Rapid Orbital Motion Emulator (ROME)

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The increasing accessibility of space has increased the demand for a platform to simulate space missions. The testing of motion control algorithms in for spacecraft are critical to the success of space missions. Currently, the ability to test these control algorithms in a laboratory environment is limited to expensive and highly specialized robotics. The following pages show the development of a platform capable of emulating orbital motion, which utilizes a 3-degrees of freedom omnidirectional ground vehicle with a 6-degree of freedom robotic manipulator mounted to it. It is capable of simulating complex spacecraft missions, from orbital motion to rendezvous and docking.

Nomenclature

EPOS - European Proximity Operations Simulator
NEA - Near-Earth Asteroid
ROME - Rapid Orbital Motion Emulator

1 Introduction

Developing motion control algorithms for spacecraft motion has been a challenging area of research for aerospace engineers since spacecraft were first launched. The ability to develop and test these algorithms on a platform that can simulate spacecraft motion in orbit, rendezvous, and servicing missions is highly desirable as more organizations develop spacecraft.

Research on this problem has already been done. For example, the mobile servicing system on the International Space Station has the Task Verification facility [1]. However, this facility is specific to the robotic manipulators on the ISS, and cannot be used for missions other than work on the ISS. The German Aerospace Center developed the European Proximity Operations Simulator, which consists of two robotic manipulators to simulate rendezvous and docking spacecraft [2]. One Robotic manipulator fixed to the ground, and the other is on a linear rail. While this facility is good for simple rendezvous and docking two spacecraft, it would be difficult to scale this design to accomplish the multi-faceted space missions that are being developed in the present day.

Caltech has developed M-STAR, a six degree of freedom facility to demonstrate orbital motion among several spacecraft in the same orbital plane. While it is an impressive facility, with a granite smooth floor and air-bearings on the robots to allow for unprecedented precision, it is an expensive facility to build and is limited to orbital motion in a single plane. [3] Texas A&M university developed HOMER, an omnidirectional robotic ground vehicle with a 6-DOF Stewart platform. This robot can simulate orbital motion in a single plane, however is unable to simulate an orbital plane change maneuver, or matching orbital plane maneuver. [4]

One such mission is a deorbiter Cubesat mission [5]. This mission uses a large ”mothership” satellite that de-

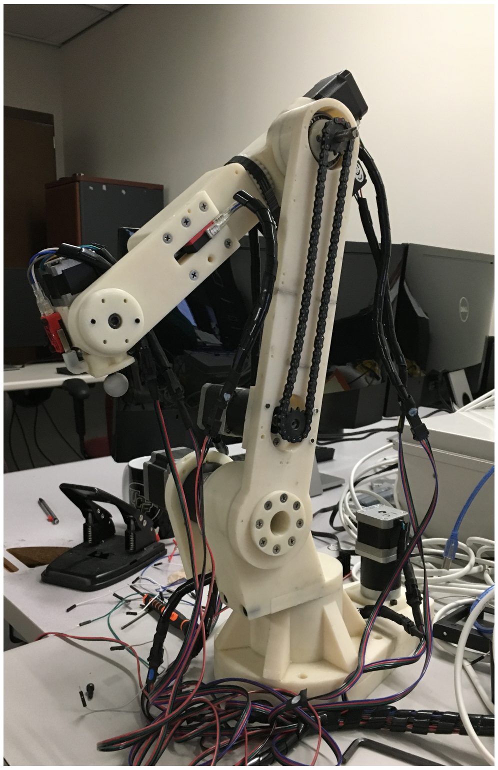

Fig. 1. The AR-2 manipulator for the first iteration of ROME

ploys multiple Cubesats to attach, reorient, and deorbit space debris. Another proposed space mission involves using a swarm of Cubesats to detumble a NEA for the purposes of asteroid mining [6]. The EPOS and Task verification facility would be unable to emulate the aforementioned missions. The Rapid Orbital Motion Emulator would be capable of performing these and other types of multifaceted missions. The cost of the first version of ROME was around $1500, which allows it to be scaled relatively inexpensively. The 9 degrees of freedom from the wheeled vehicle and the robotic manipulator gives it ultimate flexibility in a laboratory environment, with no restrictions to its movement.

2 Methods and Materials

The goal of ROME is a cost effective and scaleable way to emulate orbital motion. Therefore, instead of industrial robotic manipulators, which are very expensive, open-source robotic manipulator kits kits must be utilized. For the first iteration of ROME, the 3D printed AR-2 robotic arm designed by Chris Annin was used [7].

2.1 ROME MK1

2.1.1 Robotic Manipulator

As shown in Figure 1, the AR-2 Robotic manipulator has a structure with 3D printed parts. Building with 3D printed parts reduces costs and increases accessibility, however there are a few problems with it. First of all, the AR-2 is an open-loop control system, which results in compounding errors the longer it operates. The 3D printed parts are also not able to achieve a precise margin of error because of their flexibility. The chain and belt controlling the manipulator are prone to slippage because a sufficient tension is difficult to obtain.

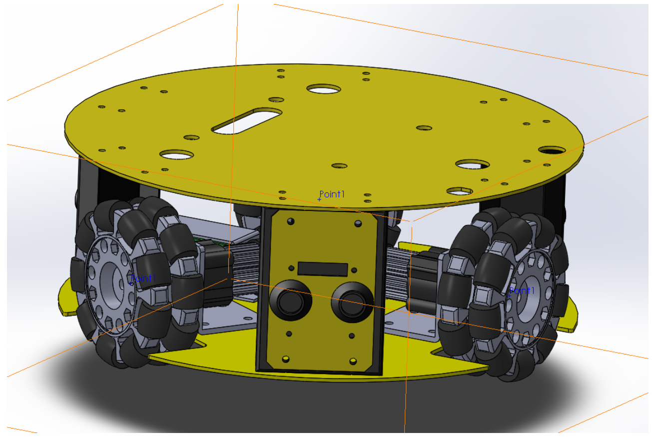

Fig. 2. The CAD for the ground vehicle of ROME MK1

2.1.2 Ground Vehicle

Shown in Figure 2 is the CAD file for the first iteration of the ground vehicle. The ground vehicle platform is constructed with a modified Nexus Robot Kit 10013, and Arduino MEGA, and an Adafruit V2 motor shield [7]. The top of the platform had holes drilled into it to provide a mounting area for the AR-2 manipulator. The omni-wheels positioned 120° apart from each other offers stability and full 3 degrees of freedom for the vehicle. However, while this iteration provided proof of concept, it ultimately did not provide satisfactory performance for reasons that will be detailed in the next section.

2.1.3 Assembled mobile manipulator

With the full assembly of the AR-2 Robotic manipulator and the modified Nexus robot, several tests were performed. While they did prove the concept, several issues with regards to usability arose. The most glaring issue is center of mass. As shown in Figure 3, the first iteration of ROME is tall and narrow, which results in stability issues. If the AR-2 manipulator moved outside of the center of mass of the Nexus robot, it would easily overbalance. This resulted in the first link of the manipulator to snap during testing.

The next issue arose because of the open-loop operations. The open-loop operations resulted in increasing margin of error with increasing simulation time [7].

The last major issue is usability. The electronics of the manipulator holding the Arduino, stepper motor drivers, and the power supply, are all housed separately from ROME and connected to it with several cables that can be seen leading away from the vehicle in Figure 3. It also uses a power supply that connects to an AC wall outlet. In addition, the cable junction for the AR2 is not fixed on the vehicle. All of these issue results in increased difficulties while using ROME.

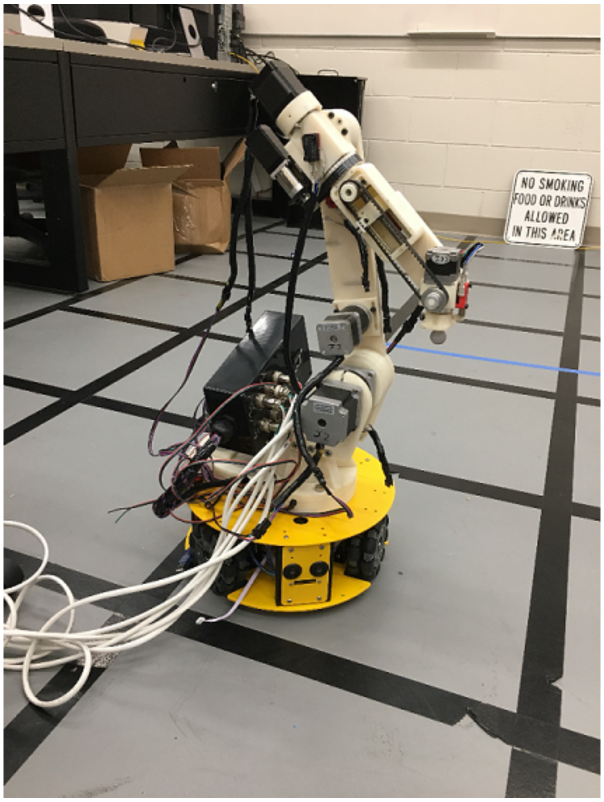

Fig. 3. The assembled ROME MK1

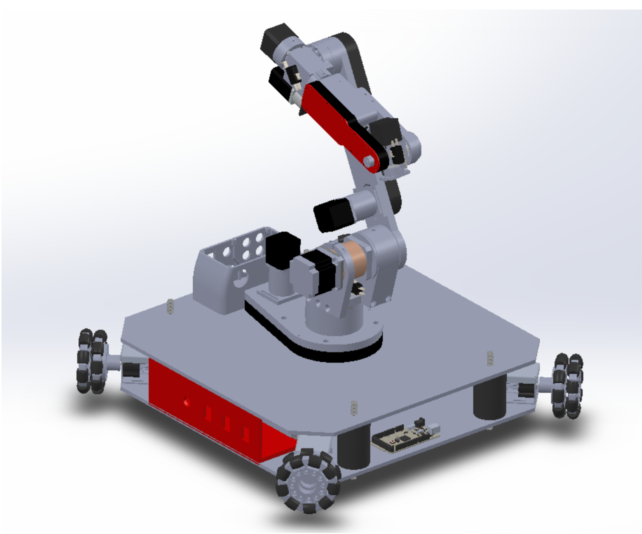

Fig. 4. CAD for ROME MK2

2.2 ROME MK2

The 2nd iteration of ROME intends to build on the proof of concept from the first vehicle and improve on its critical flaws. Shown in Figure 4 is a CAD file with the redesigned ground vehicle and the AR-3 Robotic Manipulator.

2.2.1 Robotic Manipulator

The 2nd iteration of ROME will use the AR-3 Robotic manipulator. Made primarily from machined aluminum, this manipulator improves on the AR-2 in several ways. First, the machined aluminum should have much tighter tolerances which will allow for much more accurate simulation. Each stepper motor has an encoder to provide a closed-loop control system. Finally, the AR-3 design incorporates better cable management so the manipulator is less likely to be ensnared in its own wiring. Figure 2.2 shows the current progress of construction of the AR-3 manipulator for the 2nd iteration of ROME.

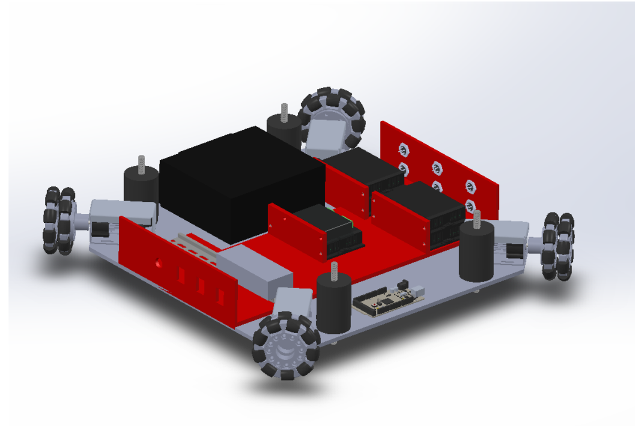

Fig. 5. The internal electronics for the ground vehicle and the manipulator are all housed within the ground vehicle. This new design will drastically improve usability. The black box towards the rear of the vehicle is the battery, and the red frame houses the stepper motor drivers for the manipulator.

2.2.2 Ground Vehicle

The ground vehicle for ROME MK2 is custom designed by Ryan Ketzner with CAD. Customizing the design allowed for several changes that were not possible with the Nexus robot kit due to its size limitations. Instead of the stepper motor drivers, Arduinos, and power supply being housed in a box detached from the robot, everything required for ROME MK2 to function is housed in the ground vehicle. Figure 2.3 shows a picture of the CAD for the full ground vehicle and figure 2.4 shows the top cover removed to show the internals. The vehicle has 4 omnidirectional wheels placed 90° from each other provides for similar mobility to the original ground vehicle, while providing a wider base to improve stability. The drivers for the stepper motor and the Arduino are housed inside the ground vehicle. The on-board battery will provide power to the ground vehicle and AR-3 manipulator without the need for a connection to an AC wall outlet, further improving the mobility of the platform and reducing possible sources of error. The whole platform has a low profile of around 3 inches tall, and the weight of the battery lowers the center of mass, further improving the stability of the vehicle.

3 Results

Construction of the AR-3 robotic manipulator portion of the ROME vehicle is completed and been tested. After fix-

Fig. 6. The completed AR-3 manipulator next to the AR-2 manipulator from ROME MK1

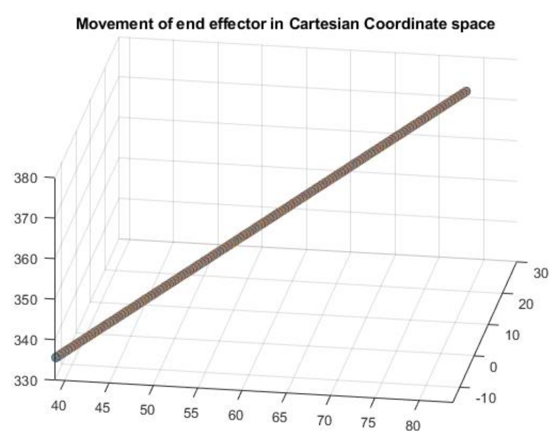

Fig. 7. The initial test command given on the AR-3 manipulator built for ROME MK2

ing a few issues with the electronics enclosure, we were able to run a few tests to show that the AR-3 manipulator is fully functional. A demonstration of the movement of the end effector in a straight line in 3-dimentional Cartesian space was conducted. A few modifications to the original design of the AR-3 were made. In the original design, the AR-3 has a pneumatic-powered end effector. For the purposes of ROME this is unnecessary and would add complexity and weight to the vehicle. In addition, the wiring box is attached to the base of the manipulator in the original design. This was changed to be detached to allow flexibility in mounting the manipulator and wiring box to the ground vehicle. The parts to make the ground vehicle have been ordered and have been shipped or made in a 3D printer in the Astrodynamics and Space Robotics lab at UCF. Work on the ROME vehicle will continue during the fall semester.

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