be seen using the technology							
Using this technology would be an invasion of my privacy							
It would be easier to just get another person to help rather than use this technology							
It's important that we develop technology that can do this							
The government should invest resources to develop these technologies							

Today, we demonstrated three different types of tiller steering systems to you.
Please rank the three tiller steering systems from 1 – 3, where 1 is the best, according to the following criteria:

1. **Which tiller steering system was more intuitive (that is, easy to understand/use without a lot of thought)?** *Please rank from 1(best) to 3.*

_____ Center Post _____ Swing Away _____ Roll Away

1a. Please explain why you ranked your first choice first? ________________________________

____

1b. Please explain why you ranked your third choice third? ________________________________

____

2. **Which tiller's detachment/storage of the steering system was more intuitive (that is, easy to understand/use without a lot of thought)?** *Please rank from 1 (best) to 3.*

_____ Center Post _____ Swing Away _____ Roll Away

2a. Please explain why you ranked your first choice first? ____________________

2b. Please explain why you ranked your third choice third? ____________________

3. **Which tiller steering system has the best adjustability?** *Please rank from 1 (best) to 3.*

_____ Center Post _____ Swing Away _____ Roll Away

3a. Please explain why you ranked your first choice first? ____________________

3b. Please explain why you ranked your third choice third? ____________________

4. **Which tiller's steering system would facilitate transferring in/out of the chair more easily?** *Please rank from 1 (best) to 3.*

_____ Center Post _____ Swing Away _____ Roll Away

4a. Please explain why you ranked your first choice first? ____________________

4b. Please explain why you ranked your third choice third? ____________________

5. **Which tiller steering system is better looking?** *Please rank from 1 (best) to 3.*

_____ Center Post _____ Swing Away _____ Roll Away

5a. Please explain why you ranked your first choice first? ______________________________

5b. Please explain why you ranked your third choice third? ______________________________

6. **Which tiller steering system seems to be more sturdy and/or durable?** *Please rank from 1 (best) to 3.*

_____ Center Post _____ Swing Away _____ Roll Away

6a. Please explain why you ranked your first choice first? ______________________________

6b. Please explain why you ranked your third choice third? ______________________________

7. **Overall, how would you rank the three tiller steering systems?** *Please rank from 1 (best) to 3.*

_____ Center Post _____ Swing Away _____ Roll Away

7a. Please explain why you ranked your first choice first? ______________________________

7b. Please explain why you ranked your third choice third? ______________________________

PRODUCT 2: THE KITCHEN BOT

The Kitchen Bot is a robotic manipulator mounted to a track in the kitchen. The track resembles a rolling bookshelf ladder which rides above the countertop and can assist with activities of daily living in a kitchen, particularly food preparation. The track can be installed into almost any kitchen configuration and provides the robotic manipulator access to the entire workspace from the ground to the top cabinets. This technology would be able to open cabinet doors and drawers, reach items that may be too high, stabilize pots or pans during cooking, or move items that are difficult to handle. The user input could be in the form of a physical "touch to move" interaction, joystick, or tablet PC.

Statement	Strongly Disagree						Strongly Agree
	1	2	3	4	5	6	7
I would choose to use the technology							
Using this technology would make my life easier							
Learning to use this technology would be easy for me							
I would be anxious about using the technology							
It would be embarrassing to be seen using the technology							
Using this technology would be an invasion of my privacy							
It would be easier to just get another person to help rather than use this technology							
It's important that we develop technology that can do this							
The government should invest resources to develop these technologies							

Statement		Times per week				
How many times per week do you use the following…	**Not at all**	**0-1**	**2-4**	**5-7**	**8-14**	**>14**
I use the microwave						
I use the sink						
I use the refrigerator						
I use the stovetop						
I use the oven						
I use the dishwasher						

How many times per week….	Not at all	0-1	2-4	5-7	8-14	>14
do you cook or prepare meals at home						
does someone assist you in meal preparation						

If my kitchen had this technology, I would cook or prepare meals: ☐ Less ☐ Same ☐ More

Subject ID: __________

Please rate your level of difficulty when using or doing each of the items listed below…

Appliance/Activity		No Difficulty						Much Difficulty
	I do not use at all	1	2	3	4	5	6	7
Microwave								
Sink								
Refrigerator								
Stove-top								
Oven								
Dishwasher								
Counter-top appliances (Coffee maker, blender, toaster oven)								
Putting away groceries								

Is there another area of the kitchen or appliance that poses difficulty for you? ______________________

How much would you be willing to pay out-of-pocket for this technology? $__________
(Please enter only numbers)

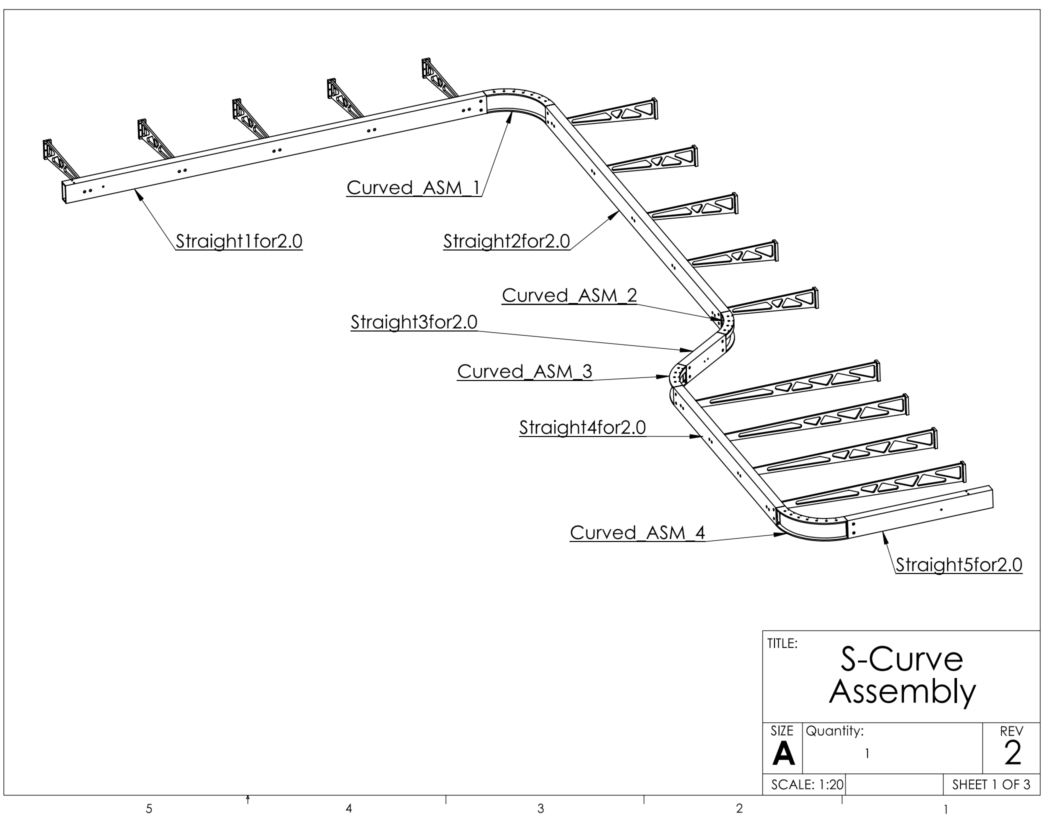
Please rate how likely you are to want the technology based on the feature described…

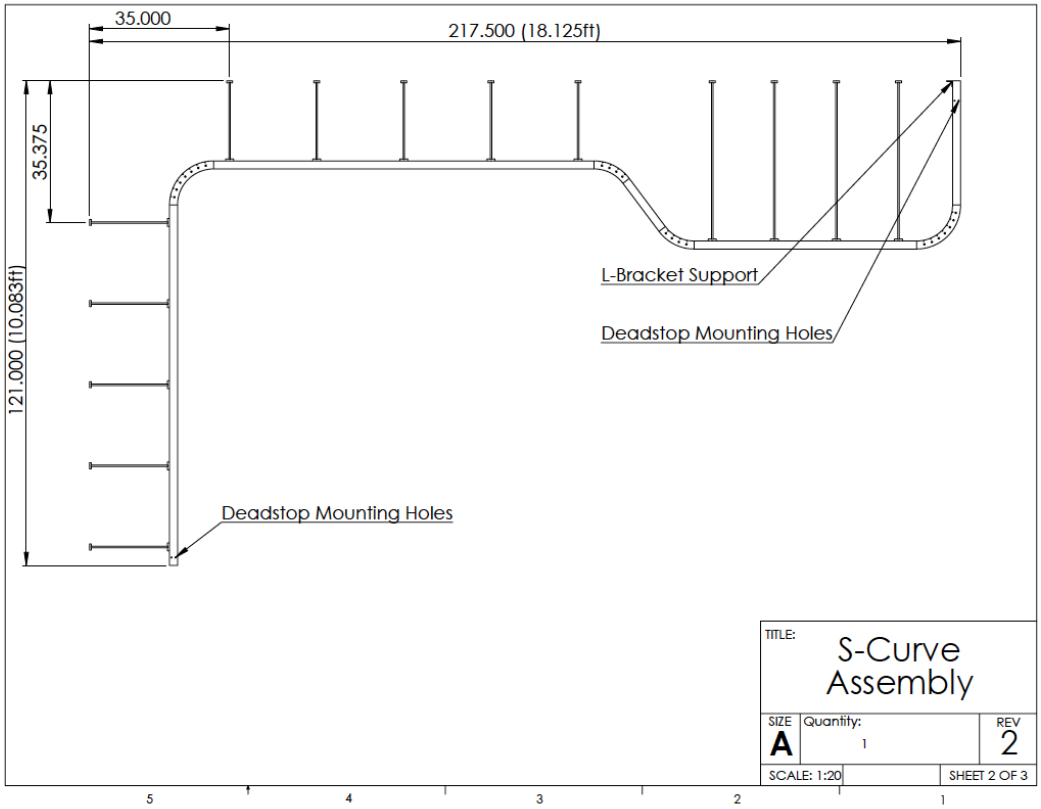
	Less likely to want it			No difference			More likely to want it
Features	1	2	3	4	5	6	7
Opening cabinet doors, drawers, and appliances							
Reaching items from the upper cabinets							
Reaching items from the lower cabinets							
Reaching items from the floor							
Stabilizing items							
Unloading groceries							
Unloading the dishwasher							
Handling hot objects							
Handling heavy (>15lbs) objects							
Control via "touch to move" interaction							
Control with a joystick							
Control with a tablet pc							
Easily hidden							

APPENDIX C

MECHANICAL DRAWINGS

C.1 HORIZONTAL TRACK




35.000
217.500 (18.125ft)
35.375
121.000 (10.083ft)
L-Bracket Support
Deadstop Mounting Holes
Deadstop Mounting Holes
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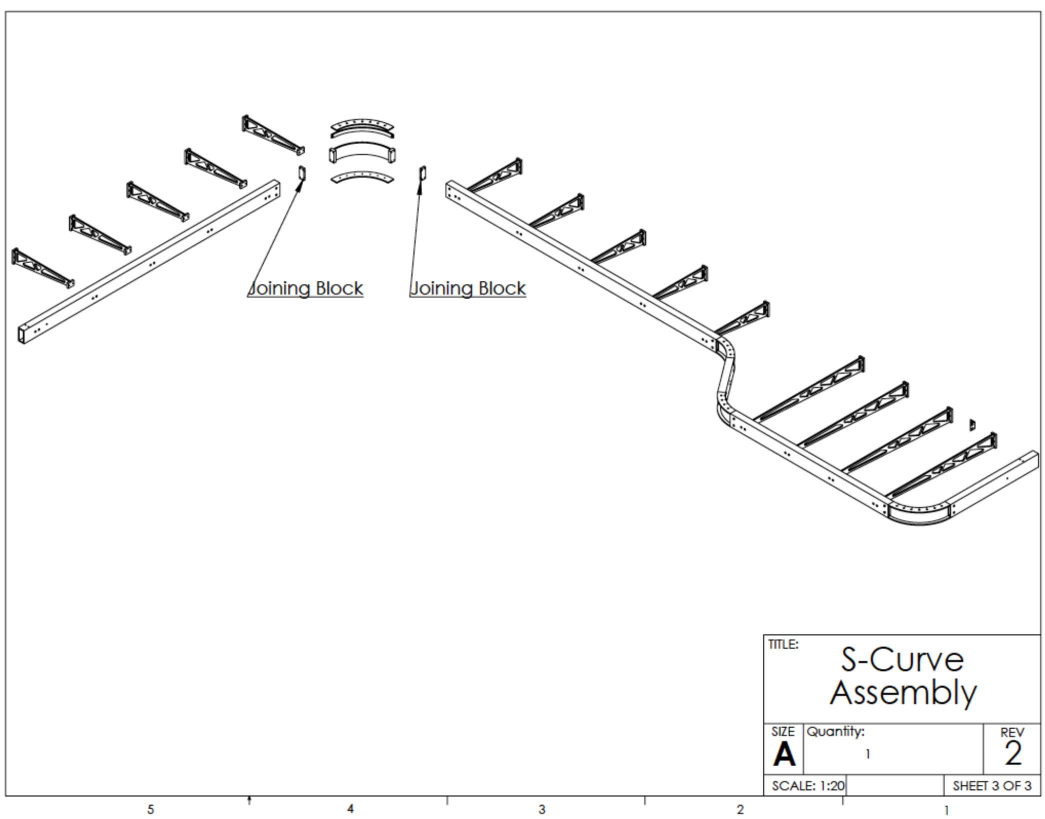
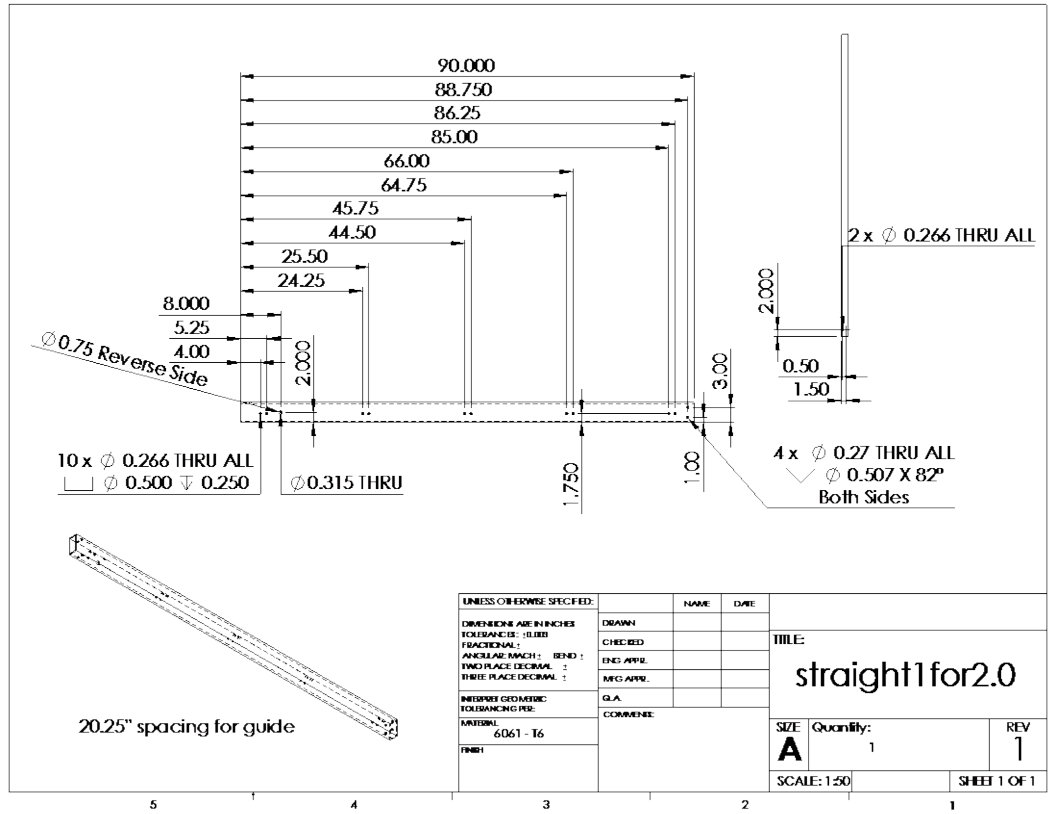
S-Curve Assembly
SIZE
A
Quantity:
1
REV
2
SCALE: 1:20
SHEET 2 OF 3
5
4
3
2
1


Joining Block
Joining Block
TITLE:
S-Curve Assembly
SIZE
A
Quantity:
1
REV
2
SCALE: 1:20
SHEET 3 OF 3
5
4
3
2
1



90.000
88.750
86.25
85.00
66.00
64.75
45.75
44.50
25.50
24.25
8.000
5.25
4.00
2.000
∅0.75 Reverse Side
10 x ∅ 0.266 THRU ALL
⌴ ∅ 0.500 ↧ 0.250
∅0.315 THRU
1.750
1.00
3.00
2 x ∅ 0.266 THRU ALL
2.000
0.50
1.50
4 x ∅ 0.27 THRU ALL
⌵ ∅ 0.507 X 82°
Both Sides
20.25" spacing for guide
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 - T6
FINISH
TITLE:
straight1for2.0
SIZE
A
Quantity:
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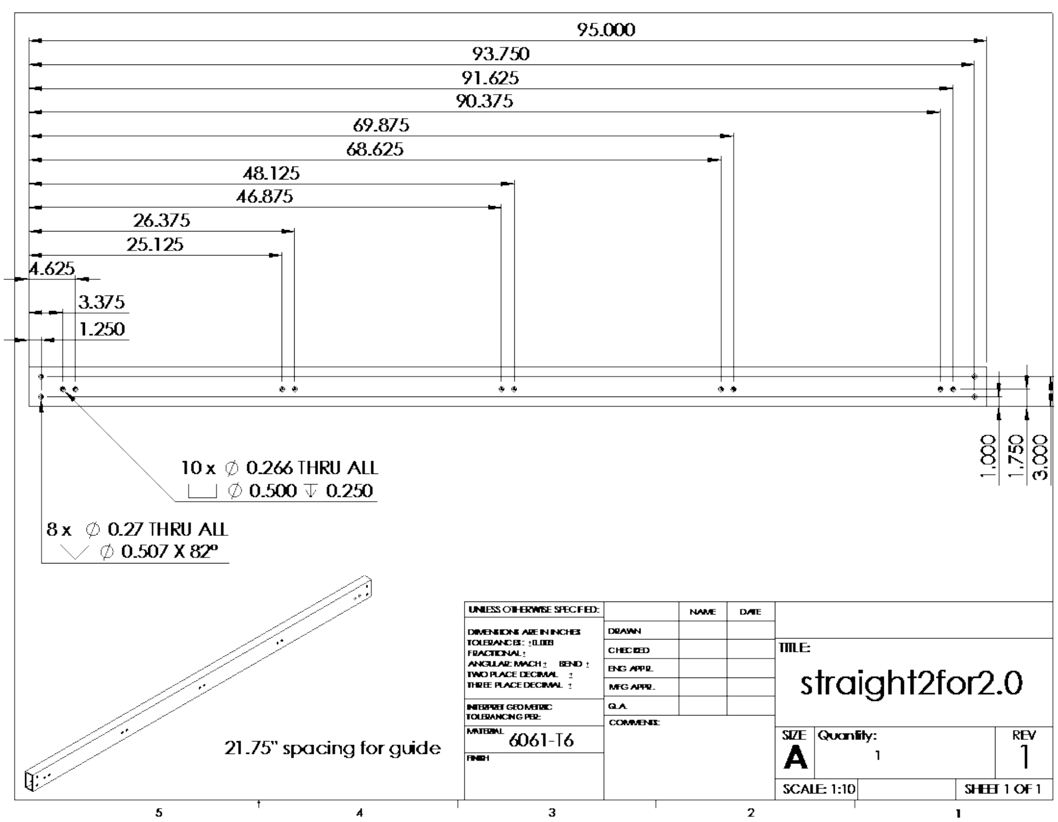
REV
1
SCALE: 1:50
SHEET 1 OF 1



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93.750
91.625
90.375
69.875
68.625
48.125
46.875
26.375
25.125
4.625
3.375
1.250
1.000
1.750
3.000
10 x ∅ 0.266 THRU ALL
⌴ ∅ 0.500 ↧ 0.250
8 x ∅ 0.27 THRU ALL
⌵ ∅ 0.507 X 82°
21.75" spacing for guide
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
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FINISH
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REV
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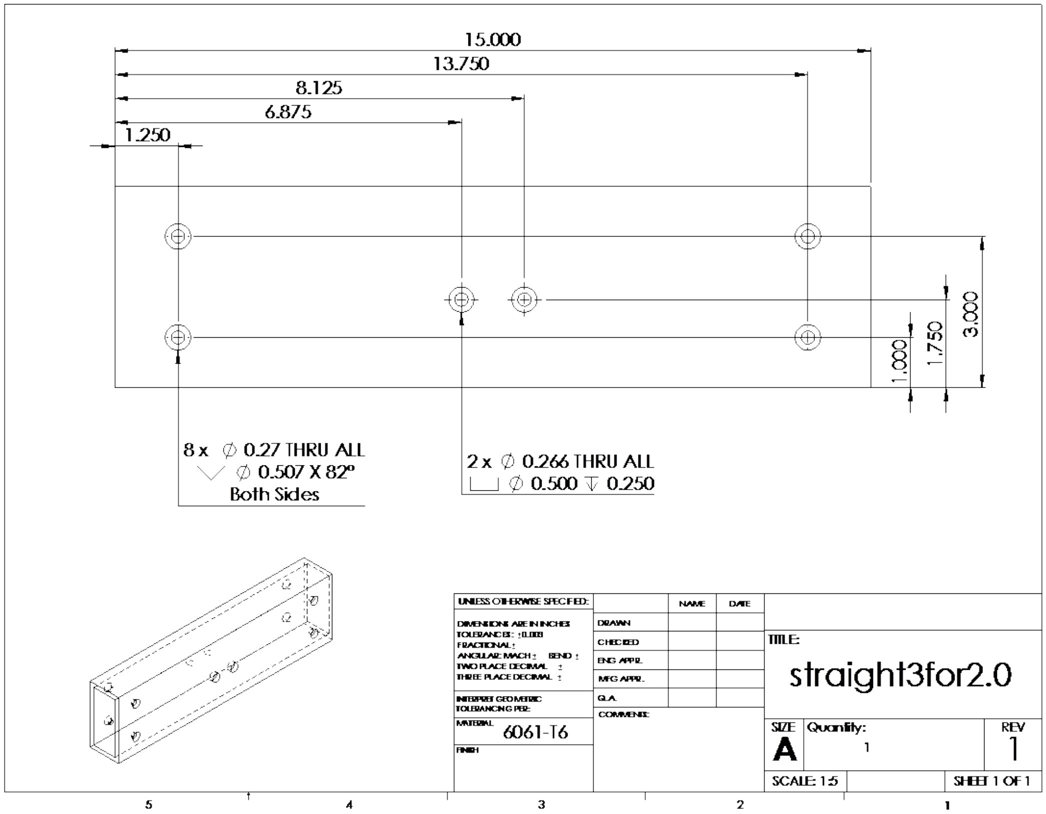
SCALE: 1:10
SHEET 1 OF 1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13.750
8.125
6.875
1.250
3.000
1.750
1.000
8 x ∅ 0.27 THRU ALL
∅ 0.507 X 82°
Both Sides
2 x ∅ 0.266 THRU ALL
∅ 0.500 ↧ 0.250
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
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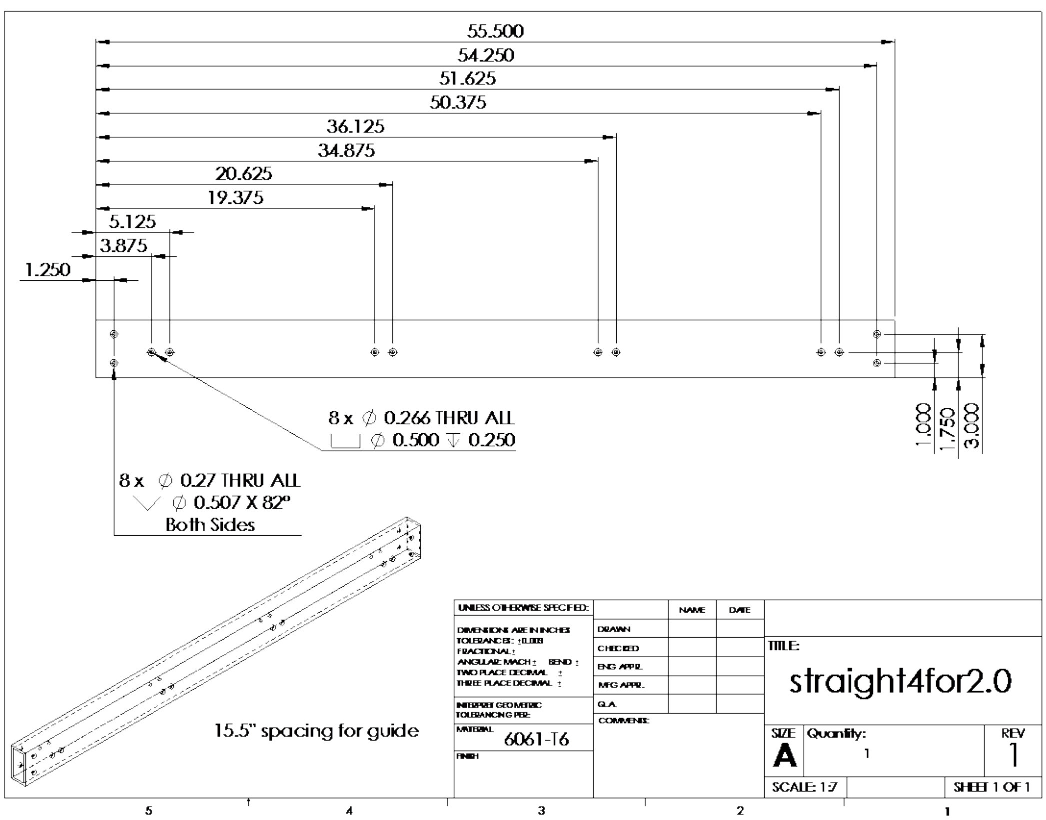
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54.250
51.625
50.375
36.125
34.875
20.625
19.375
5.125
3.875
1.250
8 x ∅ 0.266 THRU ALL
∅ 0.500 ↧ 0.250
1.000
1.750
3.000
8 x ∅ 0.27 THRU ALL
∅ 0.507 X 82°
Both Sides
15.5" spacing for guide
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
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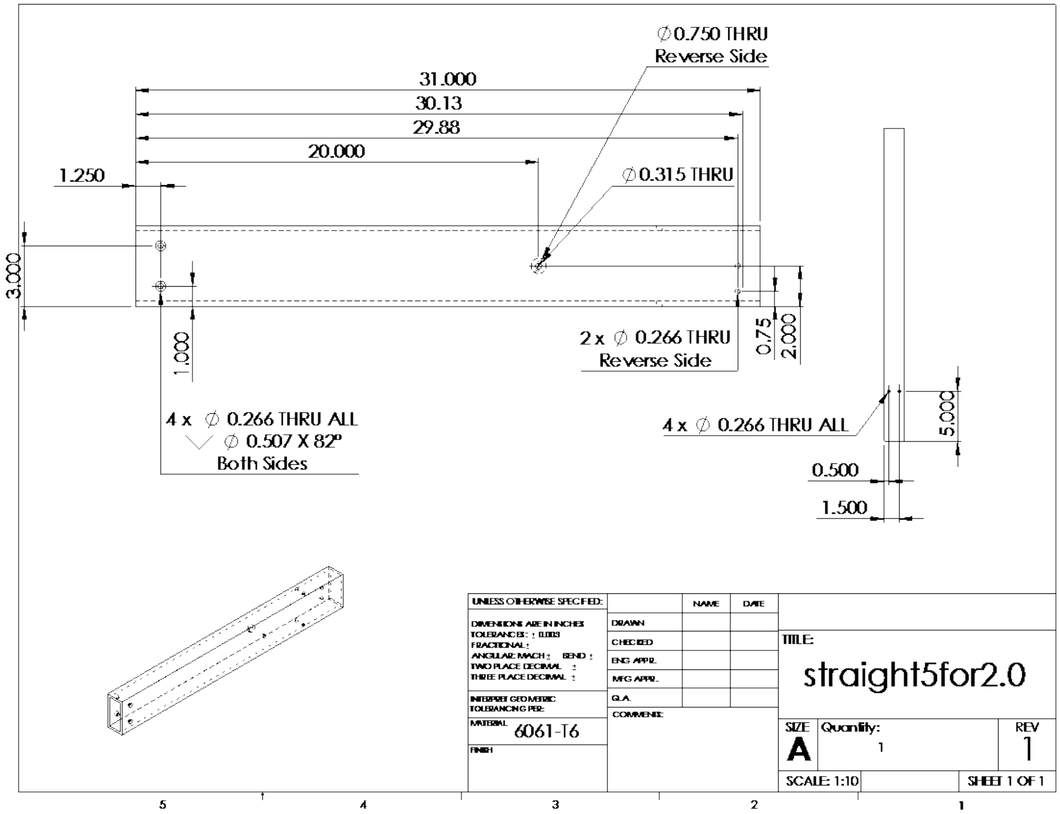
SHEET 1 OF 1



∅0.750 THRU
Reverse Side
31.000
30.13
29.88
20.000
1.250
∅0.315 THRU
3.000
1.000
2 x ∅ 0.266 THRU
Reverse Side
0.75
2.000
4 x ∅ 0.266 THRU ALL
∅ 0.507 X 82°
Both Sides
4 x ∅ 0.266 THRU ALL
5.000
0.500
1.500
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
6061-T6
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straight5for2.0
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REV
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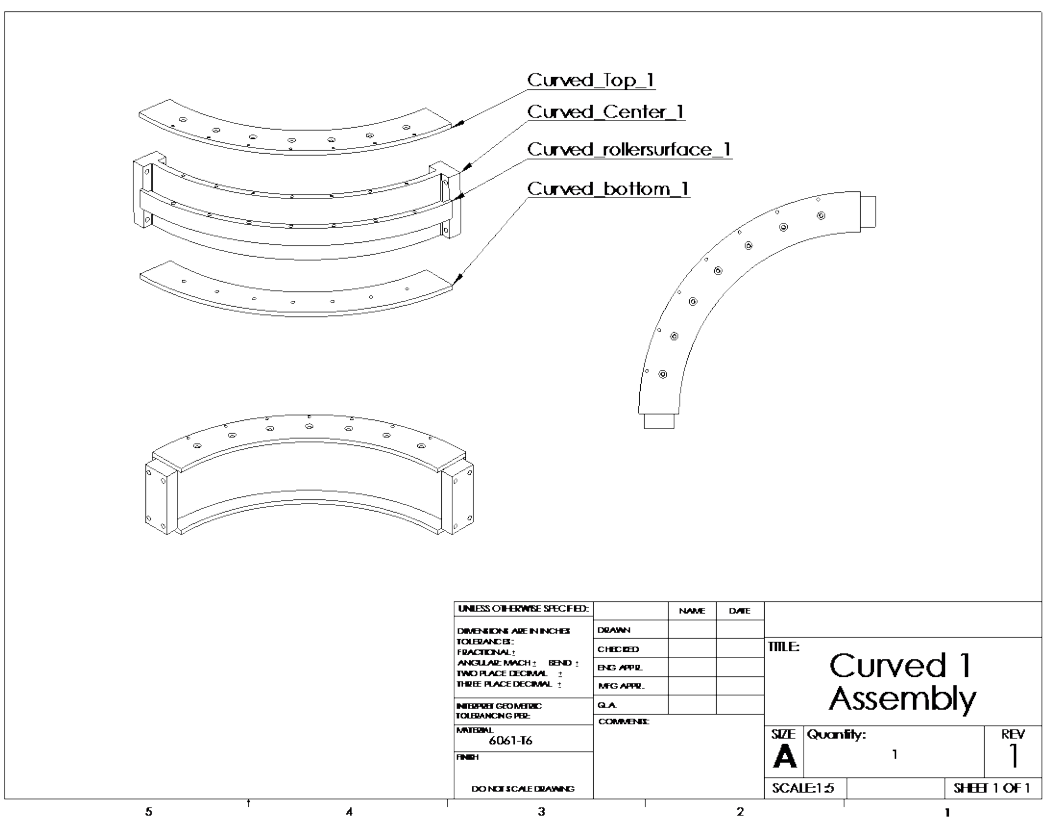
SHEET 1 OF 1



Curved_Top_1
Curved_Center_1
Curved_rollersurface_1
Curved_bottom_1
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
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ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
6061-T6
FINISH
DO NOT SCALE DRAWING
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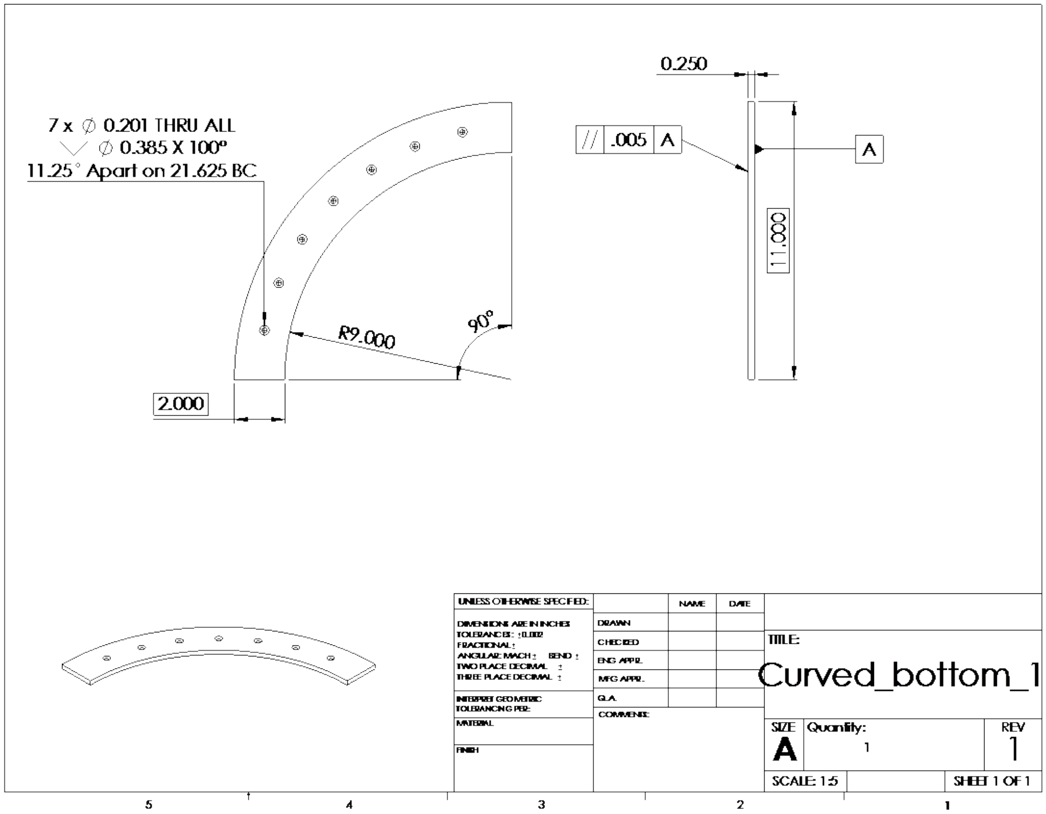
SHEET 1 OF 1


7 x ∅ 0.201 THRU ALL
∅ 0.385 X 100°
11.25° Apart on 21.625 BC
0.250
.005 A
A
11.000
R9.000
90°
2.000
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
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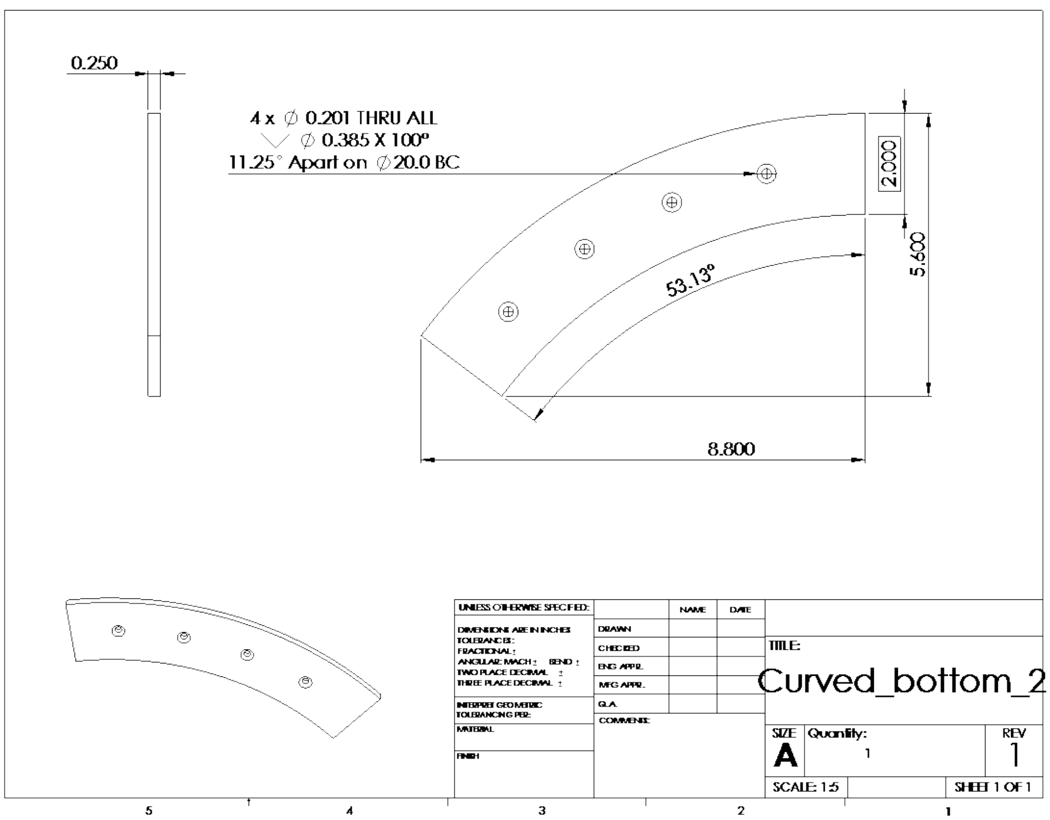
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4 x ∅ 0.201 THRU ALL
∅ 0.385 X 100°
11.25° Apart on ∅20.0 BC
2.000
5.600
53.13°
8.800
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
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3
2
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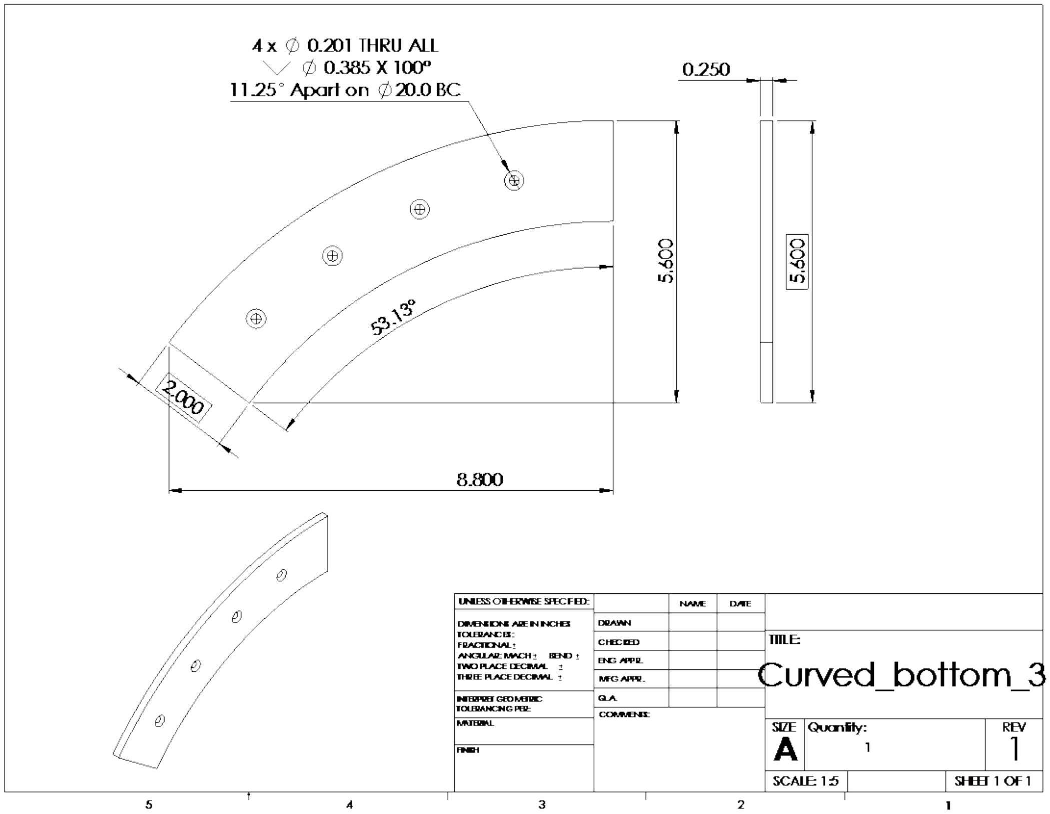
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∅ 0.385 X 100°
11.25° Apart on ∅20.0 BC
0.250
5.600
5.600
53.13°
2.000
8.800
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL:
ANGULAR: MACH: BEND:
TWO PLACE DECIMAL:
THREE PLACE DECIMAL:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
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Quantity:
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REV
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SCALE: 1:5
SHEET 1 OF 1
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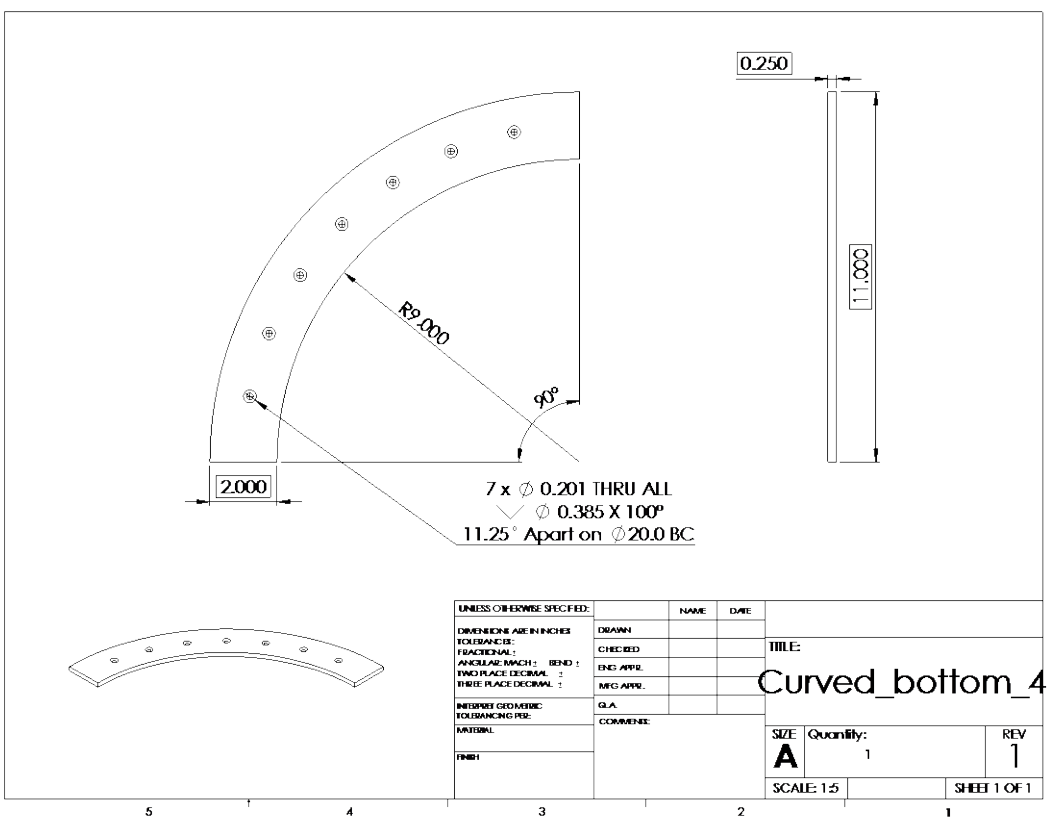
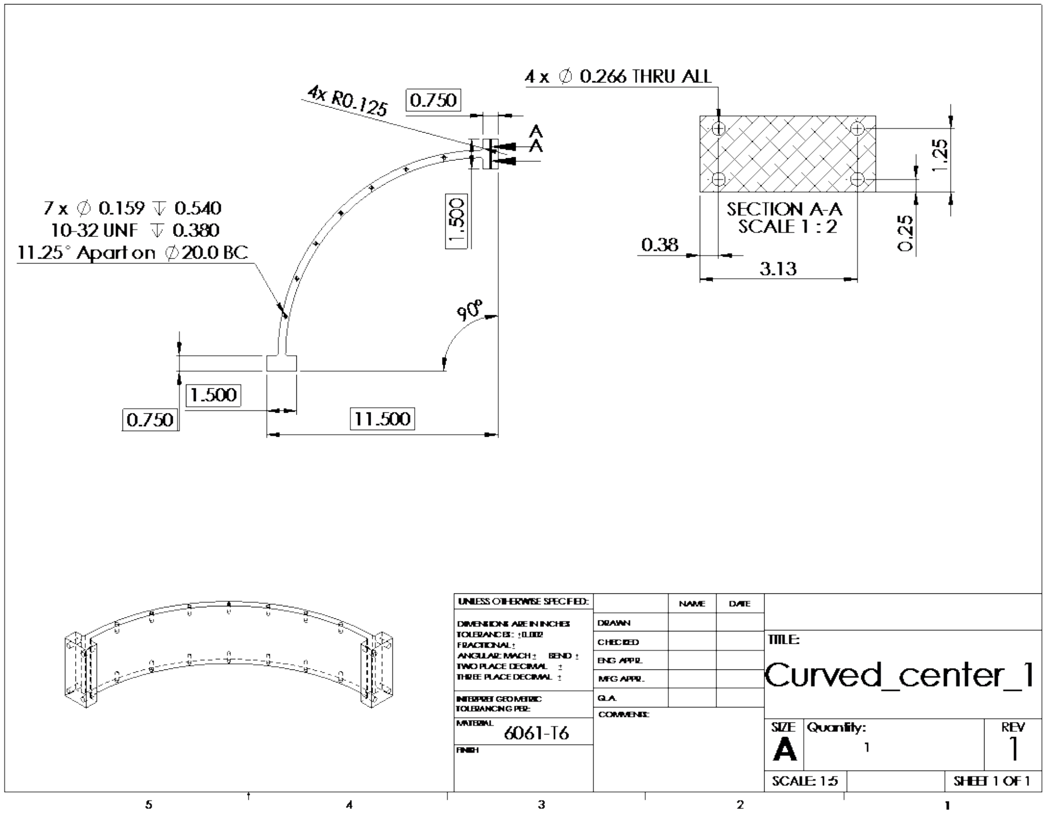
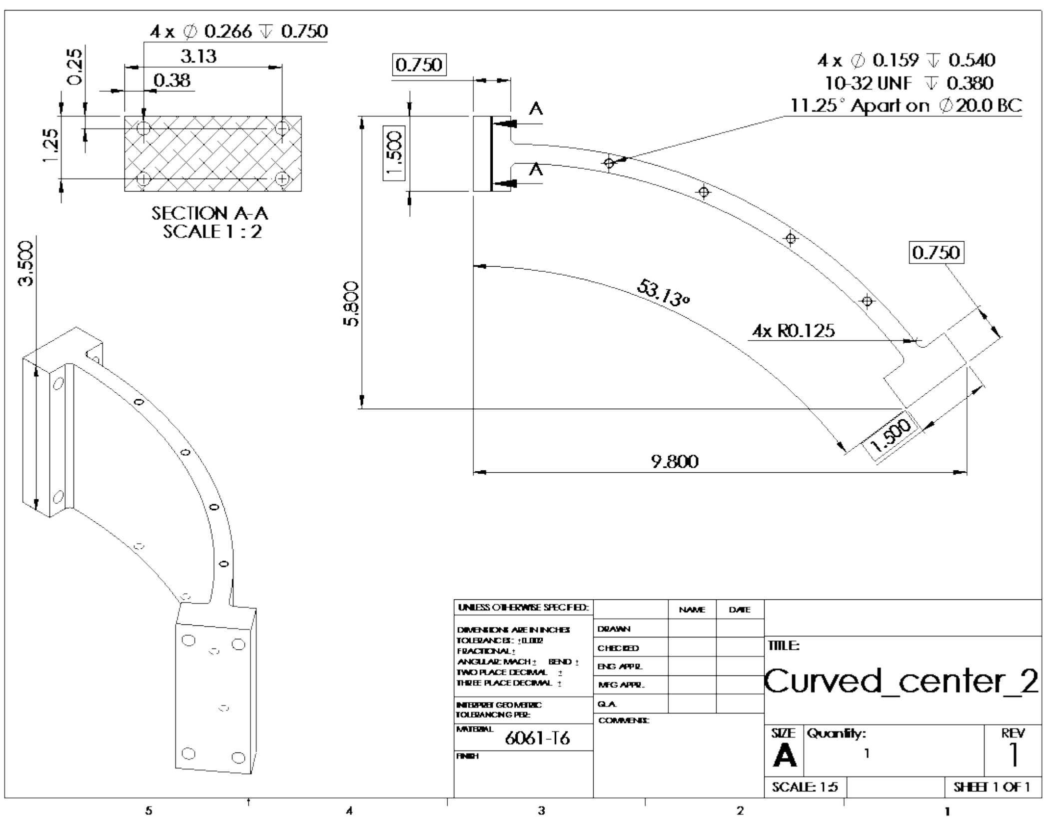
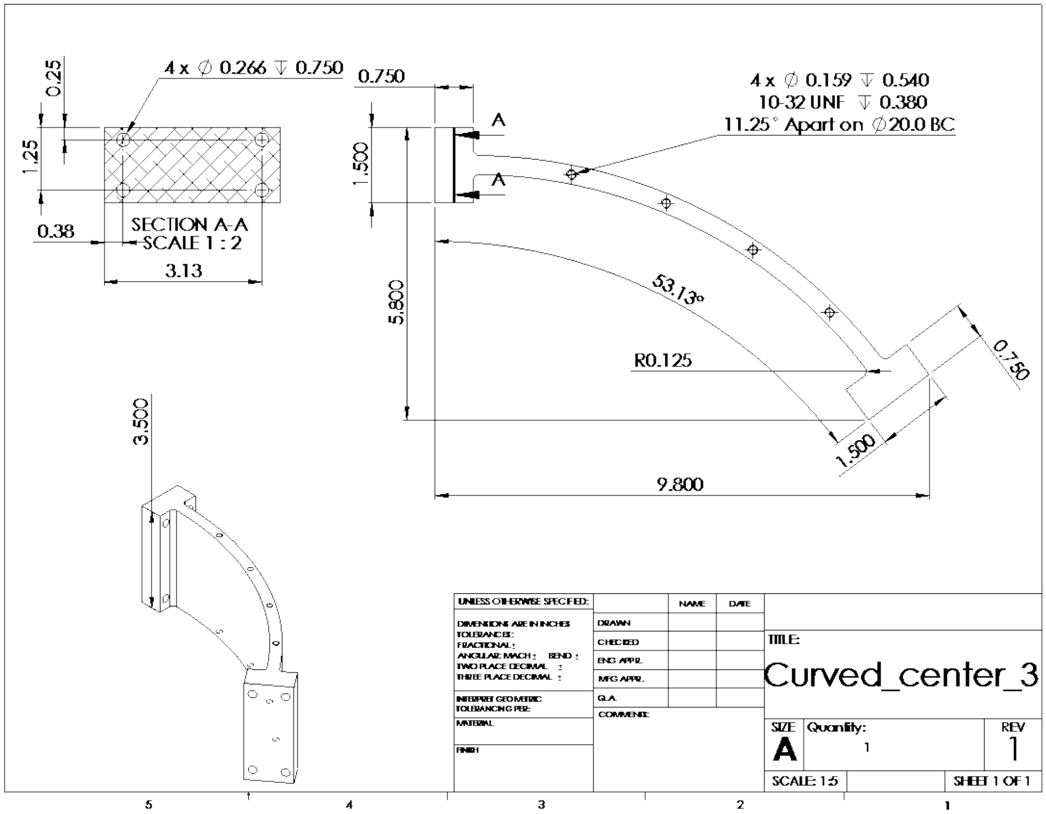
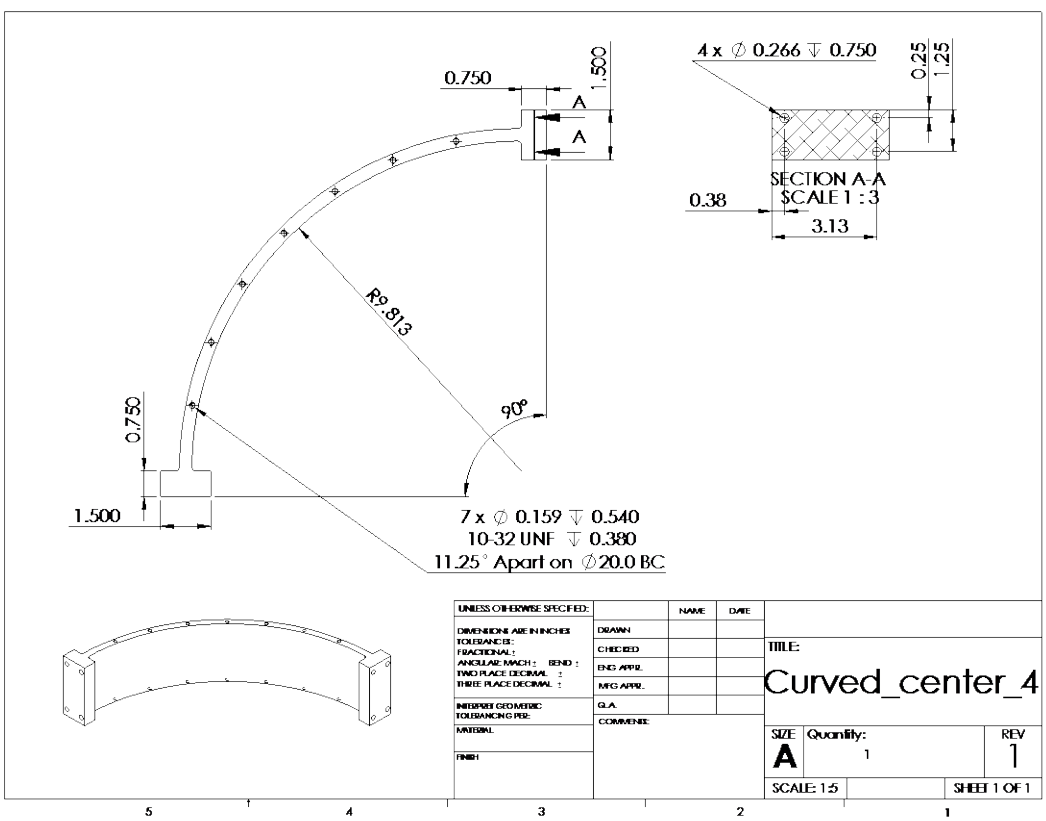
2
1

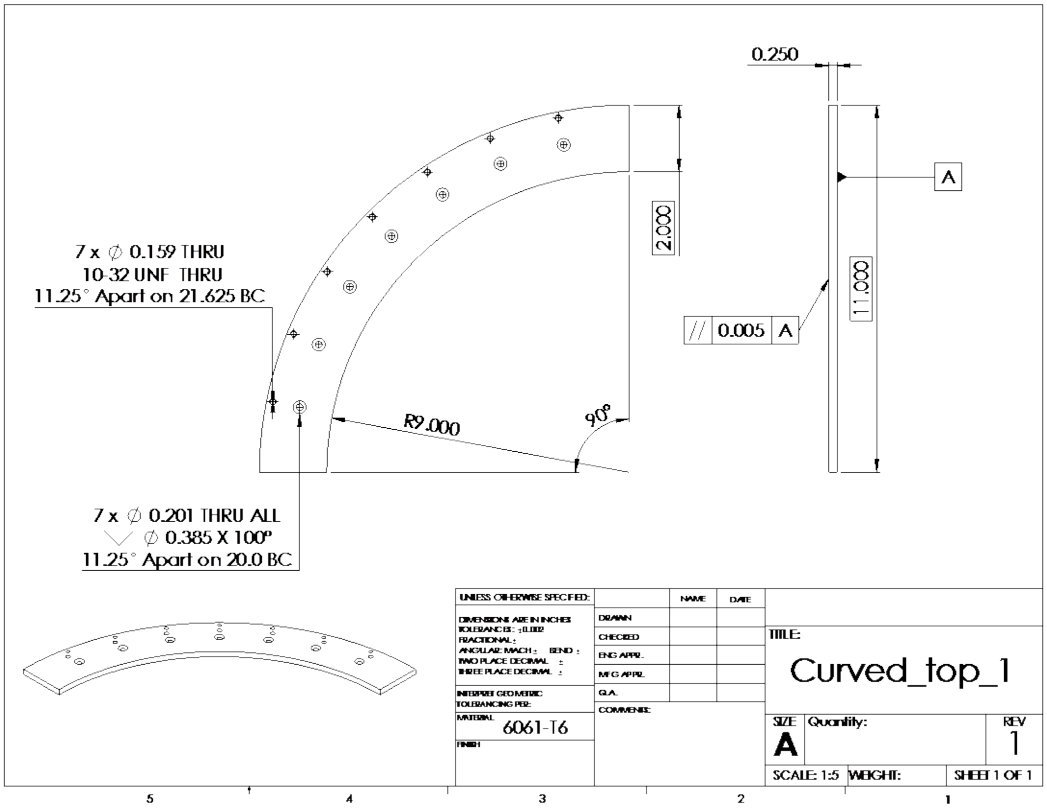

0.250
11.000
R9.000
90°
2.000
7 x ∅ 0.201 THRU ALL
∅ 0.385 X 100°
11.25° Apart on ∅20.0 BC
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL:
ANGULAR: MACH: BEND:
TWO PLACE DECIMAL:
THREE PLACE DECIMAL:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Curved_bottom_4
SIZE
A
Quantity:
1
REV
1
SCALE: 1:5
SHEET 1 OF 1
5
4
3
2
1

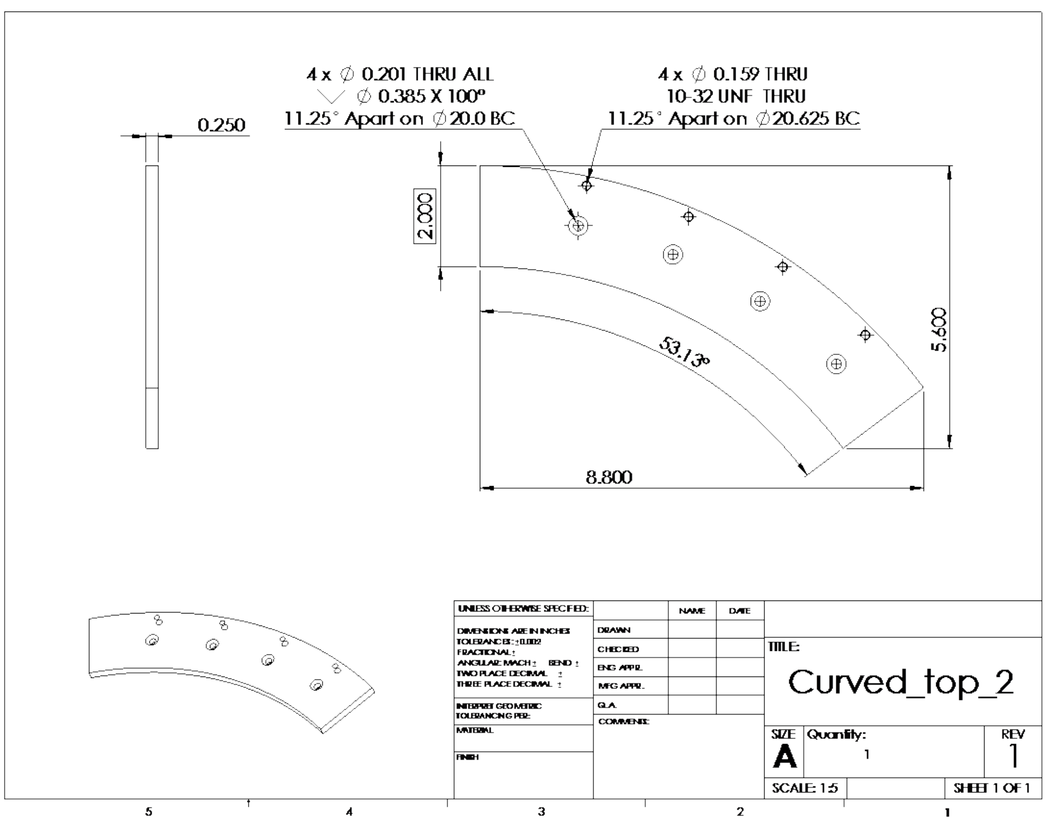

4 x ∅ 0.266 THRU ALL
4x R0.125
0.750
A
A
7 x ∅ 0.159 ↧ 0.540
10-32 UNF ↧ 0.380
11.25° Apart on ∅20.0 BC
1.500
90°
1.500
0.750
11.500
1.25
0.25
SECTION A-A
SCALE 1 : 2
0.38
3.13
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
6061-T6
FINISH
TITLE:
Curved_center_1
SIZE
A
Quantity:
1
REV
1
SCALE: 1:5
SHEET 1 OF 1

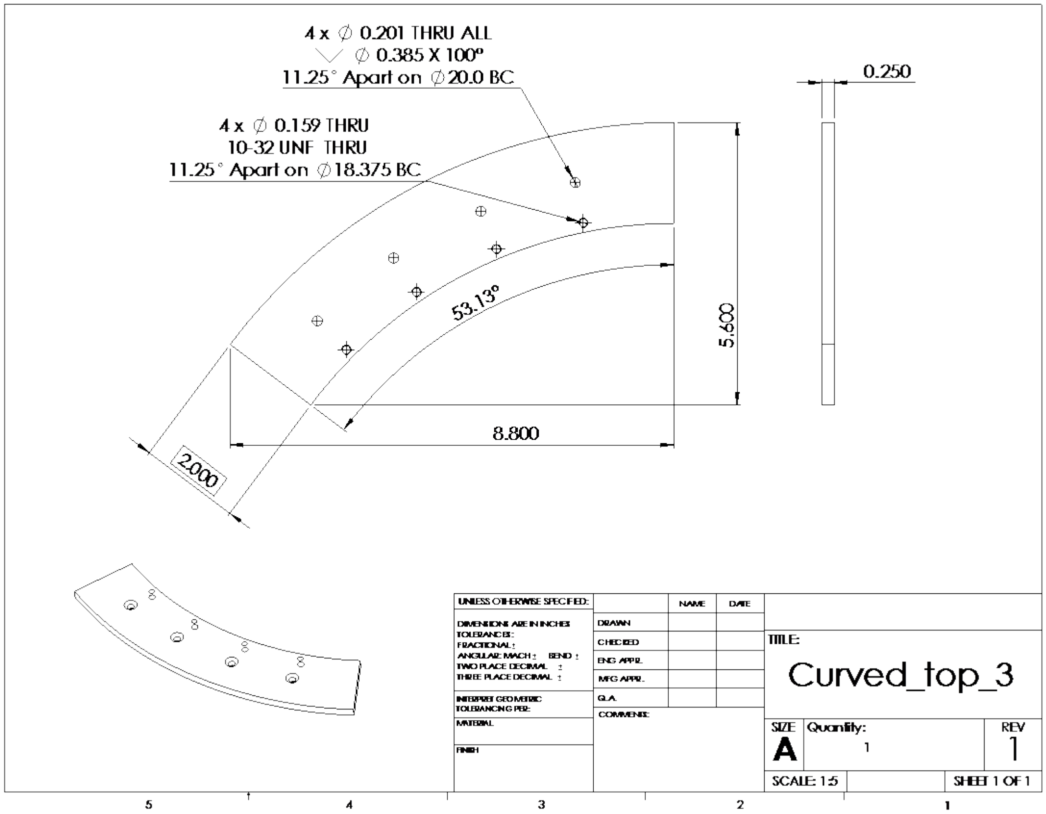

4 x ∅ 0.266 ↧ 0.750
3.13
0.38
0.25
1.25
SECTION A-A
SCALE 1 : 2
3.500
0.750
A
A
1.500
5.800
4 x ∅ 0.159 ↧ 0.540
10-32 UNF ↧ 0.380
11.25° Apart on ∅20.0 BC
0.750
53.13°
4x R0.125
1.500
9.800
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
6061-T6
FINISH
TITLE:
Curved_center_2
SIZE
A
Quantity:
1
REV
1
SCALE: 1:5
SHEET 1 OF 1

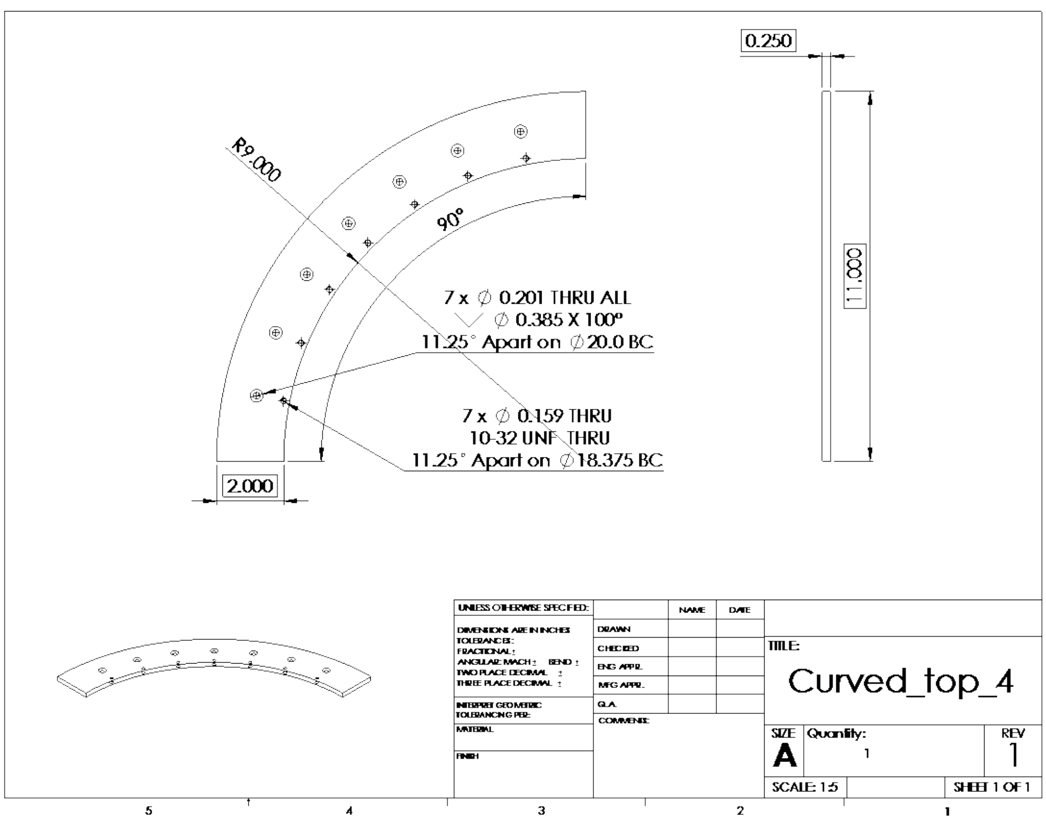

4 x ∅ 0.266 ↧ 0.750
0.25
1.25
0.38
SECTION A-A
SCALE 1 : 2
3.13
0.750
1.500
A
A
4 x ∅ 0.159 ↧ 0.540
10-32 UNF ↧ 0.380
11.25° Apart on ∅20.0 BC
5.800
53.13°
R0.125
0.750
1.500
9.800
3.500
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Curved_center_3
SIZE
A
Quantity:
1
REV
1
SCALE: 1:5
SHEET 1 OF 1
5
4
3
2
1

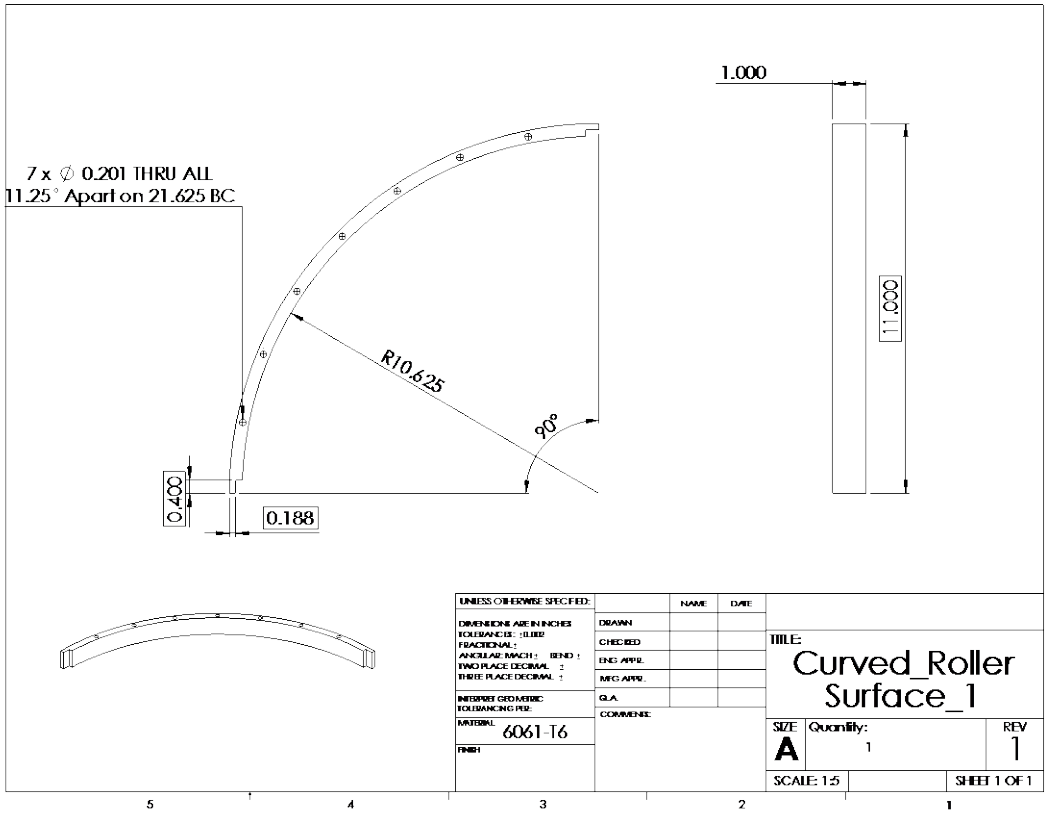

0.750
1.500
A
A
4 x ∅ 0.266 ↧ 0.750
0.25
1.25
SECTION A-A
SCALE 1 : 3
0.38
3.13
R9.813
90°
0.750
1.500
7 x ∅ 0.159 ↧ 0.540
10-32 UNF ↧ 0.380
11.25° Apart on ∅20.0 BC
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Curved_center_4
SIZE
A
Quantity:
1
REV
1
SCALE: 1:5
SHEET 1 OF 1
5
4
3
2
1


0.250
A
2.000
7 x ∅ 0.159 THRU
10-32 UNF THRU
11.25° Apart on 21.625 BC
// 0.005 A
11.000
R9.000
90°
7 x ∅ 0.201 THRU ALL
∅ 0.385 X 100°
11.25° Apart on 20.0 BC
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
6061-T6
FINISH
TITLE:
Curved_top_1
SIZE
A
Quantity:
REV
1
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

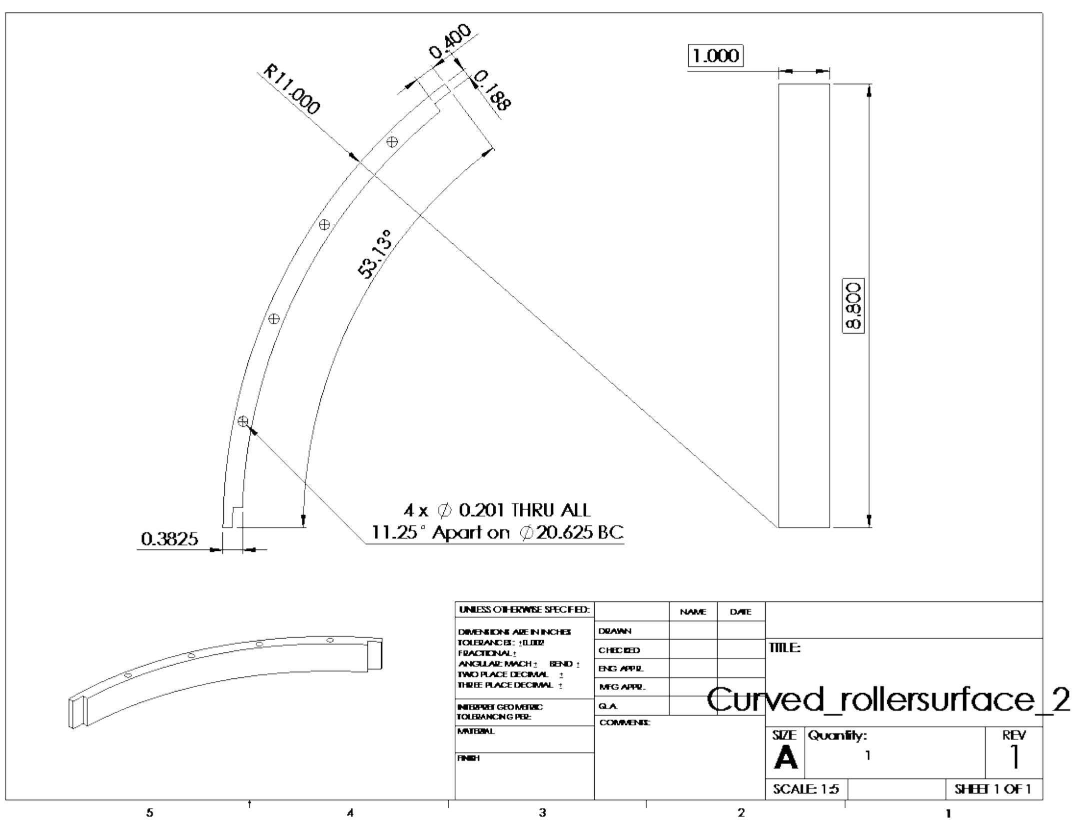

4 x ∅ 0.201 THRU ALL
∅ 0.385 X 100°
11.25° Apart on ∅20.0 BC
4 x ∅ 0.159 THRU
10-32 UNF THRU
11.25° Apart on ∅20.625 BC
0.250
2.000
5.600
53.13°
8.800
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
FINISH
TITLE:
Curved_top_2
SIZE
A
Quantity:
1
REV
1
SCALE: 1:5
SHEET 1 OF 1
5
4
3
2
1


4 x ∅ 0.201 THRU ALL
∅ 0.385 X 100°
11.25° Apart on ∅20.0 BC
0.250
4 x ∅ 0.159 THRU
10-32 UNF THRU
11.25° Apart on ∅18.375 BC
53.13°
5.600
8.800
2.000
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Curved_top_3
SIZE
A
Quantity:
1
REV
1
SCALE: 1:5
SHEET 1 OF 1
5
4
3
2
1

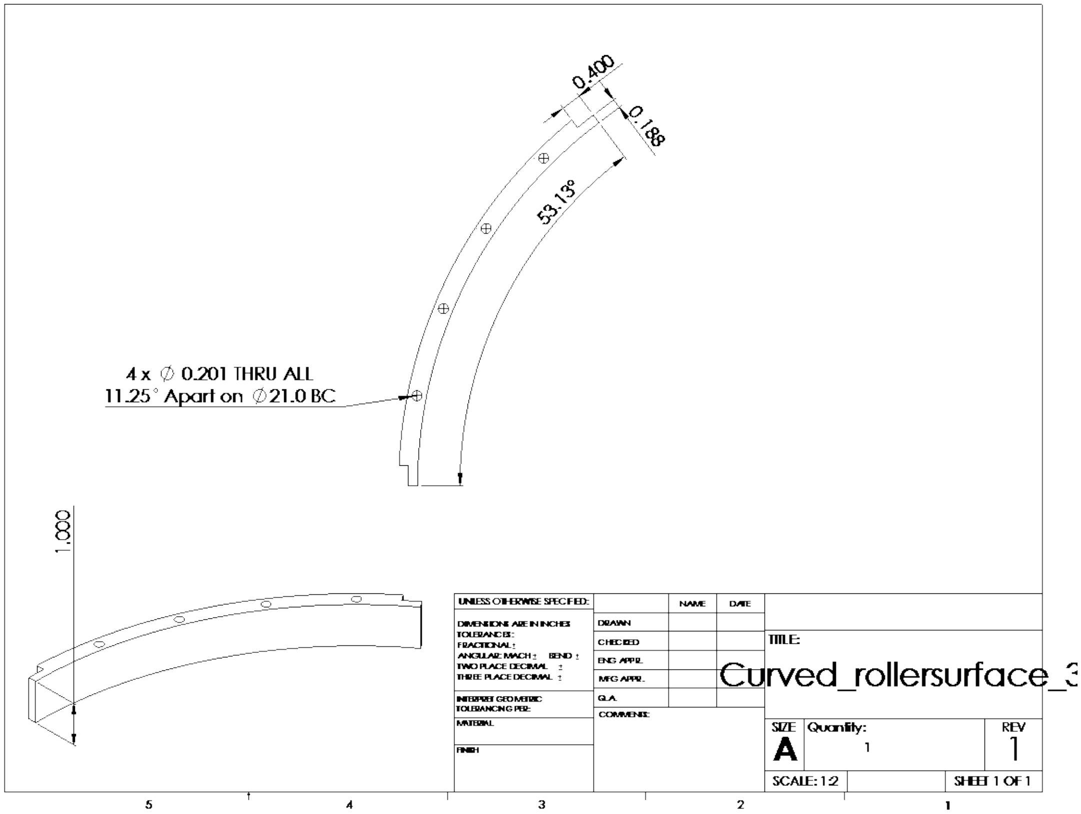

0.250
R9.000
90°
11.000
7 x ∅ 0.201 THRU ALL
∅ 0.385 X 100°
11.25° Apart on ∅20.0 BC
7 x ∅ 0.159 THRU
10-32 UNF THRU
11.25° Apart on ∅18.375 BC
2.000
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Curved_top_4
SIZE
A
Quantity:
1
REV
1
SCALE: 1:5
SHEET 1 OF 1
5
4
3
2
1

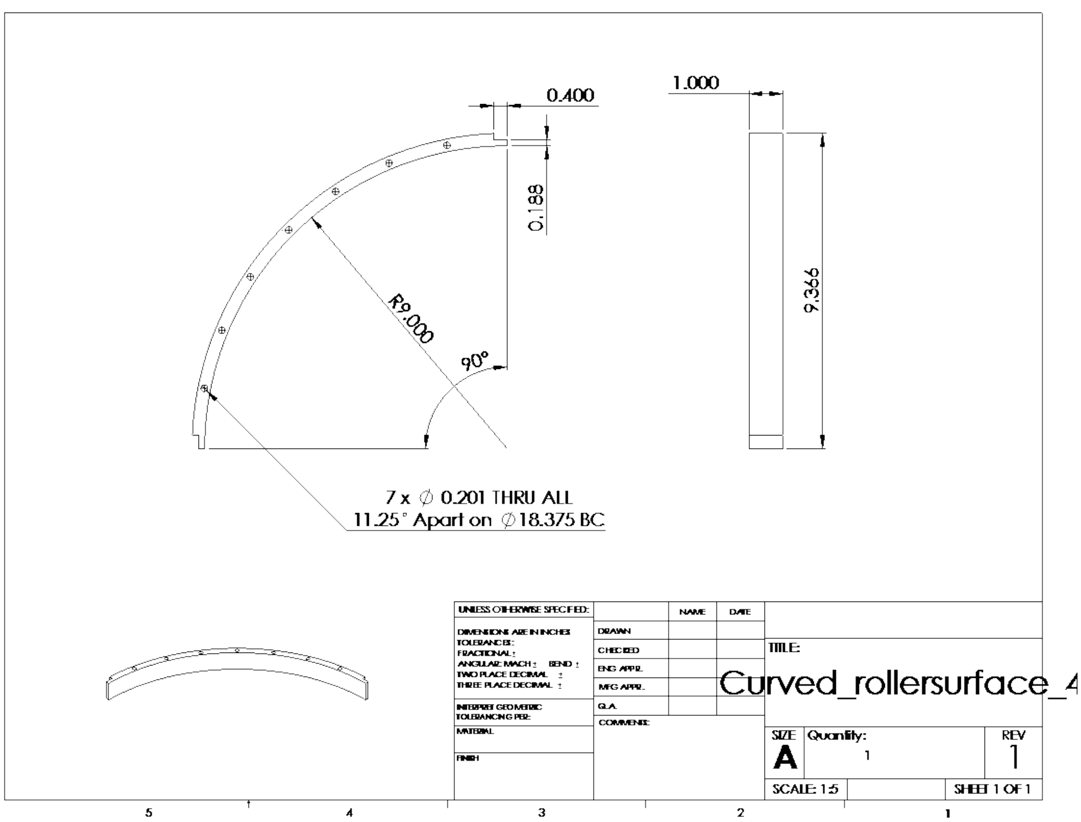


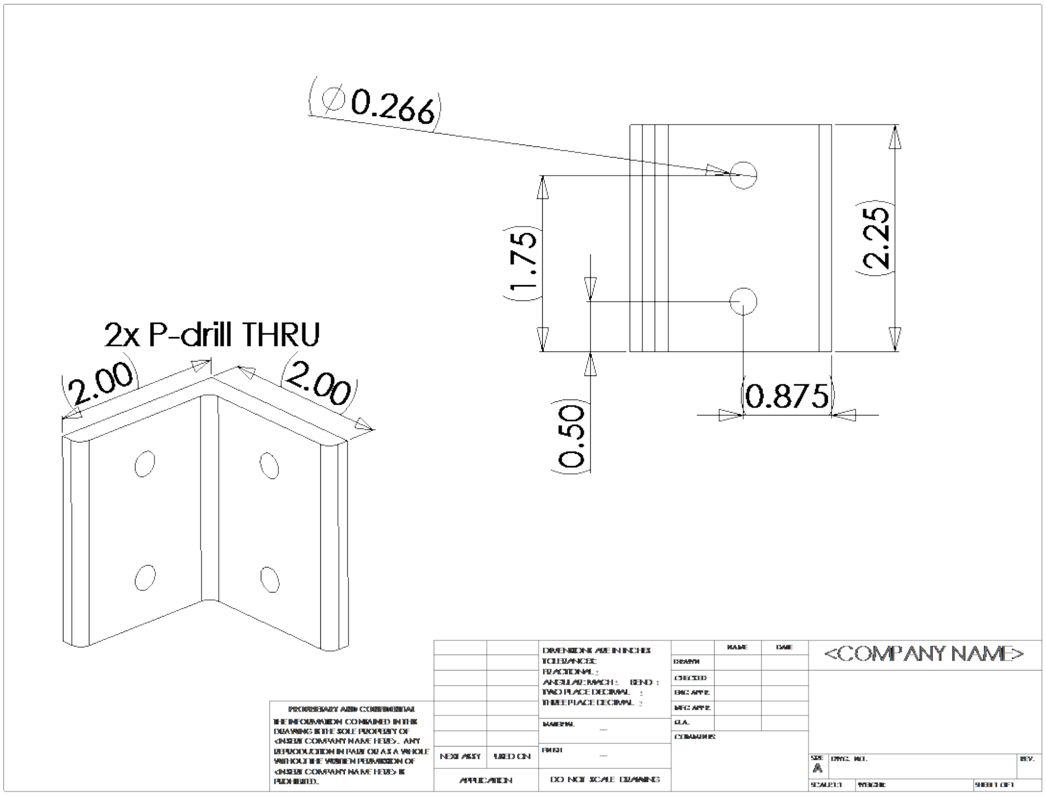
7 x ∅ 0.201 THRU ALL
11.25° Apart on 21.625 BC
R10.625
90°
0.400
0.188
1.000
11.000
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
6061-T6
FINISH
TITLE:
Curved_Roller Surface_1
SIZE
A
Quantity:
1
REV
1
SCALE: 1:5
SHEET 1 OF 1



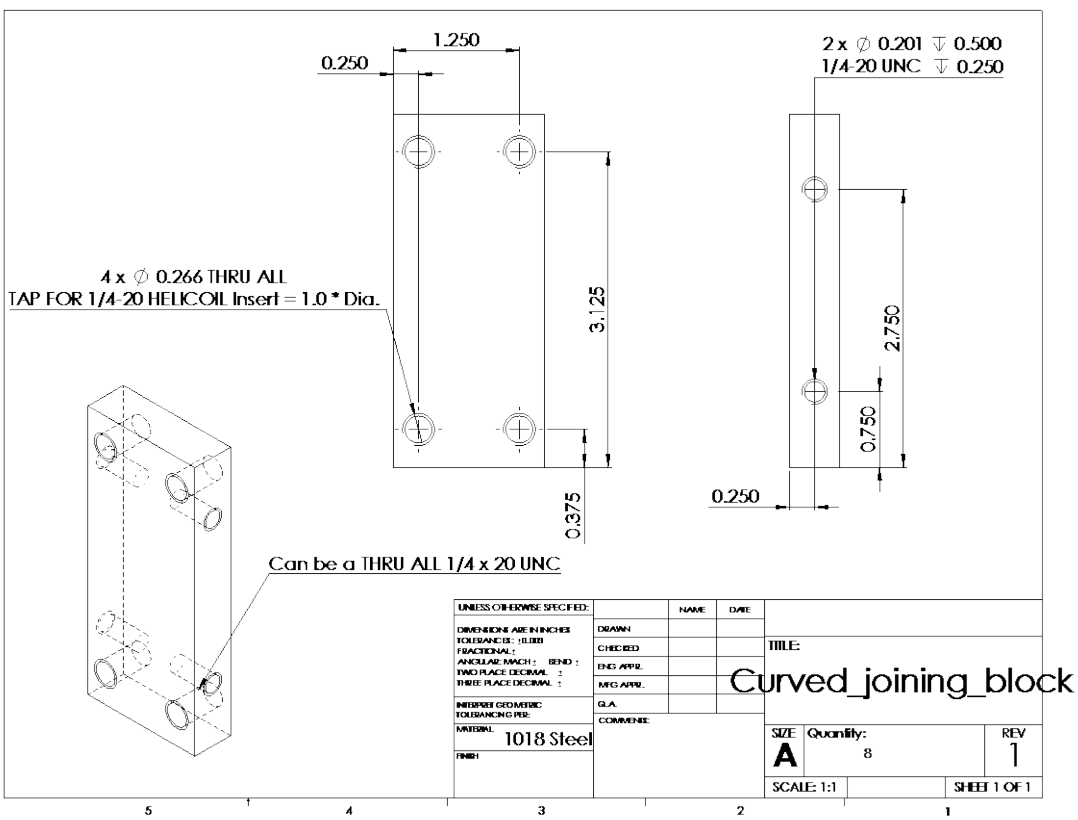
R11.000
0.400
0.188
53.13°
1.000
8.800
0.3825
4 x ∅ 0.201 THRU ALL
11.25° Apart on ∅20.625 BC
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
FINISH
TITLE:
Curved_rollersurface_2
SIZE
A
Quantity:
1
REV
1
SCALE: 1:5
SHEET 1 OF 1


0.400
0.188
53.13°
4 x ∅ 0.201 THRU ALL
11.25° Apart on ∅21.0 BC
1.000
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL:
ANGULAR: MACH: BEND:
TWO PLACE DECIMAL:
THREE PLACE DECIMAL:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Curved_rollersurface_3
SIZE
A
Quantity:
1
REV
1
SCALE: 1:2
SHEET 1 OF 1
5
4
3
2
1


0.400
1.000
0.188
R9.000
90°
9.366
7 x ∅ 0.201 THRU ALL
11.25° Apart on ∅18.375 BC
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL:
ANGULAR: MACH: BEND:
TWO PLACE DECIMAL:
THREE PLACE DECIMAL:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Curved_rollersurface_4
SIZE
A
Quantity:
1
REV
1
SCALE: 1:5
SHEET 1 OF 1
5
4
3
2
1

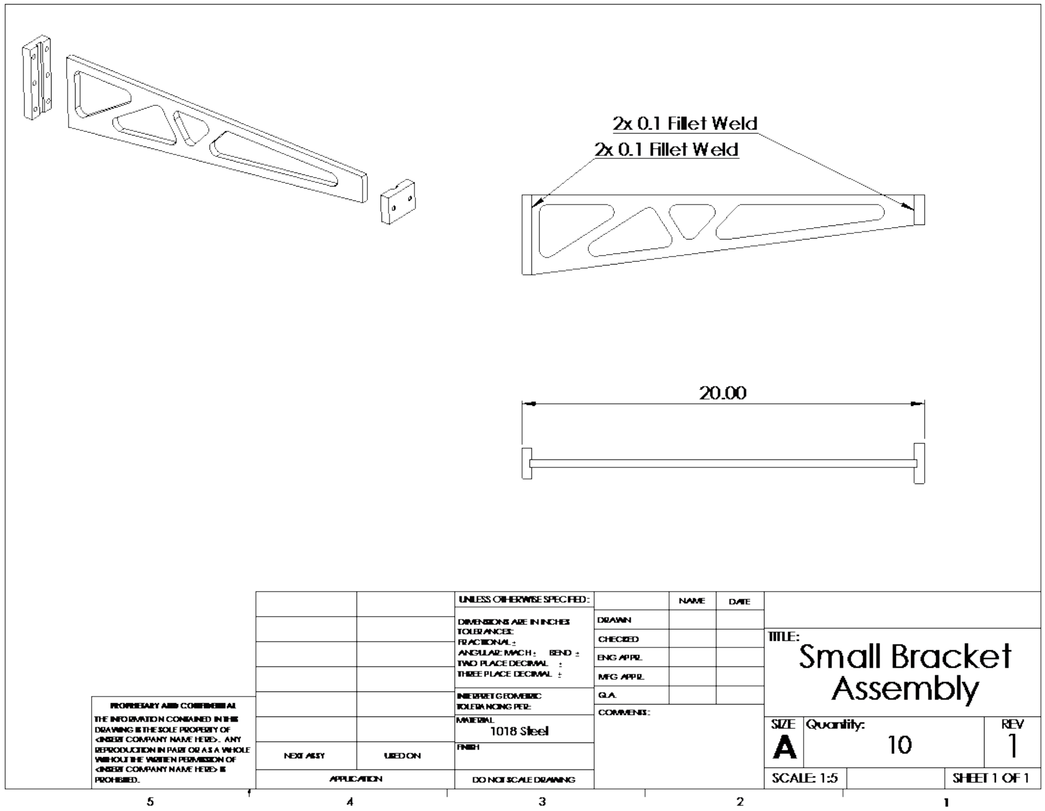


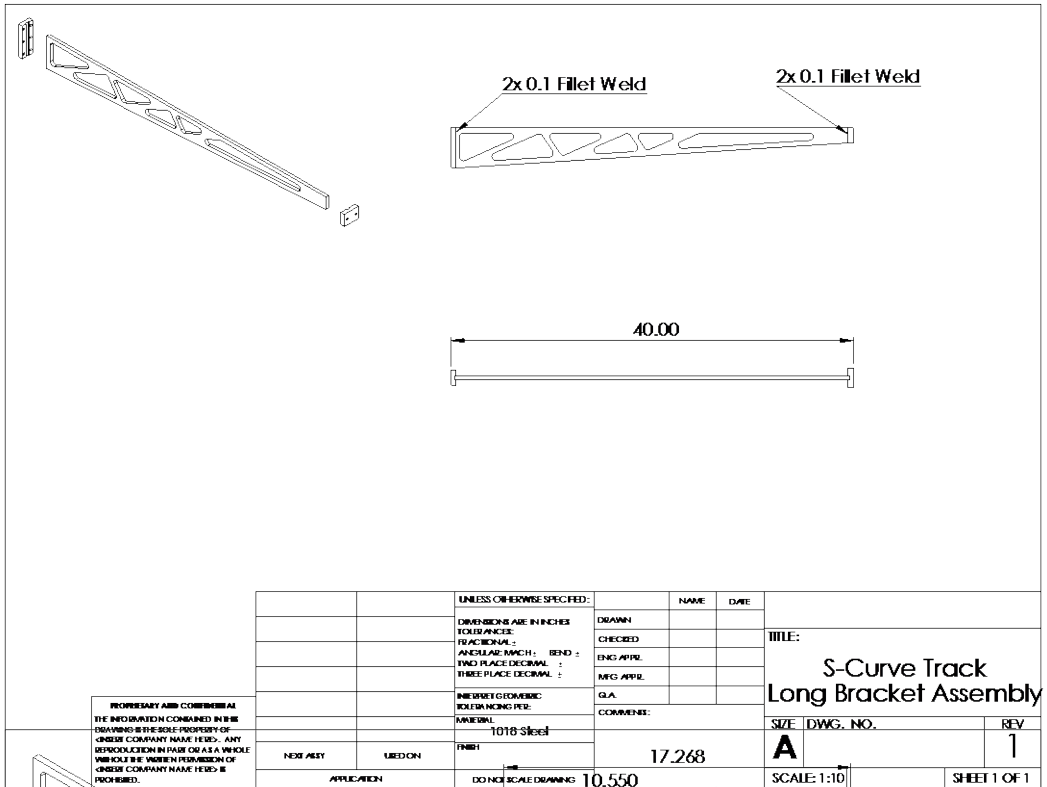
∅0.266
1.75
2.25
0.50
0.875
2x P-drill THRU
2.00
2.00
<COMPANY NAME>
DO NOT SCALE DRAWING



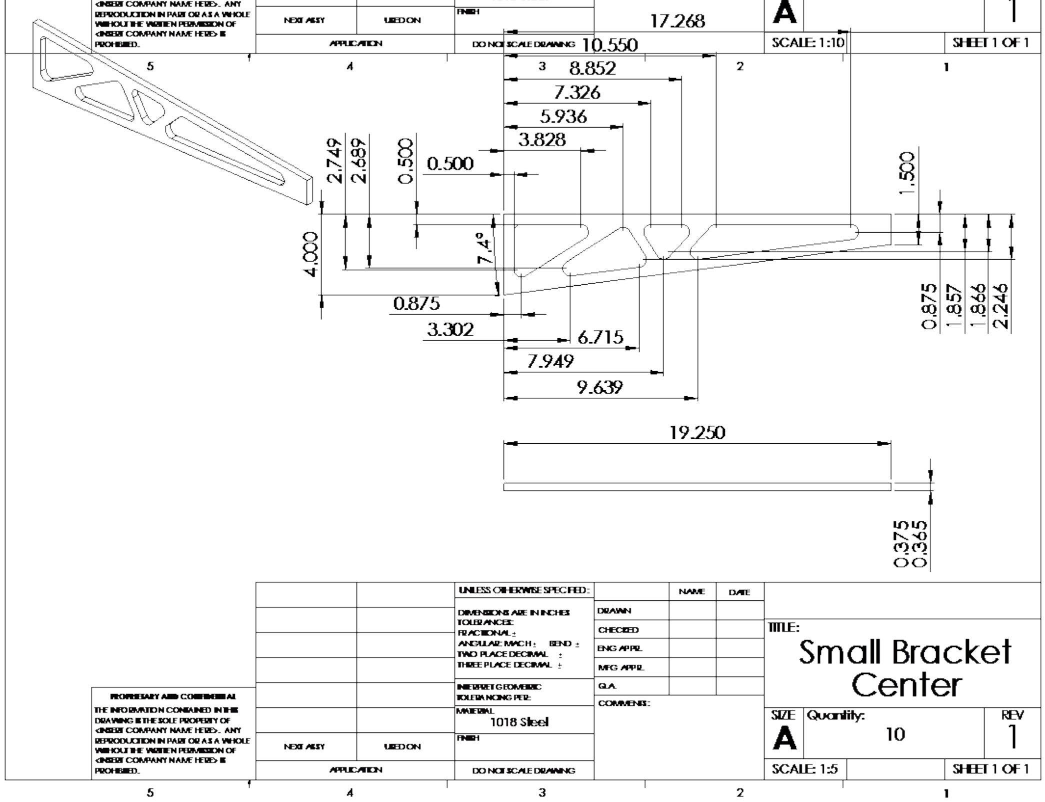
1.250
0.250
2 x ∅ 0.201 ↧ 0.500
1/4-20 UNC ↧ 0.250
4 x ∅ 0.266 THRU ALL
TAP FOR 1/4-20 HELICOIL Insert = 1.0 * Dia.
3.125
2.750
0.750
0.375
0.250
Can be a THRU ALL 1/4 x 20 UNC
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Curved_joining_block
MATERIAL
1018 Steel
FINISH
SIZE
A
Quantity:
8
REV
1
SCALE: 1:1
SHEET 1 OF 1
5
4
3
2
1

C.2 MOUNTING BRACKETS

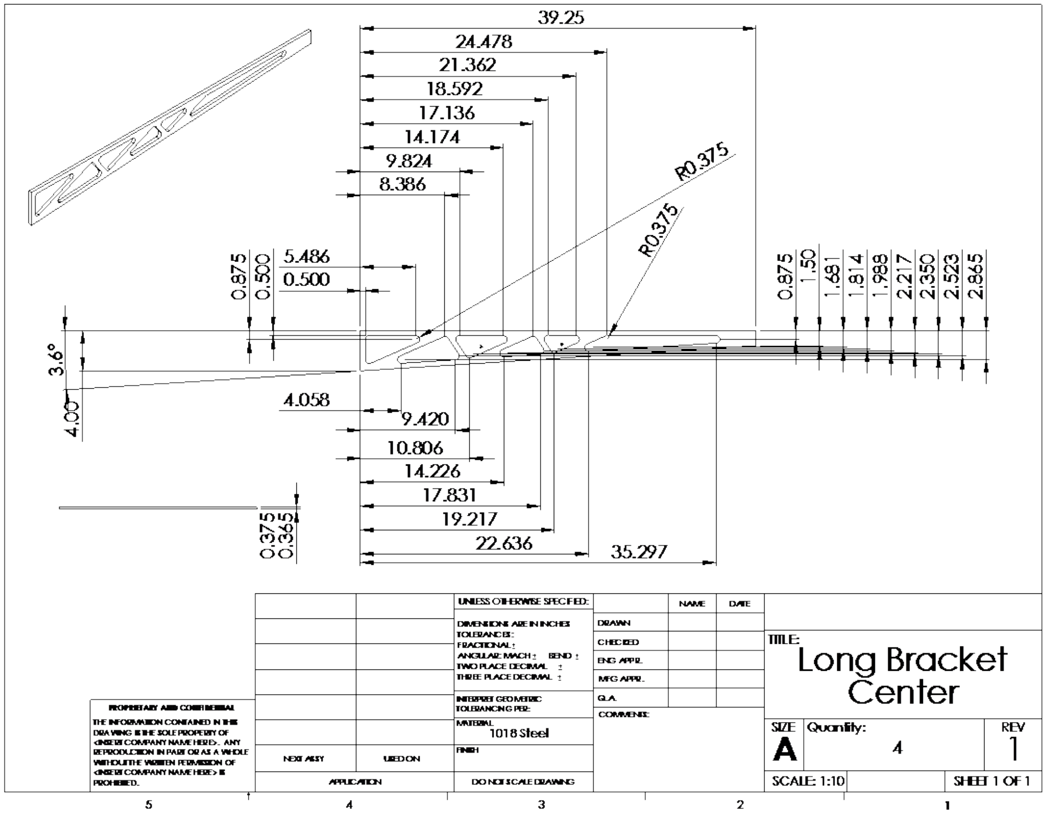


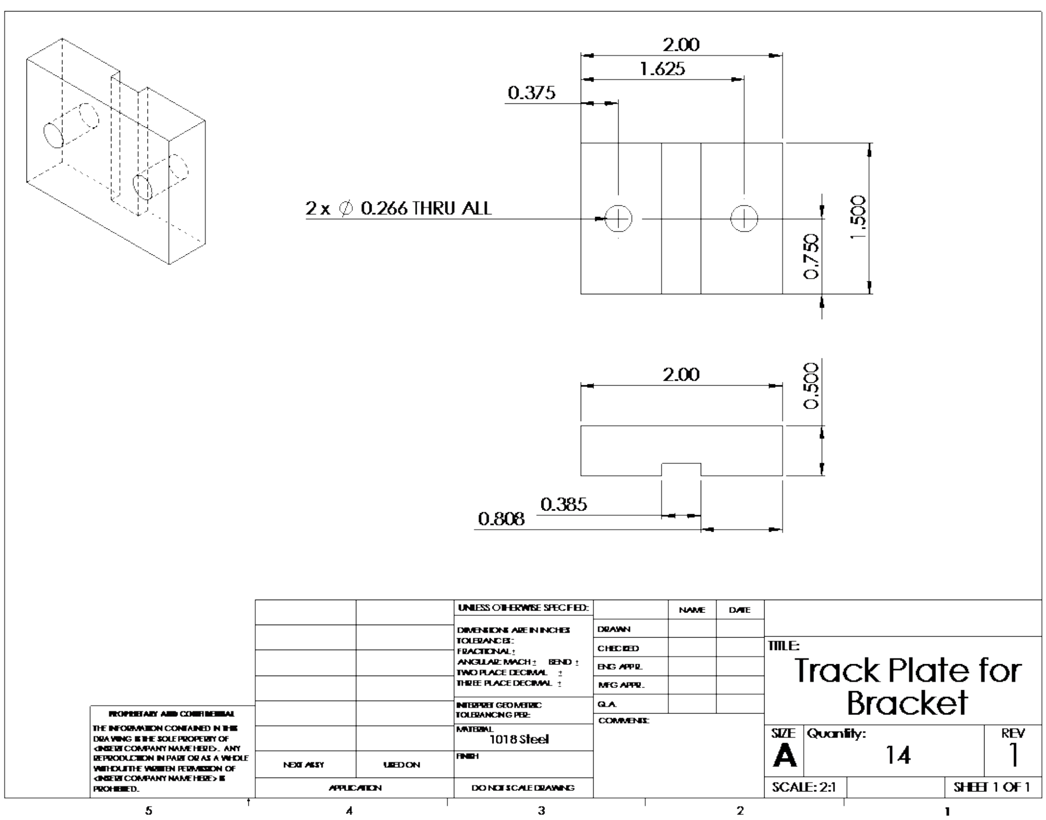


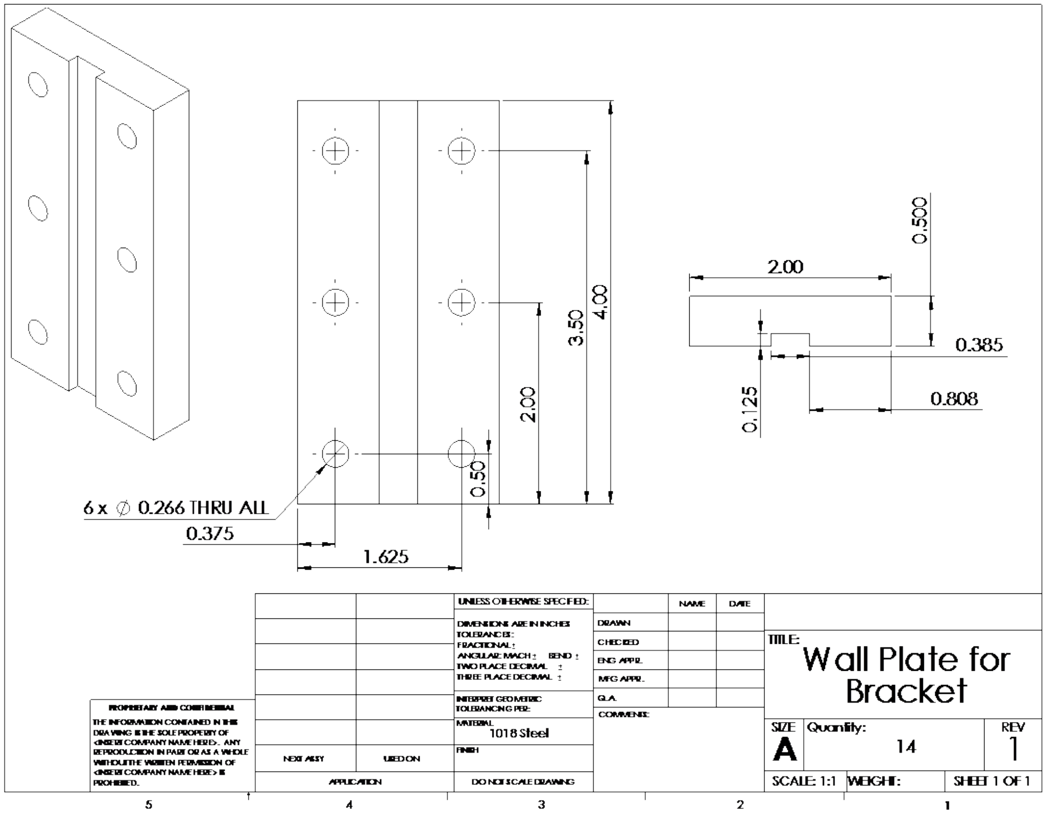
2x 0.1 Fillet Weld
2x 0.1 Fillet Weld
40.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1018 Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
TITLE:
S-Curve Track
Long Bracket Assembly
SIZE
DWG. NO.
REV
A
1
SCALE: 1:10
SHEET 1 OF 1



17.268
10.550
8.852
7.326
5.936
3.828
0.500
2.749
2.689
0.500
4.000
7.4°
0.875
3.302
6.715
7.949
9.639
1.500
0.875
1.857
1.866
2.246
19.250
0.375
0.365
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1018 Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
TITLE:
Small Bracket
Center
SIZE
Quantity:
10
REV
A
1
SCALE: 1:5
SHEET 1 OF 1


39.25
24.478
21.362
18.592
17.136
14.174
9.824
8.386
R0.375
R0.375
5.486
0.500
0.875
0.500
3.6°
4.00
4.058
9.420
10.806
14.226
17.831
19.217
22.636
35.297
0.375
0.365
0.875
1.50
1.681
1.814
1.988
2.217
2.350
2.523
2.865
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Long Bracket Center
MATERIAL
1018 Steel
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
SIZE
A
Quantity:
4
REV
1
SCALE: 1:10
SHEET 1 OF 1
5
4
3
2
1


2.00
1.625
0.375
2 x ∅ 0.266 THRU ALL
1.500
0.750
2.00
0.500
0.385
0.808
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Track Plate for Bracket
MATERIAL
1018 Steel
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
SIZE
A
Quantity:
14
REV
1
SCALE: 2:1
SHEET 1 OF 1
5
4
3
2
1



6 x ∅ 0.266 THRU ALL
0.375
1.625
0.50
2.00
3.50
4.00
2.00
0.500
0.385
0.125
0.808
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1018 Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Wall Plate for Bracket
SIZE
A
Quantity:
14
REV
1
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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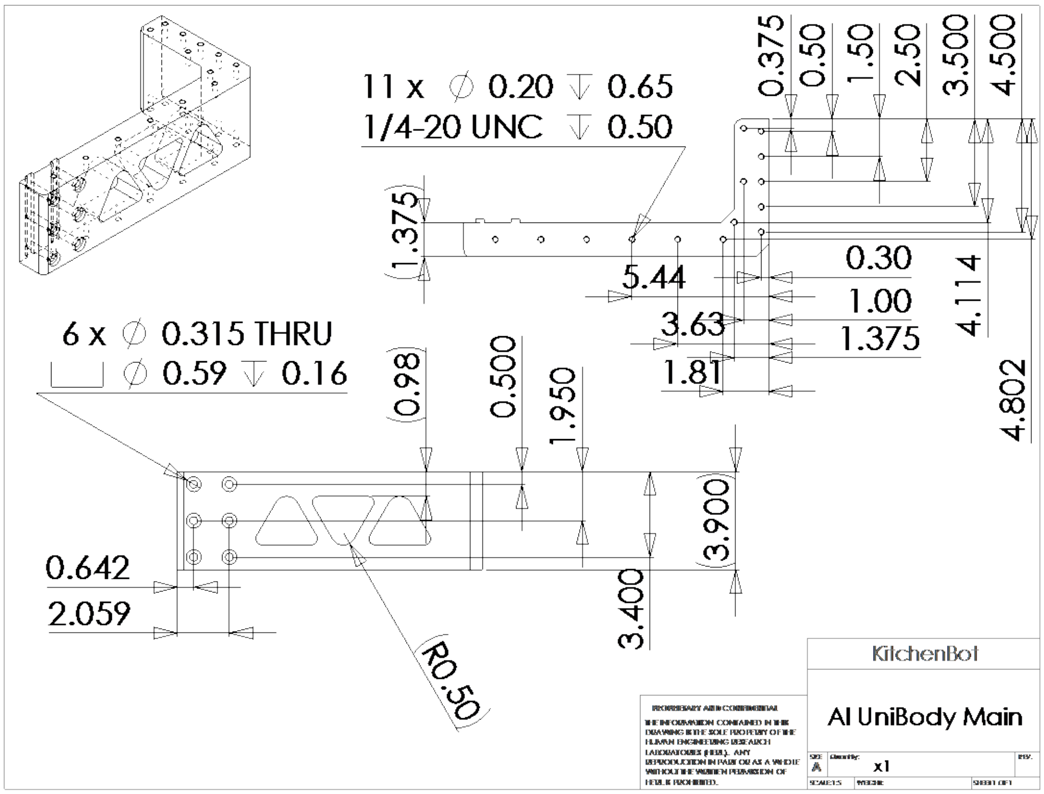
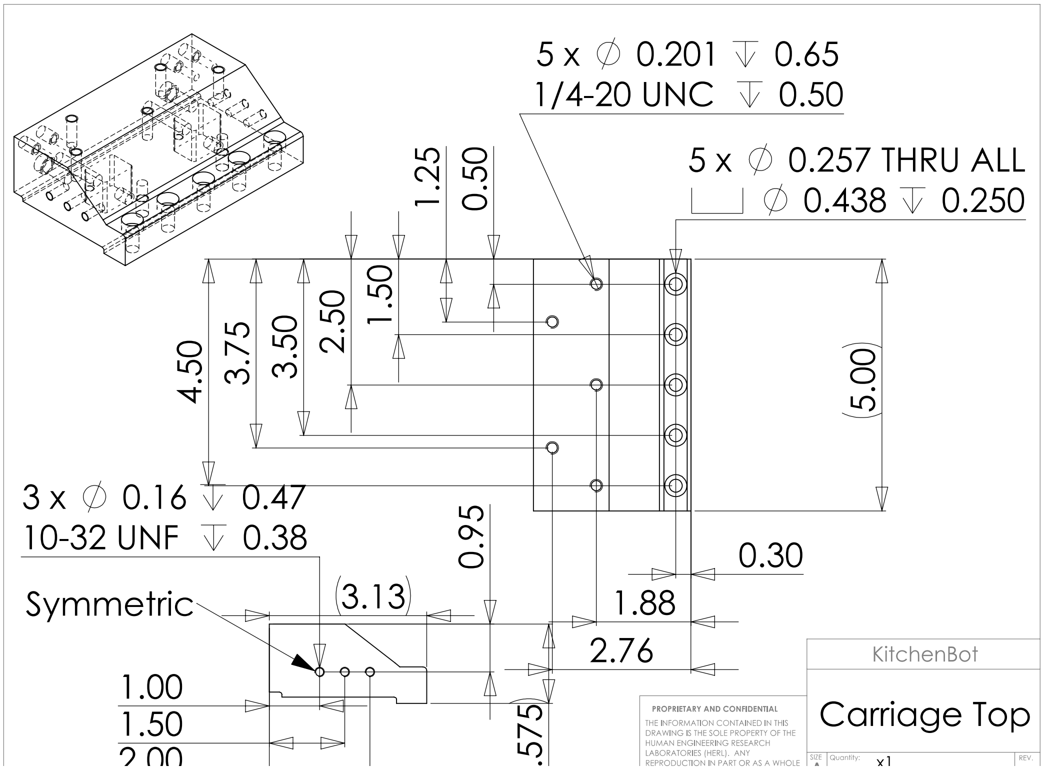
5
4
3
2
1

C.3 HORIZONTAL CARRIAGE




5 x ∅ 0.201 ↧ 0.65
1/4-20 UNC ↧ 0.50
5 x ∅ 0.257 THRU ALL
⌴ ∅ 0.438 ↧ 0.250
1.25
0.50
4.50
3.75
3.50
2.50
1.50
(5.00)
3 x ∅ 0.16 ↧ 0.47
10-32 UNF ↧ 0.38
0.95
0.30
Symmetric
(3.13)
1.88
2.76
1.00
1.50
2.00
.575
KitchenBot
Carriage Top
PROPRIETARY AND CONFIDENTIAL
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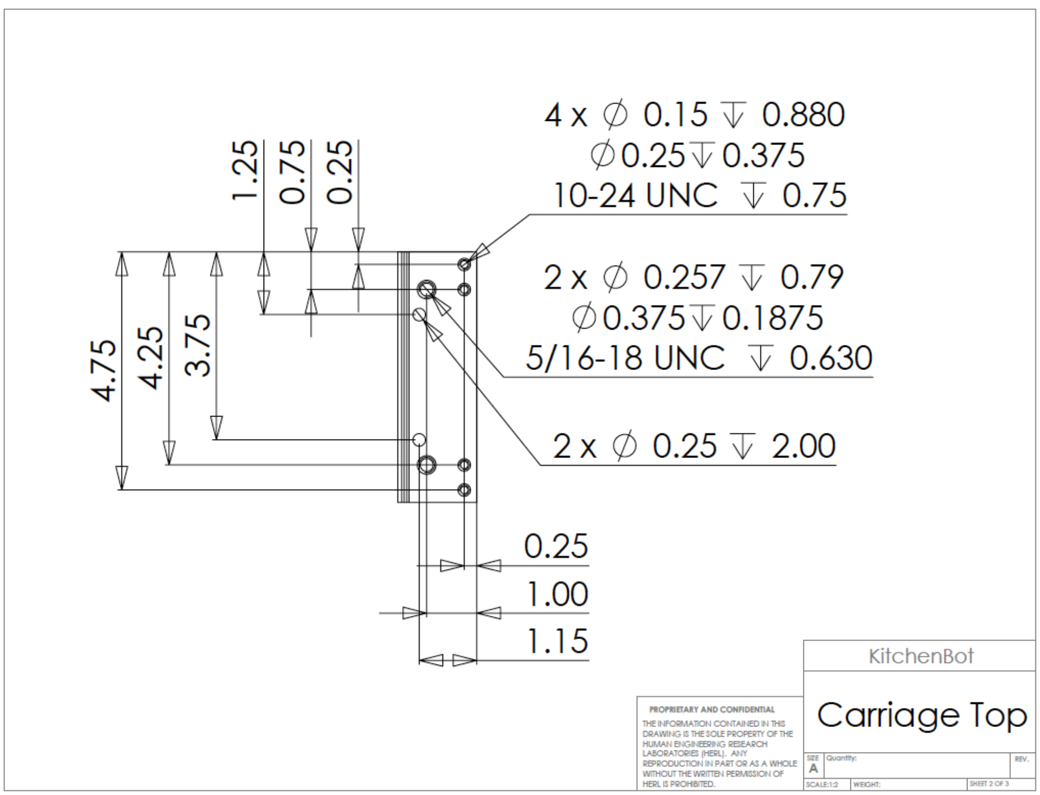
4 x ∅ 0.15 ↧ 0.880
∅0.25↧0.375
10-24 UNC ↧ 0.75
1.25
0.75
0.25
2 x ∅ 0.257 ↧ 0.79
∅0.375↧0.1875
5/16-18 UNC ↧ 0.630
4.75
4.25
3.75
2 x ∅ 0.25 ↧ 2.00
0.25
1.00
1.15
KitchenBot
Carriage Top
PROPRIETARY AND CONFIDENTIAL
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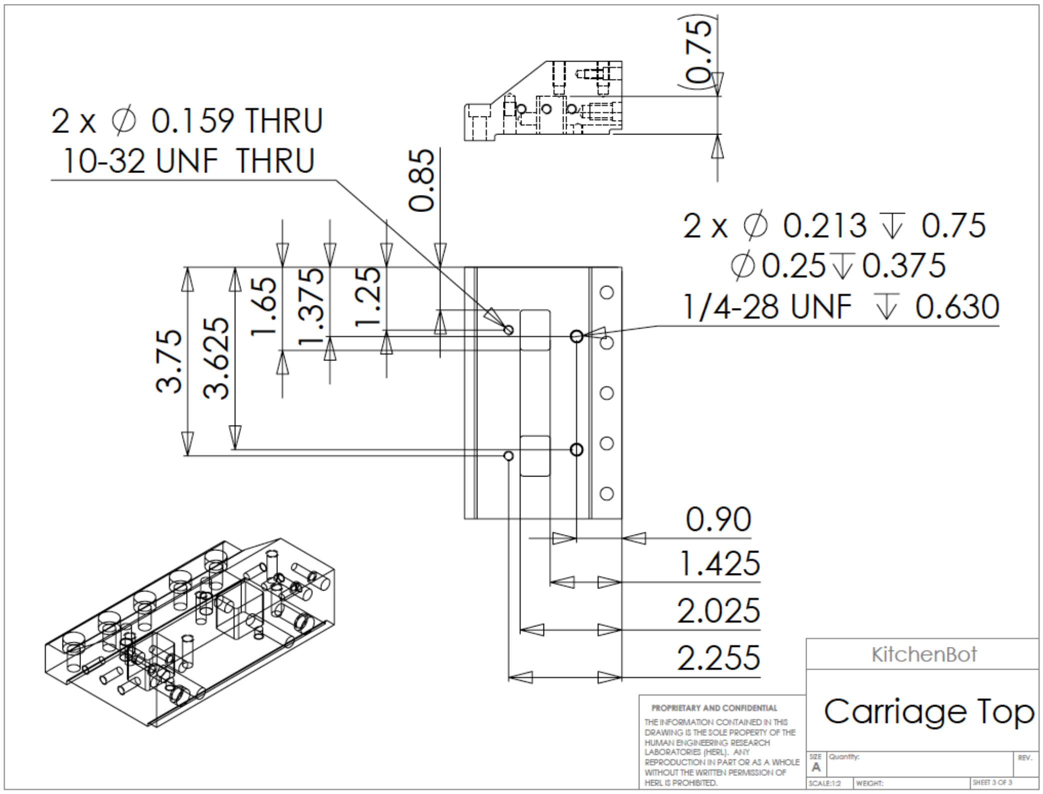
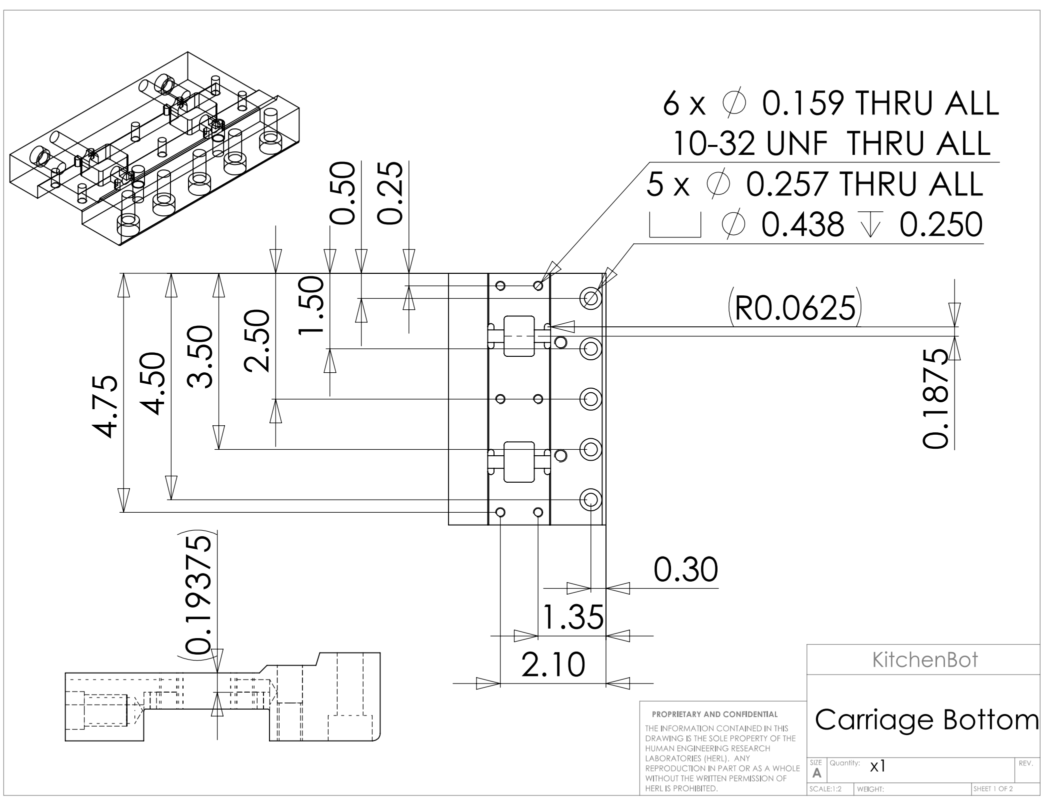
SIZE A
SCALE:1:2
SHEET 2 OF 3


2 x ∅ 0.159 THRU
10-32 UNF THRU
0.85
(0.75)
2 x ∅ 0.213 ↧ 0.75
∅ 0.25 ↧ 0.375
1/4-28 UNF ↧ 0.630
3.75
3.625
1.65
1.375
1.25
0.90
1.425
2.025
2.255
KitchenBot
Carriage Top
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF THE HUMAN ENGINEERING RESEARCH LABORATORIES (HERL). ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF HERL IS PROHIBITED.
SIZE A
SCALE:1:2
SHEET 3 OF 3


6 x ∅ 0.159 THRU ALL
10-32 UNF THRU ALL
5 x ∅ 0.257 THRU ALL
⌴ ∅ 0.438 ↧ 0.250
0.50
0.25
(R0.0625)
0.1875
4.75
4.50
3.50
2.50
1.50
(0.19375)
0.30
1.35
2.10
KitchenBot
Carriage Bottom
PROPRIETARY AND CONFIDENTIAL
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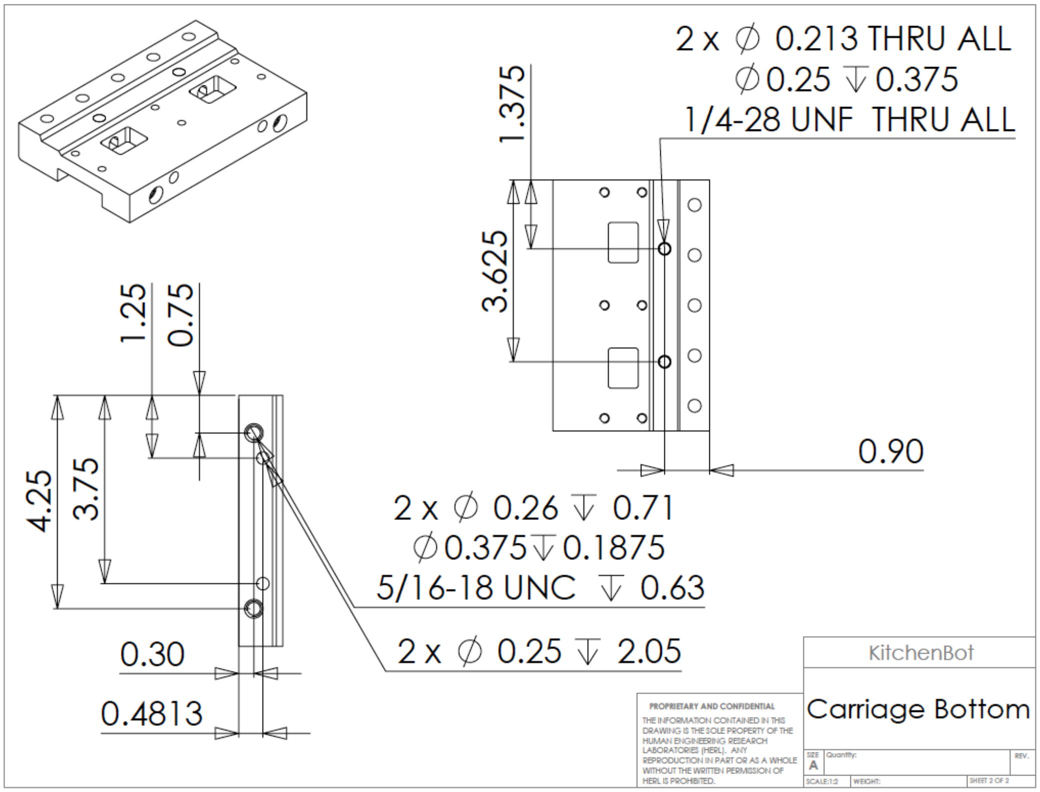
SIZE A
Quantity: x1
SCALE:1:2
SHEET 1 OF 2


2 x ∅ 0.213 THRU ALL
∅0.25 ↧0.375
1/4-28 UNF THRU ALL
1.375
3.625
0.90
1.25
0.75
4.25
3.75
2 x ∅ 0.26 ↧ 0.71
∅0.375↧0.1875
5/16-18 UNC ↧ 0.63
2 x ∅ 0.25 ↧ 2.05
0.30
0.4813
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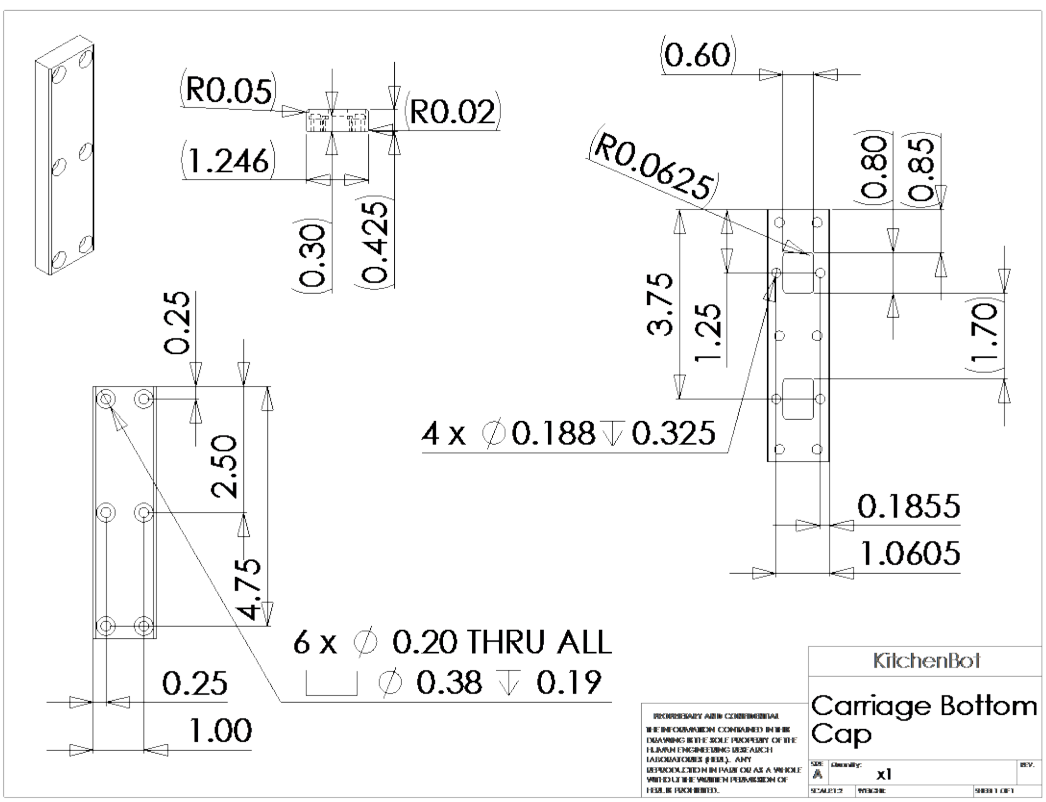
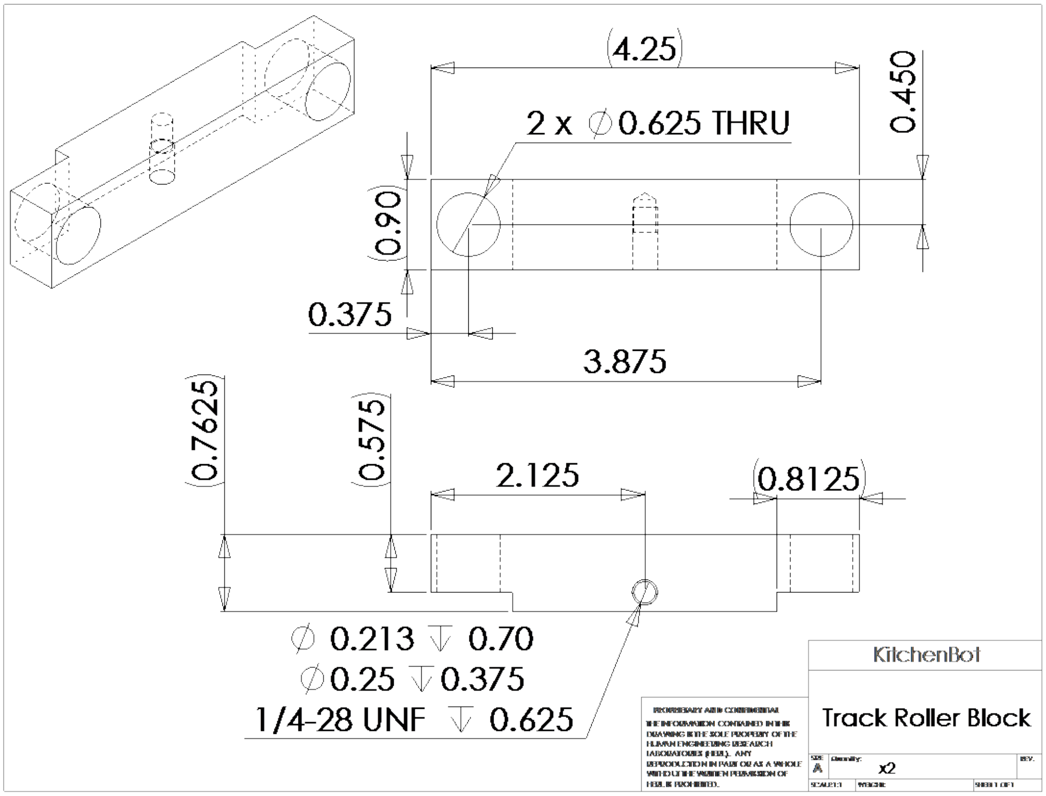
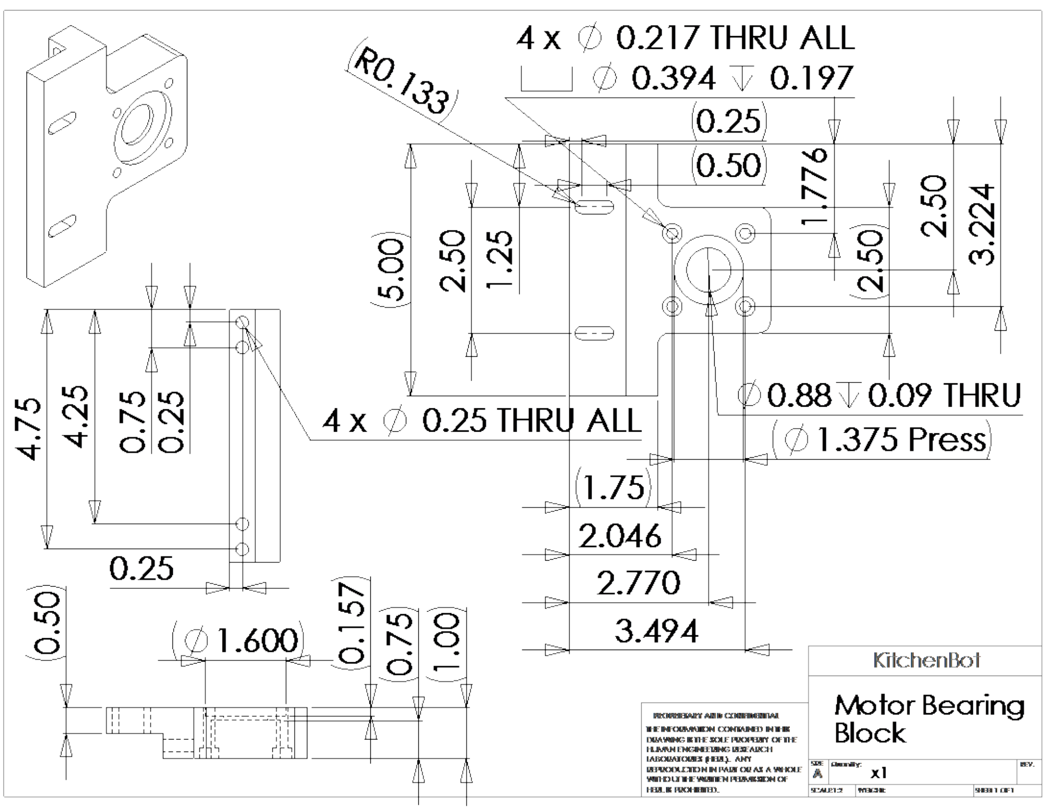
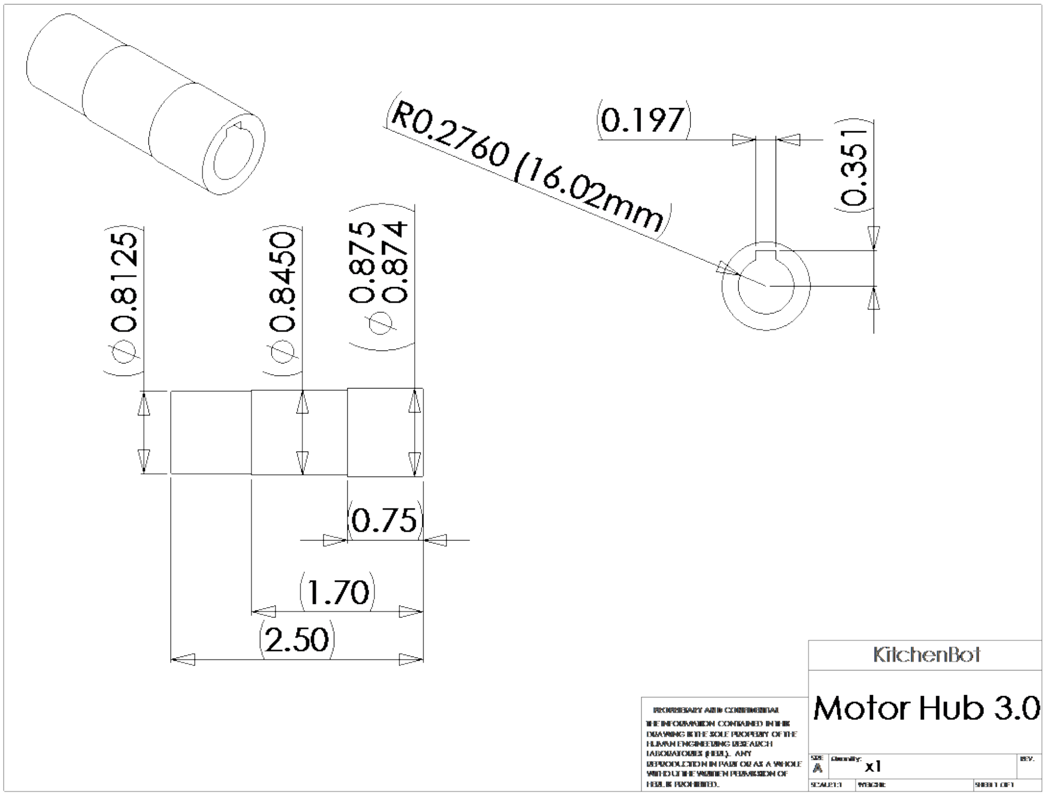
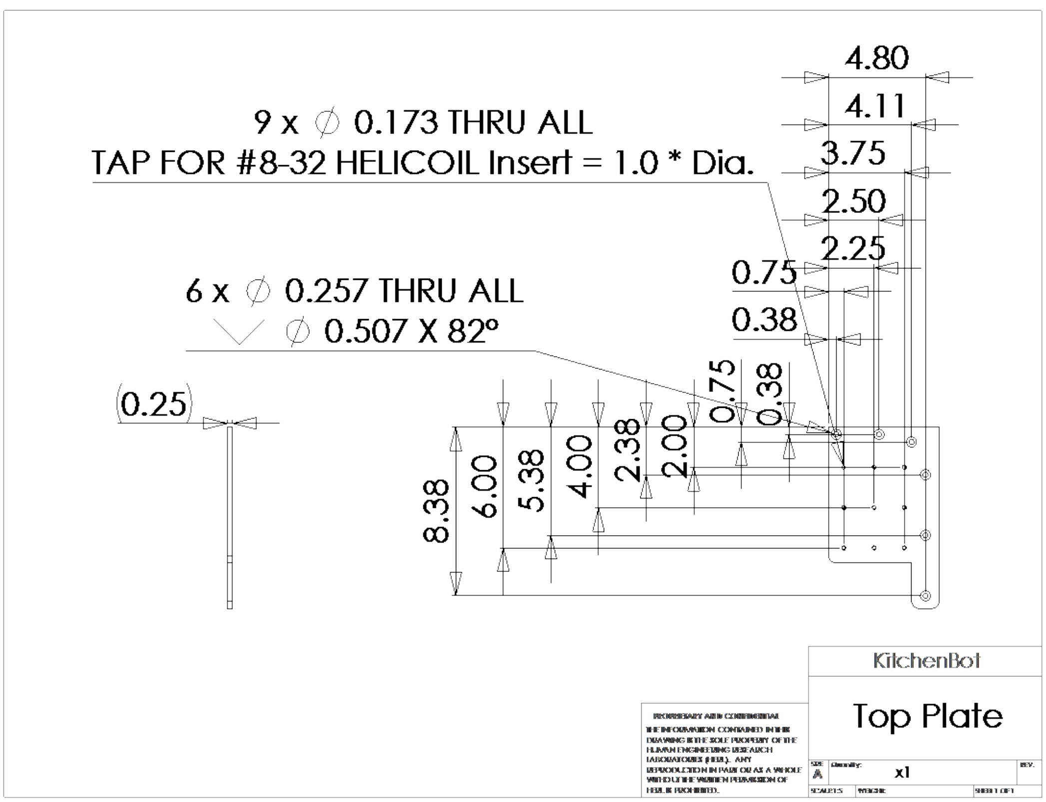
KitchenBot
Carriage Bottom
SIZE A
Quantity:
REV.
SCALE:1:2
WEIGHT:
SHEET 2 OF 2


R0.05
R0.02
1.246
0.30
0.425
0.60
R0.0625
0.80
0.85
3.75
1.25
1.70
4 x ∅0.188↧0.325
0.1855
1.0605
0.25
2.50
4.75
6 x ∅ 0.20 THRU ALL
⌴ ∅ 0.38 ↧ 0.19
0.25
1.00
PROPRIETARY AND CONFIDENTIAL
KitchenBot
Carriage Bottom Cap
SIZE A
Quantity:
x1
REV.


(4.25)
0.450
2 x ∅0.625 THRU
(0.90)
0.375
3.875
(0.7625)
(0.575)
2.125
(0.8125)
∅ 0.213 ↧ 0.70
∅0.25 ↧0.375
1/4-28 UNF ↧ 0.625
KitchenBot
Track Roller Block
x2

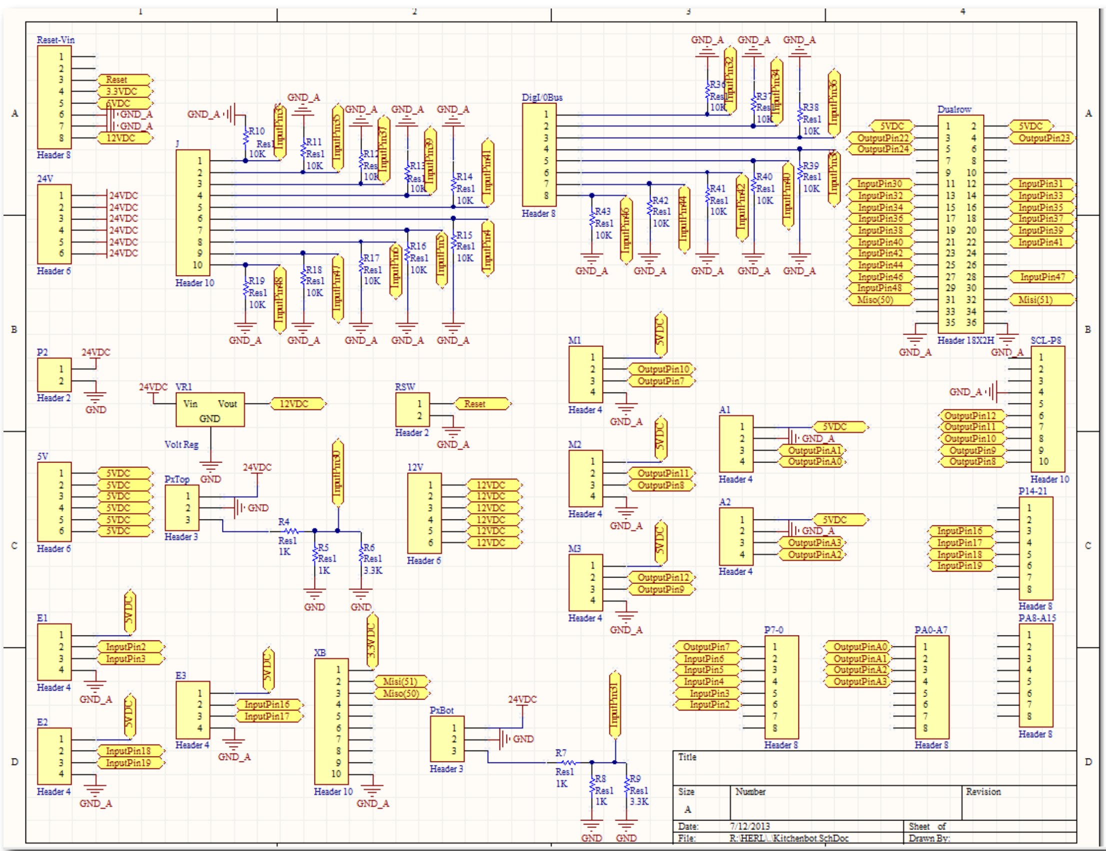

4 x ∅ 0.217 THRU ALL
⌴ ∅ 0.394 ↧ 0.197
R0.133
(0.25)
(0.50)
1.776
2.50
3.224
(5.00)
2.50
1.25
(2.50)
∅0.88↧0.09 THRU
(∅1.375 Press)
4 x ∅ 0.25 THRU ALL
4.75
4.25
0.75
0.25
0.25
(1.75)
2.046
2.770
3.494
(0.50)
(∅1.600)
0.157
0.75
1.00
KitchenBot
Motor Bearing Block
x1

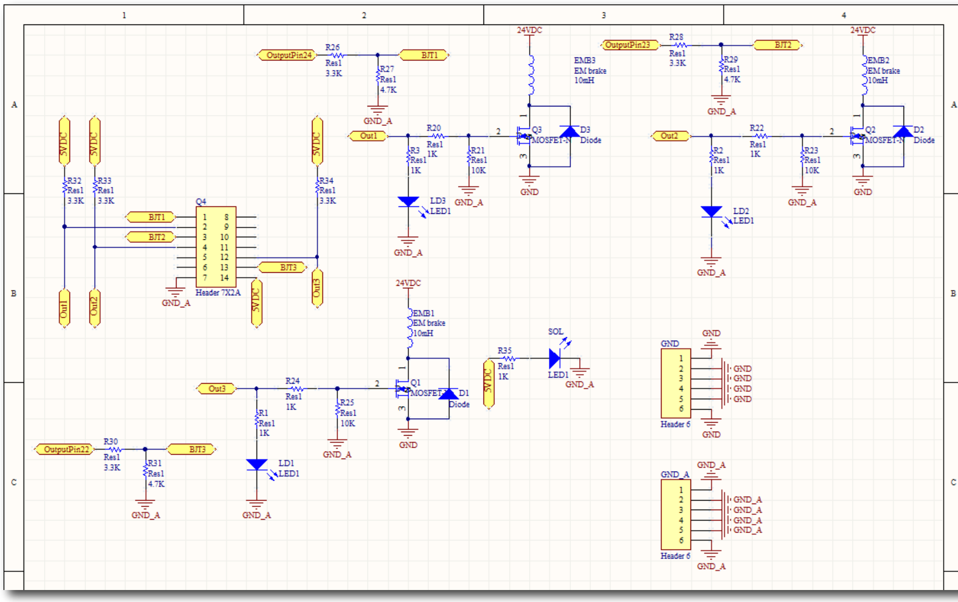

R0.2760 (16.02mm)
0.197
0.351
Ø0.8125
Ø0.8450
Ø 0.875 0.874
0.75
1.70
2.50
KitchenBot
Motor Hub 3.0
x1


9 x Ø 0.173 THRU ALL
TAP FOR #8-32 HELICOIL Insert = 1.0 * Dia.
6 x Ø 0.257 THRU ALL
Ø 0.507 X 82°
0.25
4.80
4.11
3.75
2.50
2.25
0.75
0.38
8.38
6.00
5.38
4.00
2.38
2.00
KitchenBot
Top Plate
x1

APPENDIX D

ELECTRONICS AND CONTROL CODE






```
//KitchenBot Control Code v19
//Created by: Joshua Telson
//NOTES: ALWAYS apply power via supply before connecting USB for debugging
//NOTES: CAUTION when bottom carriage tilts towards cabinets
//NOTES: EEPROM (memory) has recommended life span of 100,000 read/writes

#include <SoftwareSerial.h>
#include <EEPROM.h>
//#define ENCODER_OPTIMIZE_INTERRUPTS
#include <Encoder.h>
#include "EEPROMAnything.h"
#include <math.h>

SoftwareSerial mySerial(50, 51); //RX, TX
int PWM_1 = 7; //Horizontal
int PWM_2 = 8; //Vertical
int PWM_3 = 9; //Bottom
int dir_1 = 10; //Horz
int dir_2 = 11; //Vert
int dir_3 = 12;
int rotate_1_speed = 100; //horizontal     //Designed speed should be 200PWM, anything higher than 100 will result
in missed "auto_motion" (i.e. cannot hit X_in value)
int rotate_2_speed = 200; // vertical     //Designed speed should be 255PWM
int rotate_3_speed = 100; //bottom
int brake_1 = 22;
int brake_2 = 23;
int brake_3 = 24;
int brakeDelay = 50;
int LED = 13;
int incomingByte = 50;
int forward = 4; //joystick input
int right = 5;
int backward = 6;
int left = 47;
```

```
int red = 48;
int Limit_vert_top = 30;
int Limit_vert_bottom = 31;
boolean limit_counter_vert;
boolean limit_counter_bottom;

int X_input_1 = A0;
int Y_input_1 = A1;
int X_input_2 = A2;
int Y_input_2 = A3;
float angleX1;
float angleY1;
float angleX2;
float angleY2;
float angleXavg;
float angleYavg;
float corr_speed;
float max_corr_speed = 20;
float angleX_max = 5;

Encoder myEncX(2,3);
//long oldposX = -999;
float newposXinch;
Encoder myEncY(18,19);
//long oldposY = -999;
float newposYinch;
long newposX;
long newposY;
int save_count;

char xy_input_flag;
float X_in;
float Y_in;
boolean auto_motion_x;
boolean auto_motion_y;
float accuracy_threshold = 0.1;

//Signifies Arduino Reset
void blinkLED(int whatPin, int howManyTimes, int miliSecs) {
 int i = 0;
 for (i = 0; i < howManyTimes; i++) {
  digitalWrite(whatPin, HIGH);
  delay(miliSecs/2);
  digitalWrite(whatPin,LOW);
  delay(miliSecs/2);
 }
}
//END

void motor(int type, boolean dir, int speedy) {
  //Serial.println(speedy);
  if (dir == HIGH) {
    switch (type) {
      case 1:
        digitalWrite(dir_1, HIGH);                    //CHECK
        if (digitalRead(brake_1) == LOW){
```

```
        digitalWrite(brake_1,HIGH);
        delay(brakeDelay);
      }
      analogWrite(PWM_1, speedy);
    break;
    case 2:
      digitalWrite(dir_2, HIGH);                //CHECK
      if (digitalRead(brake_2) == LOW){
        digitalWrite(brake_2,HIGH);
        delay(brakeDelay);
      }
      analogWrite(PWM_2, speedy);
    break;
    case 3:
      digitalWrite(dir_3, HIGH);                //CHECK
      if (digitalRead(brake_3) == LOW){
        digitalWrite(brake_3,HIGH);
        delay(brakeDelay);
      }
      analogWrite(PWM_3, speedy);
    break;
  }
 }
 else if (dir == LOW) {
  switch (type) {
    case 1:
      digitalWrite(dir_1, LOW);              //CHECK
      if (digitalRead(brake_1) == LOW){
        digitalWrite(brake_1,HIGH);
        delay(brakeDelay);
      }
      analogWrite(PWM_1, speedy);
    break;
    case 2:
      digitalWrite(dir_2, LOW);              //CHECK
      if (digitalRead(brake_2) == LOW){
        digitalWrite(brake_2,HIGH);
        delay(brakeDelay);
      }
      analogWrite(PWM_2, speedy);
    break;
    case 3:
      digitalWrite(dir_3, LOW);              //CHECK
      if (digitalRead(brake_3) == LOW){
        digitalWrite(brake_3,HIGH);
        delay(brakeDelay);
      }
      analogWrite(PWM_3, speedy);
    break;
  }
 }
}

void move_right() {
      //Serial.println("I'm movin' right");
      motor(1, LOW, rotate_1_speed);
```

```
        //get_position();
        save_count = 0;
    if ((newposXinch >= 82 && newposXinch <= 100) || (newposXinch >= 200 && newposXinch <= 210)) {
        //Serial.println("I'm movin' right in a curve"); //turn off motor 3
      }
    else {
      motor(3, LOW, rotate_3_speed - corr_speed); //subtracting a negative corr_speed == addition
    }
}
void move_left() {
      //Serial.println("I'm movin' left");
      motor(1, HIGH, rotate_1_speed);
      //get_position();
      save_count = 0;
    if ((newposXinch >= 82 && newposXinch <= 100) || (newposXinch >= 200 && newposXinch <= 210)) {
       //Serial.println("I'm movin' left in a curve"); //turn off motor 3
      }
    else {
      motor(3, HIGH, rotate_3_speed + corr_speed);
    }
}
void move_down() {
    //Serial.println("I'm movin' down");
    motor(2,LOW,rotate_2_speed);
    //get_position();
    save_count = 0;
}
void move_up() {
    //Serial.println("I'm movin' up");
    motor(2,HIGH,rotate_2_speed);
    //get_position();
    save_count = 0;

}
//void lock_n_save_x() {
//       //Serial.println("Locked");
//      analogWrite(PWM_1, 0);
//      //analogWrite(PWM_2, 0);
//      analogWrite(PWM_3, 0);
//      digitalWrite(brake_1,LOW);
//      //digitalWrite(brake_2,LOW);
//      digitalWrite(brake_3,LOW);
//      if (save_count_x == 0) {
//            save_position ();
//            Serial.println("Last position saved");
//            save_count_x = 1;
//      }
//}
void lock_x() {
      analogWrite(PWM_1, 0);
      //analogWrite(PWM_2, 0);
      analogWrite(PWM_3, 0);
      digitalWrite(brake_1,LOW);
      //digitalWrite(brake_2,LOW);
      digitalWrite(brake_3,LOW);
}
```

```
void lock_y() {
      //analogWrite(PWM_1, 0);
      analogWrite(PWM_2, 0);
      //analogWrite(PWM_3, 0);
      //digitalWrite(brake_1,LOW);
      digitalWrite(brake_2,LOW);
      //digitalWrite(brake_3,LOW);
}
//void lock_n_save_y() {
//       //Serial.println("Locked");
//      //analogWrite(PWM_1, 0);
//      analogWrite(PWM_2, 0);
//      //analogWrite(PWM_3, 0);
//      //digitalWrite(brake_1,LOW);
//      digitalWrite(brake_2,LOW);
//      //digitalWrite(brake_3,LOW);
//      if (save_count == 0) {
//            save_position ();
//            Serial.println("Last position saved");
//            save_count_y = 1;
//      }
//}

float get_X_angle_1 ( ) {
  int i;
  float valX = 0;
  for (i=0;i<3;i++) {
    valX = valX + analogRead(X_input_1);
  }
  valX = (valX/3); //gets the average of 3 counts
  float volX = ((valX/1024)*4.87); //converts 10bit number into voltage (dependent on Vin) 4.79 on conv. 4.66 on
usb
  //Serial.print("VolX_1:");
  //Serial.println(volX);
  float radX = asin((volX - 1.65)/.750); //change base value for 5V
  float degX1 = radX * 57296 / 1000 ;
  return degX1;
}
float get_Y_angle_1 ( ) {
  int i;
  float valY = 0;
  for (i=0;i<3;i++) {
    valY = valY + analogRead(Y_input_1);
  }
  valY = (valY/3);
  float volY = ((valY/1024)*4.87);
  //Serial.println(volY);
  float radY = asin((volY - 2.30)/.750); //change base value for 5V
  float degY1 = radY * 57296 / 1000 ;
  return degY1;
}
float get_X_angle_2 ( ) {
  int i;
  float valX = 0;
  for (i=0;i<3;i++) {
    valX = valX + analogRead(X_input_2);
```

```
  }
  valX = (valX/3); //gets the average of 3 counts
  float volX = ((valX/1024)*4.87); //converts 10bit number into voltage (dependent on Vin) 4.87 on conv. 4.66 on
usb
   //Serial.print("VolX_2:");
  //Serial.println(volX);
  float radX = asin((volX - 1.65)/.750); //change base value for 5V
  float degX2 = radX * 57296 / 1000 ;
  return degX2;
}
float get_Y_angle_2 ( ) {
  int i;
  float valY = 0;
  for (i=0;i<3;i++) {
    valY = valY + analogRead(Y_input_2);
  }
  valY = (valY/3);
  float volY = ((valY/1024)*4.87);
  //Serial.println(volY);
  float radY = asin((volY - 2.30)/.750); //change base value for 5V
  float degY2 = radY * 57296 / 1000 ;
  return degY2;
}

void get_position () {
    newposX = (myEncX.read())/4; //x4 counting
    newposY = (myEncY.read())/4;
    newposXinch = (4*PI/25000)*(newposX); // 100:1 gearhead ratio, 250PPR encoder, 2in Radius wheel
    newposYinch = (6.299/40000)*(newposY); // 160:1 gearhead ratio, 250PPR encoder, 160mm linear travel to one
rev
}

struct config_t
{
    float X;
    float Y;
} storage;

void save_position () {
  storage.X = newposXinch;
  storage.Y = newposYinch;
  EEPROM_writeAnything(0, storage);
    Serial.print("wrote to eeprom (x,y):");
    Serial.print("(");
    Serial.print(storage.X);  //saves position [inch]
    Serial.print(",");
    Serial.print(storage.Y);
    Serial.println(")");
}

float getline() {
  uint8_t idx = 0;
  char c;
  char buffer [5];
  do
  {
```

```
    while (Serial.available() == 0) ; // wait for a char this causes the blocking
    c = Serial.read();
    buffer[idx++] = c;
  }while (c != 'a' && c != '\r');

  buffer[idx] = 0;
  return atoi(buffer);
}

void setup() {

 Serial.begin(9600);
 Serial.println("Begin Awesome");
 mySerial.begin(9600);
 mySerial.println("Hello, I am the KitchenBot");

 pinMode(PWM_1,OUTPUT); //Motor 1 PWM -- SDA_1
 pinMode(PWM_2,OUTPUT); //Motor 2 PWM -- SDA_2
 pinMode(PWM_3,OUTPUT); //Motor 3 PWM -- SDA_3
 pinMode(dir_1,OUTPUT); //Motor Direction -- SCL_1
 pinMode(dir_2,OUTPUT); //Motor Direction -- SCL_2
 pinMode(dir_3,OUTPUT); //Motor Direction -- SCL_3
 pinMode(brake_1,OUTPUT); //EM Signal 1
 pinMode(brake_2,OUTPUT); //EM Signal 2
 pinMode(brake_3,OUTPUT); //EM Signal 2

 pinMode(forward,INPUT); //joystick input
 pinMode(right,INPUT);
 pinMode(backward,INPUT);
 pinMode(left,INPUT);
 pinMode(red,INPUT);

 pinMode(Limit_vert_top,INPUT); //Vertical limit proximity switches
 pinMode(Limit_vert_bottom,INPUT);
 limit_counter_vert = 0;
 limit_counter_bottom = 0;

 pinMode(X_input_1,INPUT); //Accelerometer input
 pinMode(Y_input_1,INPUT);
 pinMode(X_input_2,INPUT); //Accelerometer input
 pinMode(Y_input_2,INPUT);

 digitalWrite(brake_1,LOW); // Initialize Failsafe Brake
 digitalWrite(brake_2,LOW);
 digitalWrite(brake_3,LOW);

 EEPROM_readAnything(0, storage);
 newposXinch = storage.X;
 newposYinch = storage.Y;
 newposX = 4*((newposXinch*25000)/(4*PI));
 newposY = 4*((newposYinch*40000)/(6.299));
 myEncX.write(newposX); //writes position [tick counts]
 myEncY.write(newposY);
 Serial.print("Initial read from eeprom (x,y):");
 Serial.print("(");
 Serial.print(newposXinch);
```

```
 Serial.print(",");
 Serial.print(newposYinch);
 Serial.println(")");
 save_count = 1;

 auto_motion_x = LOW;
 auto_motion_y = LOW;
 X_in = 0;
 Y_in = 0;

 blinkLED(LED,3,333);
 Serial.println("End Setup");
}

void loop() {
  get_position();
  angleXavg = ((get_X_angle_1()+get_X_angle_2())/2);
  angleYavg = ((get_Y_angle_1()+get_Y_angle_2())/2);
  if (angleXavg > angleX_max) {
    angleXavg = angleX_max;
  }
  else if (angleXavg < -angleX_max) {
    angleXavg = -angleX_max;
  }
  //corr_speed = (max_corr_speed/angleX_max)*abs(angleXavg);
  corr_speed = (max_corr_speed/angleX_max)*(angleXavg);
  //Serial.println(angleXavg);
  //angleY = get_Y_angle();
  //Serial.print("X angle is: ");
  //Serial.println(angleX);
  //delay(250);
  //Serial.print("Y angle is: ");
  //Serial.println(angleY);
  //delay(250);


  if (mySerial.available()) {
    incomingByte = mySerial.read();
    Serial.print("I received: ");
    Serial.println(incomingByte, DEC);
  }

  if (Serial.available()) {
    xy_input_flag = Serial.read();
    if (xy_input_flag == 'A') {
      Serial.println("Type desired X position:");       //MUST type int followed by lowercase 'a'
      while(!Serial.available());
      X_in = getline();
      Serial.println(X_in);
      Serial.println("Type desired Y position:");
      while(!Serial.available());
      Y_in = getline();
      Serial.print(Y_in);
      auto_motion_x = HIGH;
      auto_motion_y = HIGH;
    }
```

```
  }

if (auto_motion_x == HIGH) {
  //goto (xin, yin)
  //Serial.println("Ready to Auto X");
  if (newposXinch < (X_in - accuracy_threshold/2)) {
    move_right();
    get_position();
    //Serial.println("auto right");
  }
  if (abs(newposXinch - X_in) <= accuracy_threshold) {
    Serial.println("Auto X finished");
    save_count = 0;
    lock_x();
    delay(100);
    auto_motion_x = LOW;
  }
  if (newposXinch > (X_in + accuracy_threshold/2)) {
    move_left();
    get_position();
  }
}
if (auto_motion_y == HIGH) {
  //Serial.println("Ready to Auto Y");
  if (newposYinch < (Y_in - accuracy_threshold/2)) {
    move_down();
    get_position();
    //Serial.println("auto down");
  }
  if (abs(newposYinch - Y_in) <= accuracy_threshold) {
    Serial.println("Auto Y finished");
    save_count = 0;
    lock_y();
    delay(100);
    auto_motion_y = LOW;
  }
  if (newposYinch > (Y_in + accuracy_threshold/2)) {
    move_up();
    get_position();
  }
}


if (incomingByte == 10) {
      analogWrite(PWM_1, 0);
      analogWrite(PWM_2, 0);
      analogWrite(PWM_3, 0);
      digitalWrite(brake_1,LOW);
      digitalWrite(brake_2,LOW);
      digitalWrite(brake_3,LOW);
      delay(2000);
      myEncX.write(0);
      newposXinch = 0;
      save_position();
      save_count = 1;
      //stop robot
```

```
        Serial.println("At X home by dishwasher - please wait");
        delay(1000);
        incomingByte = 11;
    }

    if (incomingByte == 01) {
        analogWrite(PWM_1, 0);
        analogWrite(PWM_3, 0);
        digitalWrite(brake_1,LOW);
        digitalWrite(brake_3,LOW);
        delay(2000);
        myEncX.write(2600000);
        newposXinch = ((4*PI/25000)*(2600000))/4;
        save_position();
        save_count = 1;
        //stop robot
        Serial.println("At X home by fridge - please wait");
        delay(1000);
        incomingByte = 11;
    }

    if ((digitalRead(Limit_vert_top) == HIGH) && (limit_counter_vert == 0)) {
        analogWrite(PWM_1, 0);
        analogWrite(PWM_2, 0);
        analogWrite(PWM_3, 0);
        digitalWrite(brake_1,LOW);
        digitalWrite(brake_2,LOW);
        digitalWrite(brake_3,LOW);
        delay(2000);
        myEncY.write(0);
        newposYinch = 0;
        save_position();
        save_count = 1;
        //stop robot
        Serial.println("At Y vertical home by track - please wait");
        delay(1000);
        limit_counter_vert = 1;
    }

    if ((digitalRead(Limit_vert_bottom) == HIGH) && (limit_counter_bottom == 0)) {
        analogWrite(PWM_1, 0);
        analogWrite(PWM_2, 0);
        analogWrite(PWM_3, 0);
        digitalWrite(brake_1,LOW);
        digitalWrite(brake_2,LOW);
        digitalWrite(brake_3,LOW);
        delay(2000);
        myEncY.write(500000);
        newposYinch = (6.299/40000)*(500000);
        save_position();
        save_count = 1;
        //stop robot
        Serial.println("At Y vertical home by base - please wait");
        delay(1000);
        limit_counter_bottom = 1;
    }
```

```
if (digitalRead(Limit_vert_top) == LOW) { //reset the limit counter
  limit_counter_vert = 0;
}
if (digitalRead(Limit_vert_bottom) == LOW) { //reset the limit counter
  limit_counter_bottom = 0;
}

if ((digitalRead(forward) == HIGH) && (digitalRead(right) == LOW) && (digitalRead(backward) == LOW) &&
(digitalRead(left) == LOW)) {
        move_up();
        get_position();
        auto_motion_x = LOW; //stops auto motion
        auto_motion_y = LOW; //stops auto motion
  }
else if ((digitalRead(forward) == LOW) && (digitalRead(right) == HIGH) && (digitalRead(backward) == LOW)
&& (digitalRead(left) == LOW)) {
        move_right();
        get_position();
        auto_motion_x = LOW; //stops auto motion
        auto_motion_y = LOW; //stops auto motion
  }
else if ((digitalRead(forward) == LOW) && (digitalRead(right) == LOW) && (digitalRead(backward) == HIGH)
&& (digitalRead(left) == LOW)) {
         move_down();
         get_position();
        auto_motion_x = LOW; //stops auto motion
        auto_motion_y = LOW; //stops auto motion
  }
else if ((digitalRead(forward) == LOW) && (digitalRead(right) == LOW) && (digitalRead(backward) == LOW)
&& (digitalRead(left) == HIGH)) {
         move_left();
         get_position();
        auto_motion_x = LOW; //stops auto motion
        auto_motion_y = LOW; //stops auto motion
  }
else if (digitalRead(red) == HIGH) {
    Serial.println("SAFETY DELAY for 5sec");
        auto_motion_x = LOW; //stops auto motion
        auto_motion_y = LOW; //stops auto motion
    delay(5000);
    save_count = 0;
  }
 else {
      if ((auto_motion_x == LOW) && (auto_motion_y == LOW)) {
         lock_x();
         lock_y();
        if (save_count == 0) {
          //delay(100);
           save_position ();
           Serial.println("Last position saved");
           save_count = 1;
          }
      }
    }
}
```

APPENDIX E

PROTOTYPE FOCUS GROUP

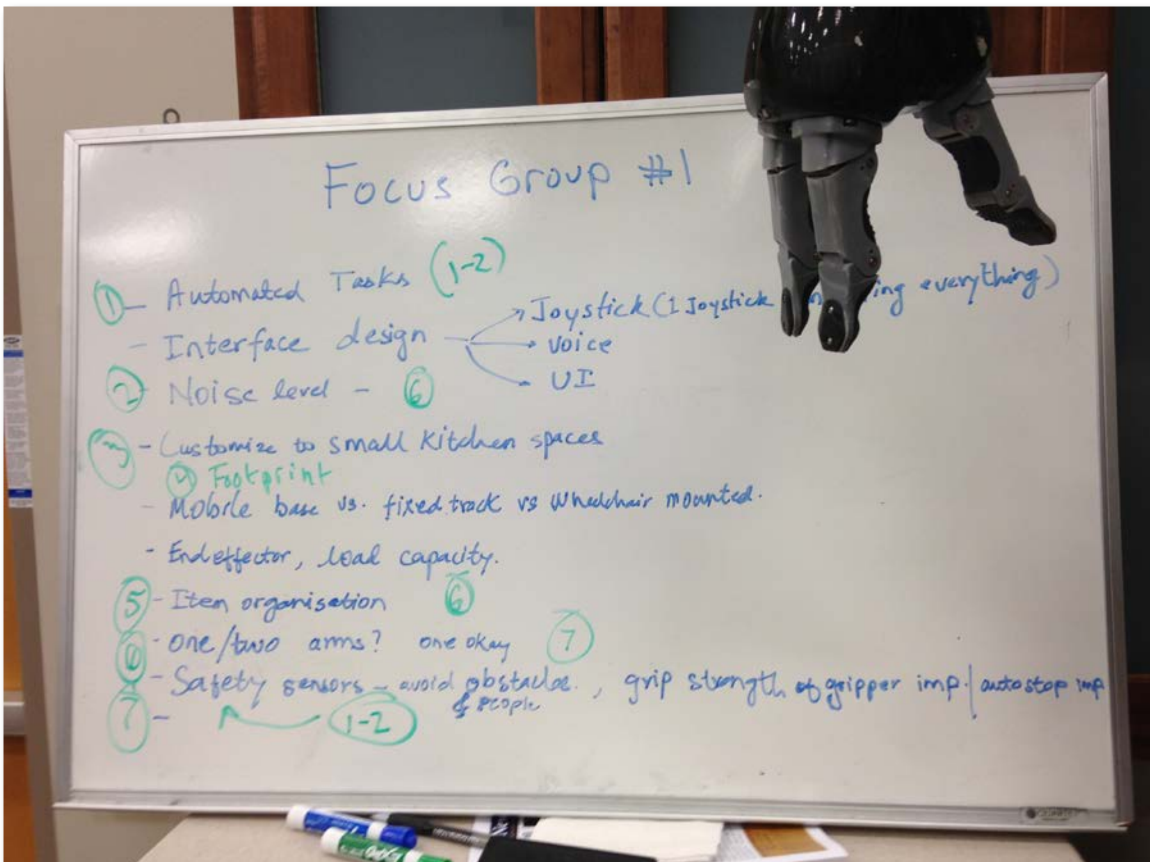


Figure 51: Focus group 1 whiteboard priority ranking

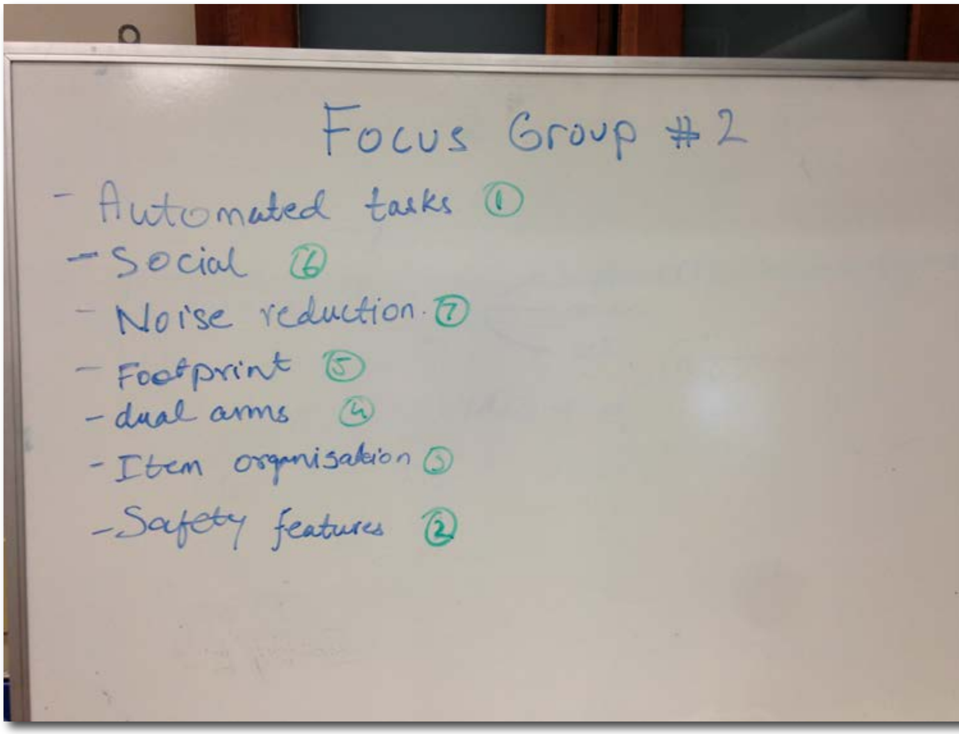


Figure 52: Focus group 2 whiteboard priority ranking

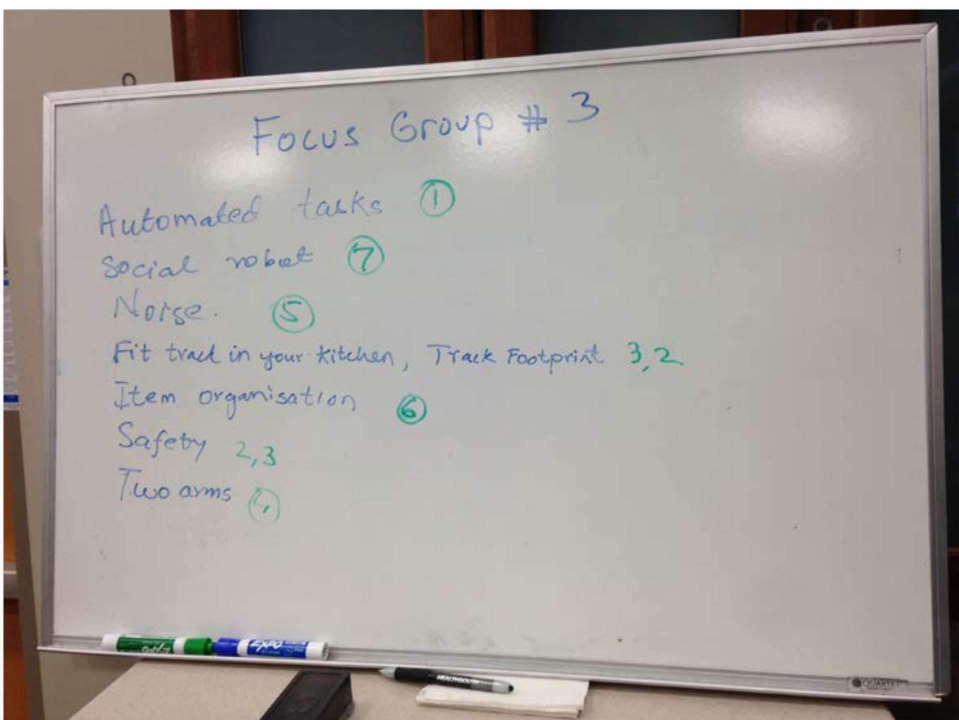


Figure 53: Focus group 3 whiteboard priority ranking

E.1 PROTOTYPE FOCUS GROUP QUESTIONNAIRE

Questionnaire Packet

Participatory Evaluation of Assistive Technologies

Human Engineering Research Laboratories of the
VA Pittsburgh Healthcare System and the University of Pittsburgh

COMPLETION LOG:	DATE:	INITIALS:	TIME:
Data Collection	/ /		
Data Entry	/ /		
Verification	/ /		

PART A: Demographics & Self-Assessment

We are interested in the relationship of disability and assistive technology to other factors in your life. The following questions deal with these factors.

1. **What is your injury or diagnosis?** ____

   ____

   Date of onset, injury, or diagnosis: _____/_____/_____

2. **Gender:** ☐ Male ☐ Female

3. **Age:** ____________

4. **Geographic Location:**

   ☐ Rural
   ☐ Suburban
   ☐ Urban
   ☐ Unsure

5. **Race/Ethnicity**

   ☐ Black or African American
   ☐ Asian
   ☐ White or Caucasian
   ☐ Hispanic or Latino
   ☐ American Indian or Alaskan Native
   ☐ Native Hawaiian or other Pacific Islander
   ☐ Two or more races

Health Information

6. For each of the following items below, please check the statement that best describes you. Do not check more than one box in each group.

   Self-care

   ☐ I have no problems with self-care
   ☐ I have some problems washing or dressing myself
   ☐ I am unable to wash or dress myself

   Usual activities (e.g. work, study, housework, family or leisure activities)

   ☐ I have no problems with performing my usual activities
   ☐ I have some problems with performing my usual activities
   ☐ I am unable to perform my usual activities

   Pain/Discomfort

   ☐ I have no pain or discomfort
   ☐ I have moderate pain or discomfort
   ☐ I have extreme pain or discomfort

7. **In which type of housing do you live?**

   ☐ Residence hall/College dormitory
   ☐ House/Apartment/Condominium
   ☐ Senior housing (independent)
   ☐ Assisted living
   ☐ Nursing Home
   ☐ Relative's home
   ☐ Other: ______________________________
   (please specify)

8. **What is the highest level of formal education you have completed?**

- ☐ 8th grade or less (includes pre-school)
- ☐ 9th through 11th grade
- ☐ High School Diploma or GED
- ☐ Associate Degree/Vocation/Technical School
- ☐ Bachelors Degree
- ☐ Masters Degree
- ☐ Doctorate: includes PhD, MD, JD etc.
- ☐ Other: ______________

9. **Which statement best describes your CURRENT work status?**

- ☐ Working full-time, outside the home
- ☐ Working part-time, outside the home
- ☐ Working full-time, inside the home
- ☐ Working part-time, inside the home
- ☐ Unable to work because of disability
- ☐ Unemployed: not able to find job in field that I was trained
- ☐ I choose not to be employed or am retired
- ☐ Student

10. **Please indicate which best describes your marital status:**

- ☐ Single
- ☐ Married
- ☐ Living with someone as if married
- ☐ Divorced/Separated
- ☐ Widowed

One's financial situation and health insurance can influence one's health.
Please check the response that best describes you.

11. **Your current approximate total household income per year is:**
(including spouse or other household income sources):

- ☐ Less than $10,000
- ☐ $10,000 – 15,000
- ☐ $15,000 – 20,000
- ☐ $20,000 – 25,000
- ☐ Prefer not to answer
- ☐ $25,000 – 35,000
- ☐ $35,000 – 50,000
- ☐ $50,000 – 75,000
- ☐ Greater than $75,000

12. **Do you feel that your disability has affected your income?**

- ☐ No
- ☐ Yes ➡ If yes, has your disability:
  - ☐ increased your income
  - ☐ decreased your income

13. **Are you currently on disability?**

- ☐ No
- ☐ Yes ➡ If yes, which type:
  - ☐ SSI
  - ☐ SSDI
  - ☐ Workman's Compensation
  - ☐ Other, please specify: ______________

14. **Please check the statement(s) that best describe you regarding health insurance:**

- ☐ I do not have health insurance; I use my private money to pay for medical expenses.
- ☐ Health insurance is provided through Medicare or Medicaid.
- ☐ Health insurance is provided by my employer, my spouse's/parent's employer, or previous employer (i.e., Champus, Tri-Care).
- ☐ I have health insurance, but I pay for it through personal monies
- ☐ Other: ______________________________

Part B: Assistive Technology

1. **On MOST DAYS which of the following assistive devices do you use?**
Check all that apply:

☐ Unassisted Walking	☐ Walker	☐ Scooter
☐ Cane	☐ Wheeled Walker	☐ Other, please specify:
☐ Quad Cane	☐ Manual Wheelchair	______________
☐ Crutches	☐ Power Wheelchair	

If you use a wheelchair….

1a. **Which type of wheelchair do you use the most?**

☐ Manual wheelchair ☐ Power wheelchair ☐ Scooter

1b. **What is the age of your current wheelchair?** _____ years

1c. **How many total years have you used a wheelchair for your mobility needs?** ______ years

5. **Are you satisfied with your current assistive technology?**

☐ Yes ☐ No ☐ Unsure

6. **Have you had a piece of assistive technology that worked especially well for you?**

☐ Yes ☐ No ☐ Unsure

6a. **If yes**, please describe: ______________________________

____

7. **Have you had a piece of assistive technology that did not work well for you?**

☐ Yes ☐ No ☐ Unsure

7a. **If yes**, please describe: ______________________________

____

8. **Have you ever built an assistive device to meet your needs?**

☐ Yes ☐ No ☐ Unsure

9. **Have you ever modified some existing technology to suit your needs?**

☐ Yes ☐ No ☐ Unsure

10. **Would you describe yourself as technologically savvy (i.e. you purchase the newest technology as soon as it is available)?**

☐ Yes ☐ No ☐ Unsure

In general, to what extent do you believe that technology:

	Not at all						Completely
	1	**2**	**3**	**4**	**5**	**6**	**7**
Makes life easy and convenient							
Makes life complicated							
Gives people control over their daily lives							
Makes people dependent							
Makes life comfortable							
Makes life stressful							
Brings people together							
Makes people isolated							
Increases personal safety and security							
Reduces privacy							

Subject ID: __________

How much does each of the following phrases describe you?

	Not at all Accurate						Extremely Accurate
Phrase	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I like to keep up with the latest technology							
I generally wait to adopt a new technology until all the bugs have been worked out							
I enjoy the challenge of figuring out high tech gadgets							
I feel confident that I have the ability to learn to use technology							
Technology makes me nervous							
If a human can complete a task as well as technology, I prefer to interact with a person							
I like the idea of using technology to reduce my dependence on other people							

How important is each of these factors for you when choosing technology?

	Not at all Important						Extremely Important
Factor	**1**	**2**	**3**	**4**	**5**	**6**	**7**
How well it meets your needs							
Ease of use							
Cost							
The way it looks (attractiveness)							
How visible it is to others							
How it affects your privacy							
How safe it is to use							

PLEASE STOP HERE UNTIL RESEARCHERS INDICATE TO MOVE ONTO THE NEXT SECTION

Part C: Prospective Technology

THE KITCHENBOT

The KitchenBot is a robotic arm mounted to a track that can help with activities of daily living in a kitchen. The track can be installed into almost any kitchen and gives the robotic manipulator access to the entire area from the ground to the top cabinets. This technology would be able to open cabinet doors and drawers, reach items that may be too high, stabilize pots or pans during cooking, or move items that are difficult to handle.

1) TASK IMPORTANCE

We would like to provide the most helpful assistive robotic product. To do so, we are trying to find a list of kitchen tasks that KitchenBot could help to complete. For each task below, please place a check mark or 'x' in the box that shows how important it would be to you to have help from the KitchenBot.

	Very Unimportant	Unimportant	Slightly Unimportant	Neutral	Slightly Important	Important	Very Important
Tasks	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Opening/closing/reaching a cabinet above the countertop							
Opening/closing/reaching a cabinet below the countertop							
Opening/closing/reaching kitchen drawers							
Opening/closing/reaching the oven							
Opening/closing/reaching the dishwasher							
Opening/closing/reaching the refrigerator							
Retrieving items from the floor							
Stabilizing pots on the stove							
Stabilizing a bowl or plate on the countertop							
Stabilizing food during preparation							
Unloading groceries							
Loading/unloading the dishwasher							
Moving hot objects from the stove							
Moving hot objects from the microwave							
Moving hot objects from the oven							
Put in/take out heavy objects (such as a chicken inside the oven)							
Carrying heavy objects (such as moving a pot of water)							

Other: ______________ (please specify)							
Other: ______________ (please specify)							

2) ASSISTANCE FREQUENCY

Furthermore, in an attempt to provide the most helpful assistive robotic product, we would like to know the how often you might need help with each task listed. This means, on average, the percent of the time that you would require help with each task. In this table, based on your experience, please place a check mark or 'x' in the box to indicate how often you need help completing the task that is listed.

	Never	Rarely (10%)	Occasionally (30%)	Sometimes (50%)	Frequently (70%)	Usually (90%)	Every time
Tasks	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Opening/closing a cabinet above the countertop							
Opening/closing a cabinet below the countertop							
Opening/closing kitchen drawers							
Opening/closing the oven							
Opening/closing the dishwasher							
Opening/closing the refrigerator							
Retrieving items from the floor							
Stabilizing pots on the stove							
Stabilizing a bowl or plate on the countertop							
Stabilizing food during preparation							
Unloading groceries							
Loading/unloading the dishwasher							
Moving hot objects from the stove							
Moving hot objects from the microwave							
Moving hot objects from the oven							
Put in/take out heavy objects (such as a chicken inside the oven)							
Moving heavy objects (such as moving a pot of water)							
Other: ______________ (please specify)							
Other: ______________ (please specify)							

How many times in a typical week …	Not at all	0-1	2-4	5-7	8-14	>14
do you cook or prepare meals at home						
does someone assist you in meal preparation						

3) INTERFACE

Today, we discussed three different ways for positioning the arm along the track and controlling the position and orientation of the gripper, respectively. Please rank the three control methods from 1 – 3, where 1 is the best, according to the following:

3.1) Overall, how would you rank the three ways that you can position the arm along the track?

Please rank from 1 (best) to 3.

_____ Voice Control _____ Joystick _____ Tablet PC

3.1a. Please explain why you ranked your first choice first? ______________________________

____

3.1b. Please explain why you ranked your third choice third? ______________________________

____

3.2) Overall, how would you rank the three ways that you can control the position and orientation of the gripper?

Please rank from 1 (best) to 3.

_____ Voice Control _____ Joystick _____ Tablet PC

3.2a. Please explain why you ranked your first choice first? ______________________________

____

3.2b. Please explain why you ranked your third choice third? ______________________________

____

4) USEABILITY

4.1) Please mark your level of agreement for each statement regarding how easy you think it would be to use the KitchenBot

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree
Statement	**1**	**2**	**3**	**4**	**5**	**6**	**7**
KitchenBot would be cumbersome to use							
Learning to operate KitchenBot would be easy for me							
Interacting with KitchenBot would be frustrating							
It would be easy to get KitchenBot to do what I want it to do							
It would be easy for me to remember how to operate KitchenBot							
Interacting with KitchenBot would require a lot of mental effort							
Interacting with KitchenBot would be understandable							
It would take a lot of effort to become skillful as using KitchenBot							
It would be easier to just get another person to help rather than use KitchenBot							
I would be anxious about using KitchenBot							
Overall, KitchenBot would be easy to use							

4.2) Please mark your level of agreement for each statement about how you think the KitchenBot might be useful to you.

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree or Disagree	Somewhat Agree	Agree	Strongly Agree
Statement	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Using KitchenBot would allow me to complete kitchen tasks that I cannot do independently							
KitchenBot would enable me to complete kitchen tasks more quickly							
Using KitchenBot would improve my performance with kitchen tasks							
Using KitchenBot would allow me to complete more kitchen tasks than would otherwise be possible							
Using KitchenBot would enhance my effectiveness with kitchen tasks							
Using KitchenBot would make my life easier							
It would be embarrassing to be seen using KitchenBot							
Overall, KitchenBot would be useful in my daily routine							
The government should invest resources to develop KitchenBot							

5) OTHER QUESTIONS

How much would you be willing to pay out-of-pocket for KitchenBot? $________________________
(Please enter only numbers)

	Definitely Not	Very Unlikely	Unlikely	Unsure	Likely	Very Likely	Definitely Yes
	1	2	3	4	5	6	7
Would you be willing to put a KitchenBot in your home if it was available at the price you stated above?							

	Not at all Concerned	Slightly Concerned	Somewhat Concerned	Moderately Concerned	Extremely Concerned
	1	2	3	4	5
Are you concerned about human/animal safety with KitchenBot?					
Are you concerned about property damage with KitchenBot?					

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