An Interdisciplinary Capstone Project in Assistive Robotics

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Abstract

As the population of the United States ages, their desire to retain independence as their mobility and health may be declining will increasingly look to assistive technologies to support their performance of basic Activities of Daily Living (ADLs). Toward the goal of providing such support in the home so as to facilitate *aging in place,* development of intelligent assistive robotic agents is a field of much ongoing research. Robotic agents that sense the actions of the user, discern intentions and preferences, and respond in an intuitive and socially pleasing manner will be of greatest efficacy in meeting the needs of a population whose abilities are changing over time. This paper presents the design and development of a novel overhead assistive manipulator. The work was undertaken as a senior capstone project by students at Western Carolina University during the 2016-17 academic year. Mechanical, electrical, and software design components were successfully integrated in the construction of a planar two degree-of-freedom (DOF) translation frame on which a manipulator arm is to be mounted. The agent incorporates a gesture-based command interface to support object retrieval tasks for a user in a home or hospital setting. The apparatus serves as a platform for ongoing research in adaptive human-robot interaction.

1. Introduction

Motivation

For individuals who wish to remain in their homes as they age, a reduced ability to perform Activities of Daily Living (ADLs) may result in decreased independence and a greater reliance on caregivers, possibly leading to institutionalization.[1] For unskilled or impaired users, as may be present in an aging population, models of nonverbal communication with intelligent assistive agents offer the promise of intuitive and adaptive interaction.[2]

Command interfaces based on hand/arm gesture (static and dynamic), eye gaze, or voice, present options for nonverbal communication which would be easily adopted by this target population. Typically, Human-Robot Interaction (HRI), regardless of the command form, depends on a command language which is predefined by the system designers. In such cases, gestures, voice commands or hand positions must approximate one of a fixed catalog of possibilities. Thus, the response by the robotic agent is a direct mapping of user action to a predetermined robotic response.[3] This scheme limits the usability of the interface, and correspondingly, the rate of its adoption by users. Further, as the abilities of the user change with time, their ability to properly perform a given command choreography may diminish. Therefore, it is important for the long-term usability of the interface that the agent sense the behavioral patterns of the user and adjust its responses accordingly.[4,5,6]

Related Work

Coupled with the need for a flexible, intuitive interface, the authors envision a novel robotic addition to the built environment of individuals dealing with infirmity such as patients in hospitals or home recovery situations. Assistive agents are frequently floor-based mobile units[7,8,9] which must navigate among furnishings and other obstacles, while they themselves act as potential obstacles to the human occupants of a room. Alternatively, overhead agents overcome these limitations by situating the manipulator above furnishings and people. Several agents have been designed to assist with ambulation and transference,[10,11,12] to carry a user's personal items,[11] or to execute office desktop tasks through an on-screen interface.[13]

The work described in this paper involves the construction an overhead robotic agent whose workspace spans the floor area of a bed or hospital room while translating overhead without posing an impediment to human movement. The proposed design overcomes some obstacle-related limitations of floor-based designs, while providing a practical room-size scale to the use model of previous overhead versions. The project is envisioned to provide a base apparatus for more advanced research in HRI.

Project Based Learning

Project Based Learning (PBL) is a practice that facilitates inductive learning wherein a task to be accomplished may be poorly defined, and thus, necessitates particular skills and tools that students need to acquire in order to complete it.[14] The PBL paradigm has been shown to increase student motivation and to promote learning.[15,16] PBL has been used as a vehicle for teaching technical and project management skills[17,18] as well as more socially intensive aspects of modern engineering practice demanded by employers[19,20] such as leadership,[21,22] interpersonal communication, teaming in diverse groups, problems solving, and engineering ethics[21].

Western Carolina University (WCU), where the work described here was performed, offers degree programs in electrical/power and mechanical engineering, electrical and computer engineering technology, and mechanical engineering technology. Within the curricula of these programs is a PBL sequence of five courses as shown in Figure 1. Students registering for these courses are mixed across the four degree programs described above so as to provide a robust interdisciplinary population. Within these courses, students undertake progressively open-ended projects that could have multiple viable solutions. Typically, capstone projects at WCU have industrial or faculty (research) sponsors. The capstone project described in this paper was undertaken in the ENGR400 and ENGR450 courses of the sequence during the 2016-2017 academic year with author Yanik acting as faculty sponsor and mentor.

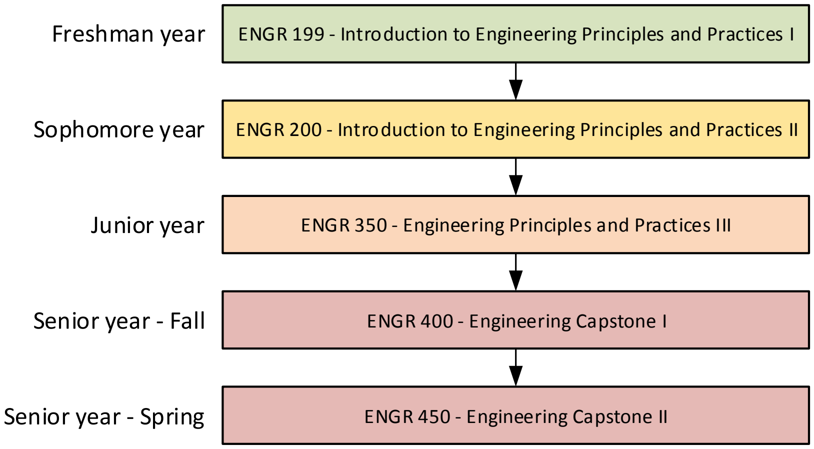


Figure 1 – The PBL course sequence at Western Carolina University

As student projects, robotics design and programming have found application as a common vehicle for teaching interdisciplinary aspects of electrical and mechanical engineering, and computer science[23,24] requiring integration of disciplines, teaming, and critical thinking to solve real world problems.[25] Given these qualities of a robot-based project, the design described here offered the student team an intense learning opportunity to constrain, propose, specify, schedule, order parts, integrate, test, and present all facets of their project.

2. Method

As mentioned above, the Overhead Assistive Robot (OAR) was conceived as automated agent which helps a user of limited mobility (e.g. a hospital- or home-bound patient) to retain independence in the performance of Activities of Daily Living (ADLs). The agent is designed as an overhead, articulated robot manipulator that can move throughout a room-scale space without presenting an obstacle to room occupants as would a mobile floor-based design. Functionally, the robot would perform object retrieval tasks for users whose mobility is compromised. An intuitive arm-scale gesture-based command interface supports easy adoption by users who are not technology-literate and whose dexterity may be diminished or changing over time.

Mechanical Design

When fully operational, the OAR will consist of a 2D planar translation platform on which a robotic arm manipulator will be mounted. The focus of student work to date has been construction of the 2D translation unit. This section describes key design features of the planar translator and details of the mechanical design. A concept image along with the final implementation of the translator are shown in Figure 2.

The frame of the translator system is constructed using 1.5” 80/20 extruded aluminum components with corner supports added to improve rigidity. Two moving carriages were constructed so as to translate the arm manipulator in the *x*- and *y*-axes. The carriages are shown in Figure 3.

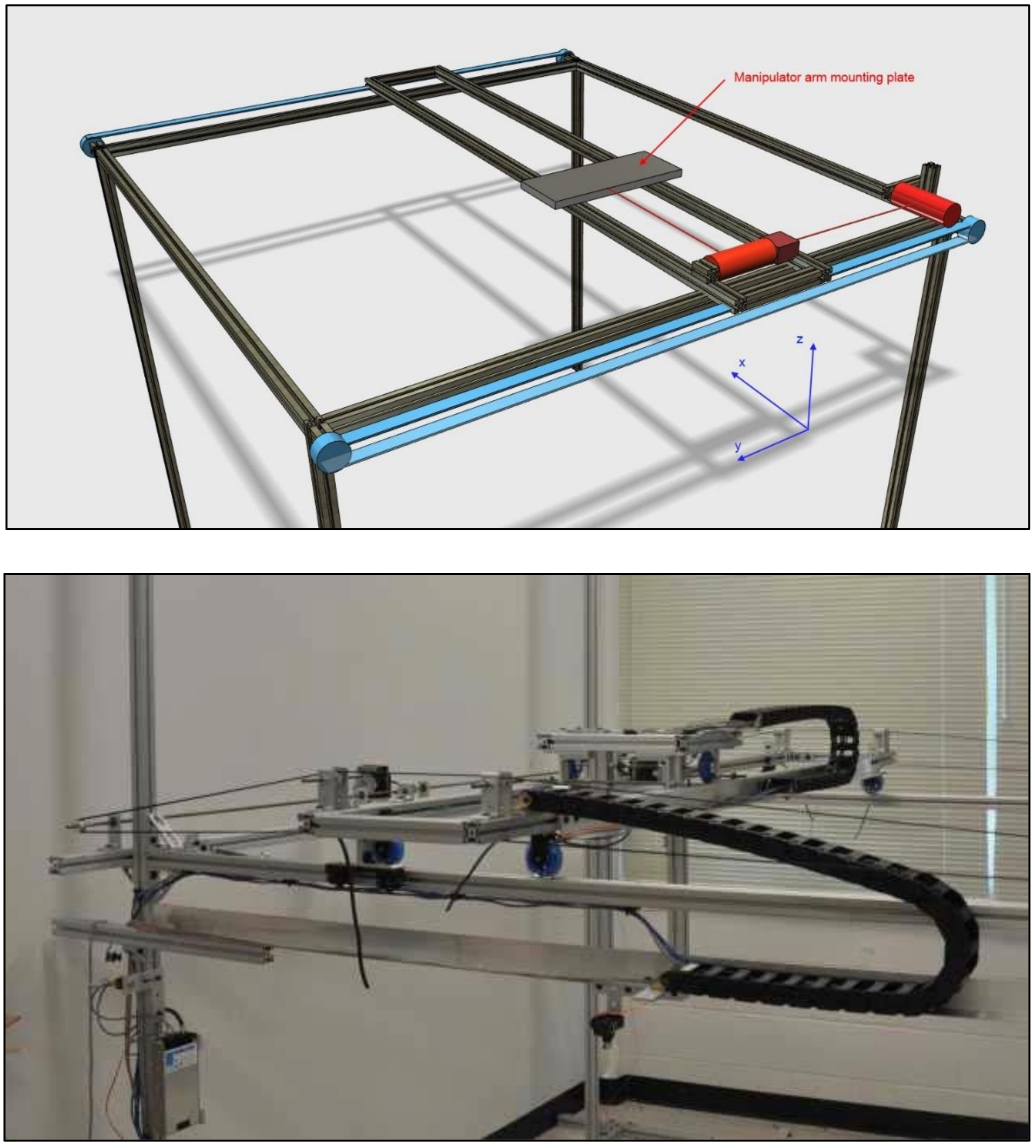
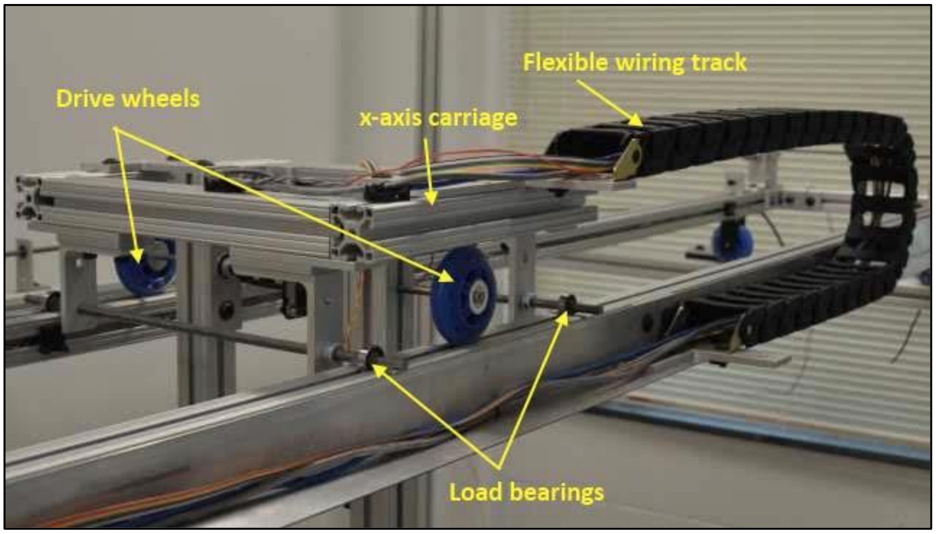


Figure 2 – (top) Concept image of the overhead 2D translation platform on a room-scale frame. The manipulator (not shown) hangs in the negative *z*-axis. (bottom) The constructed 2D translation platform, shown lowered to waist height for easy access during the build phase.

***x*-Axis Carriage.** The *x*-axis carriage (Figure 3– top) translates along the length of the *y*-axis carriage. It is carried on common skate-board wheel bearings. To reduce noise, these bearings roll on custom 3D-printed plastic inlays set into the top grooves of the structural aluminum members. The carriage is propelled by a stepper motors which turns roller blade wheels. The motor uses simple on/off control and is actuated to produce a carriage speed of approximately one foot per second. The roller blade wheels also ride along the top-groove of the structural members. Lateral motion is limited by brackets which keeps the wheels on track.

***y*-Axis Carriage.** The *y*-axis carriage is carried on roller-blade wheels. It is propelled by a stepper motor mounted on the system frame (Figure 3 - bottom). The motor turns an axle which is attached to parallel drive belts that provide even force to both ends of the carriage simultaneously and produce translation speed of approximately one foot per second.



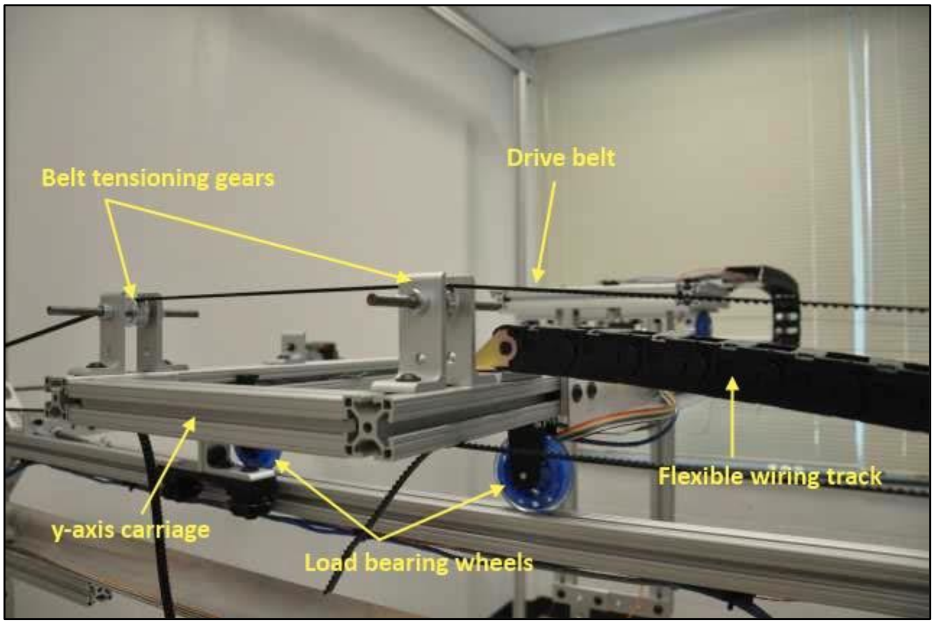


Figure 3 - (top) The *x*-axis carriage. This carriage contains its own drive motor on board and is propelled by drive wheels. It translates along the *y*-axis carriage. (bottom) The *y*-axis carriage. The drive motor (Figure 4) for this carriage is mounted to the system frame and is propelled by parallel drive belts - one on each end of the carriage.

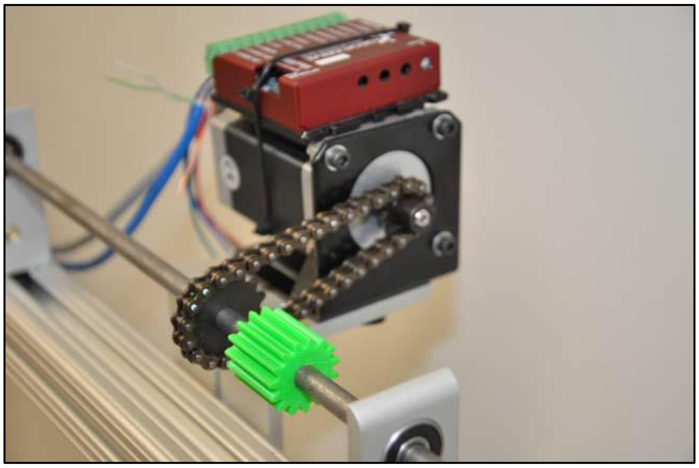


Figure 4 **-** The *y*-axis carriage drive motor. The motor turns an axel which actuates drive belts to provide even force to both ends of the carriage simultaneously.

System Power. The system is powered by a 12 V, 12.5 A, 300 W dc power supply (Figure 5). This provides power to both the *x*-axis and *y*-axis stepper motors, as well as an Arduino microcontroller that activates the stepper motor controllers.

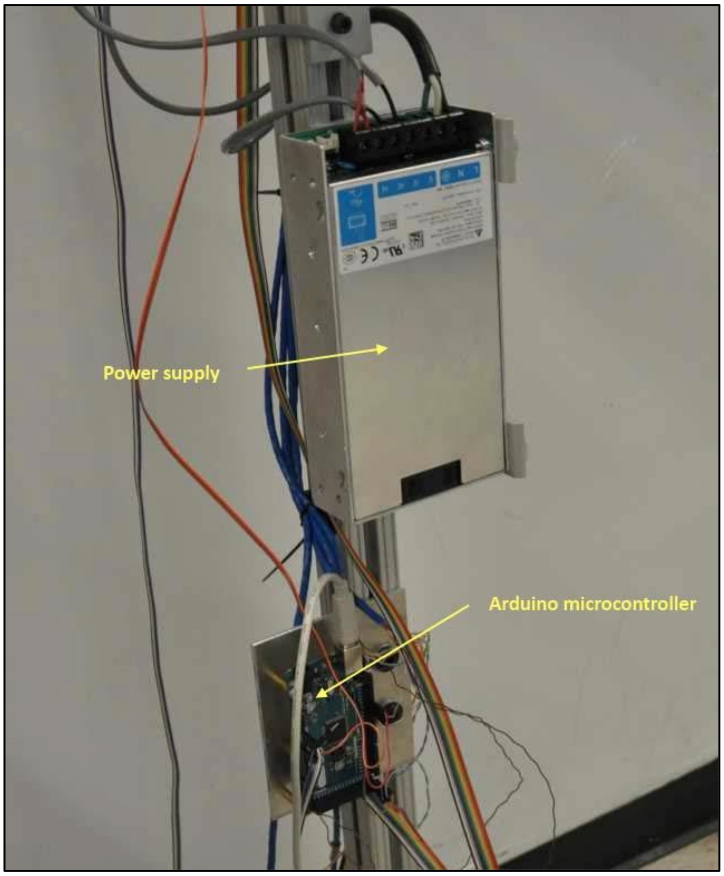


Figure 5 - The power supply and Arduino microcontroller.

Operating Mode Select. The OAR may be controlled using either arm-scale gestures (as described in the following section), or by joystick. A mode select switch is provided to allow the user to select the desired operating mode (Figure 6).

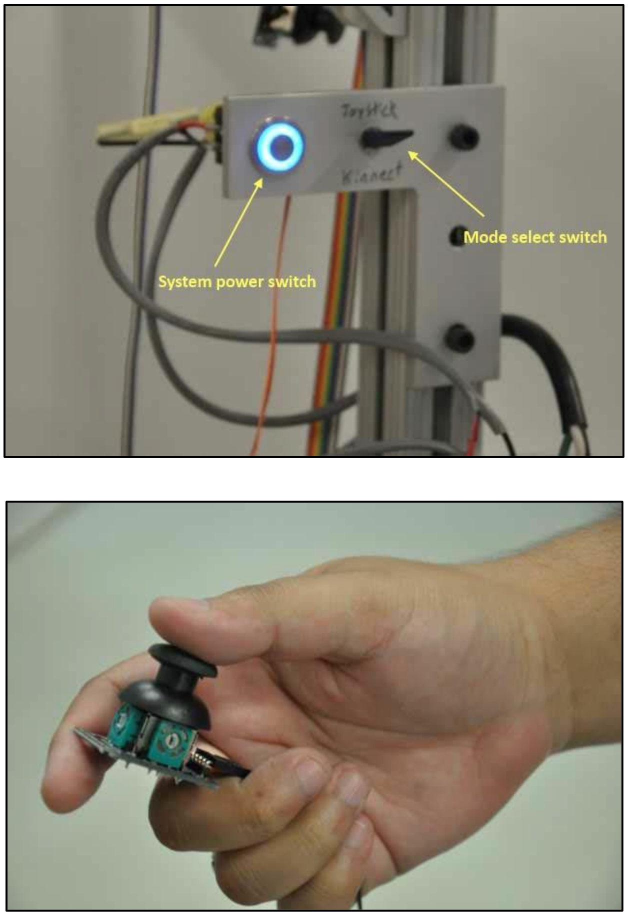


Figure 6 - (top) The Mode Select and system power switches. (bottom) The joystick.

Gesture Recognition

As previously stated, on mode of control for the OAR is through the use of user-formed arm-scale gestures. A Kinect camera/depth sensor is integrated into the OAR system to enable gesture recognition. The Kinect is capable of tracking the skeletal joints of a human user. By tracking the joints of the arms, a basic gesture recognition system was implemented. The control software written for the OAR includes an on-screen representation of the tracked skeleton, and a classification of the gesture being performed. (Figure 7).

Figure 7 – (top) the Kinect depth sensing camera (retrieved from liliputing.com). (bottom) The OAR software interface showing skeletal tracking and the recognized STOP command gesture.

Coarse Motion. With the user's right hand positioned above the waist and beyond the elbow, the left hand may be used to direct motion to a desired quadrant of the 2D overhead plane. Motion is designed to be intuitive with the high positions of the hand indicating near left and right quadrants, and low positions indicating far left and right quadrants (Figure 8 – left).

Fine Motion. With the user's right hand positioned above the waist and inside the elbow, the left hand may be used to drive the OAR along either the *x*- or *y*-axes (Figure 8 – center).

Manipulator Actuation. With the user's left below the waist, the right hand may be used to open or close the manipulator's gripper to pick up or drop off a retrieved object. This capability is written into the system software at this writing, but has not been tested on the OAR (Figure 8 – right).

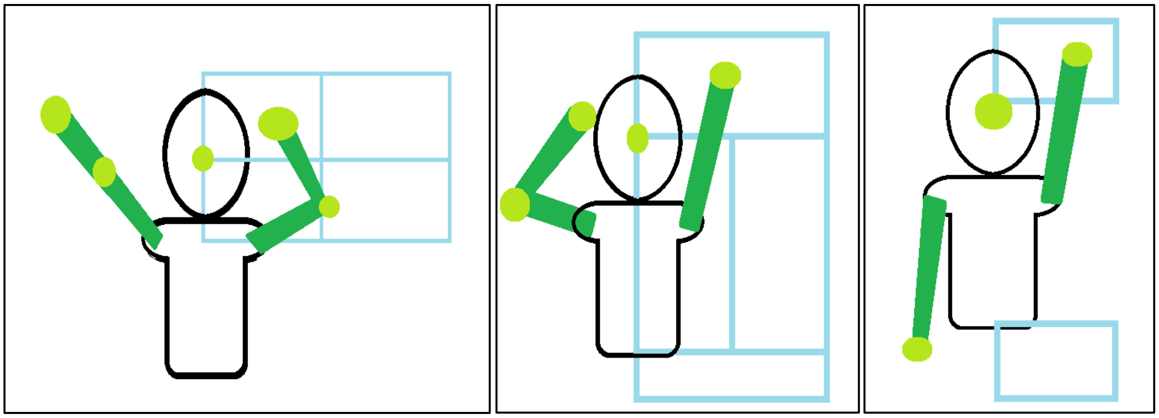


Figure 6 - Gesture motion schematics for coarse motion (left), fine motion (center) and manipulator actuation (right).

Parts List and Cost

Capstone sponsors at the host university typically pay $2,500 for access to the capstone project process. This affords them a team of two to three students plus a faculty mentor throughout the capstone course sequence (ENGR400 and ENGR450). Additionally, sponsors agree to pay the costs of all materials and parts needed by the team. In this case, the faculty mentor sponsored the project himself, which allowed the capstone course administrator to waive the sponsorship fee. Parts and materials were paid for through grant funding obtained by the faculty mentor.

Table 1 gives cost totals for the various parts categories used to implement the OAR excluding extruded aluminum and the Microsoft Kinect. Extruded aluminum components (80/20), and the Microsoft Kinect were not purchased specifically for this project as they are commonly stocked for use in the faculty mentor's lab space. The estimated value of 80/20 parts used in this project was approximately $1,500. The Microsoft Kinect costs $150. A detailed parts list is given in Table 2.

Table 1 – Parts costs by category

Description	**Amount ($)**
Belts, gears, wheels	170
Motors, related parts	344
Miscellaneous hardware	134
Linked flexible wiring track	257
Power supply, microcontroller, and related electronics	310
Total	1,215

Table 2 – Parts list

Description	Quantity	Description	Quantity
80/20 1.5” × 8’	14	Washers with set screw	20
80/20 1.5” × 2’	8	Aluminum cable tray, 9’	1
80/20 1.5” × 1’	6	80/20 screw/washer fastener	~200
80/20 1.5” × 1’ corner brace	4	Gear, 15 tooth, 1”	1
80/20 4 hole gusseted inside corner bracket	20	Gear, 9 tooth, 3/4”	3
80/20 2 hole gusseted inside corner bracket	8	Sealed bearing, 22 mm / 7 mm × 8 mm	14
80/20 5 hole T-plate	6	Ribbon cable, 9-conductor	20’
80/20 3 hole straight transition plate	6	Limit switch	8
80/20 4 hole straight transition plate	3	Communication cable, 8-conductor	40’
80/20 2 wheel door hanger rollers	2	Power push button with LED outline	1
80/20 5 hole L-plate	3	Toggle switch	1
80/20 3 hole L-plate	16	Joystick	1
80/20 2 hole L-plate	12	Arduino Mega microcontroller board	1
80/20 4 hole L-plate	12	Power supply, 12 V	1
Roller blade wheels	6	Stepper motor, 200 steps/rev	2
Linked flexible wire track, 4” × 5’	2	Stepper motor controller	2
Toothed drive belts, 0.5” × 17’	2	Track cushions, 4”, 3D printed	96
Stainless steel rod, 3/8”, 9’	1	Chain, 12”	2
Stainless steel rod, 3/8”, 15”	3	Jumper wires	~30
Stainless steel rod, 3/8”, 6”	2	Wire tie points for 80/20	~100
Belt guide gears, 1”	8	Microsoft Kinect	1

3. Discussion and Conclusions

This paper has described the design and fabrication of an assistive robotic agent as a senior capstone project for engineering and engineering technology students. The inherently multidisciplinary nature of robotics in terms of mechanical, electrical, and software components is seen to be a strength of such projects as platforms for student learning. Given the often imprecise nature of robotic interactions with human users, the level of precision required for the candidate application was of an appropriate scope and difficulty for a project at the undergraduate level. The cost point of the research is also suitable for a capstone experience.

Extending past work on dynamic gesture-based robot commands by Yanik et al.,[4,5,6] the work described here will facilitate future research in HRI. The next phase of construction will involve the addition of the grasping arm manipulator, a Cyton Gamma 7-DOF arm. Future work will also integrate a reinforcement learning model[26,27] into the assistive robotic agent and will implement the afore mentioned interaction modalities based on dynamic arm-scale gesture, eye gaze, and voice. Trajectories of the manipulator will be shaped so as to implement socially pleasing interactions (i.e. nonthreatening with regard to speed, trajectory, and proximity) for the user.[28] The assistive agent may also incorporate aspects of care which include an inventory and locations of the user's personal effects, timing of medications, and observation to recommend and enforce physiologically therapeutic habits.

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