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Falcon Robotics, EVROV Project

Extra Vehicular Remotely Operated Vehicle

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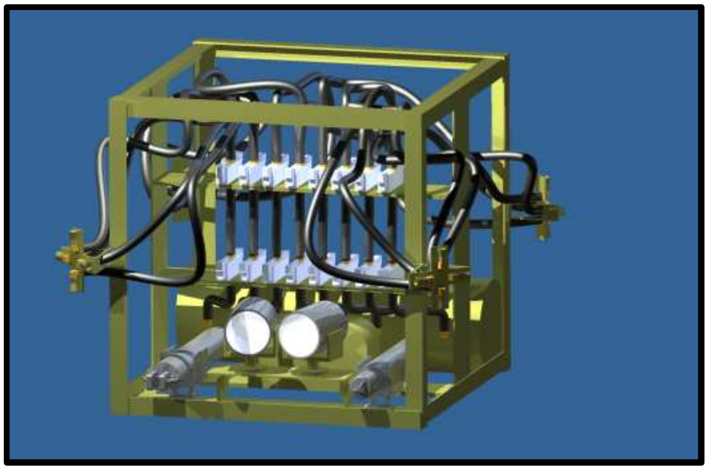

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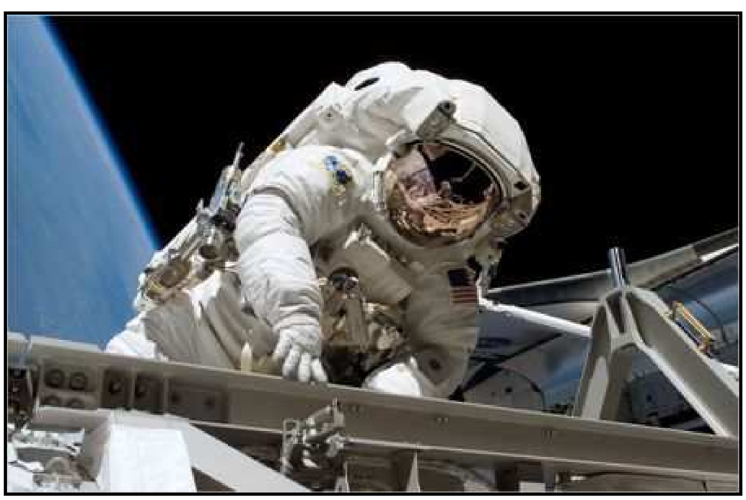
Executive Summary

A space walk is when an astronaut gets out of a vehicle while in space. This is also called an EVA, which stands for extravehicular activity. EVA's are very dangerous as astronauts risk their lives in many ways. They may float off into space and be lost forever, or they may get the "bends", or decompression sickness due to a suit puncture or system malfunction. [1]

When a space craft is out in space, it is typically orbiting the Earth at about 200 miles in altitude where there is lack of air pressure. In order to perform a space walk, astronauts must wear a pressurized space suit to protect them from the harsh space environment. The astronauts must put on their spacesuits several hours before a spacewalk and breathe pure oxygen during that time to get rid of all the nitrogen in the astronaut's body. If the astronaut does not rid their blood of nitrogen, they might have gas bubbles escape into their body. These gas bubbles can cause the astronaut to feel pain in their shoulders, elbows, wrists or knees as well as possibly risk permanent paralysis. The astronaut also uses a safety tether in order to stay close to the space craft, preventing them from floating out into space.[2]

The EVROV will decrease the number of EVAs performed by humans, leaving the times when it's absolutely necessary. The EVROV will be operated via Wi-Fi and will be able to perform extra vehicular inspections as well as complete simple tasks. The EVROV will be able to go out and perform visual reconnaissance prior to a manned space walk, evaluating what has to be done. Therefore, when the astronaut goes out, they won't have to waste time evaluating the problem themselves. This will save time and decrease the risk of complications to the astronaut. The ROV will use compressed nitrogen to maneuver, since nitrogen has a low expansion rate over a wide range of temperatures.[3]

If it is necessary for a human to perform an EVA, the EVROV will also be used to watch out for any potential dangers and to keep an eye on the astronaut. It will have two high-definition cameras for 3-D stereoscopic vision. The operator station will have a 3-D viewing system so the pilot can have depth-of-vision to be able to operate the ROV more efficiently. Video and data recording will also be accomplished at the operator station.



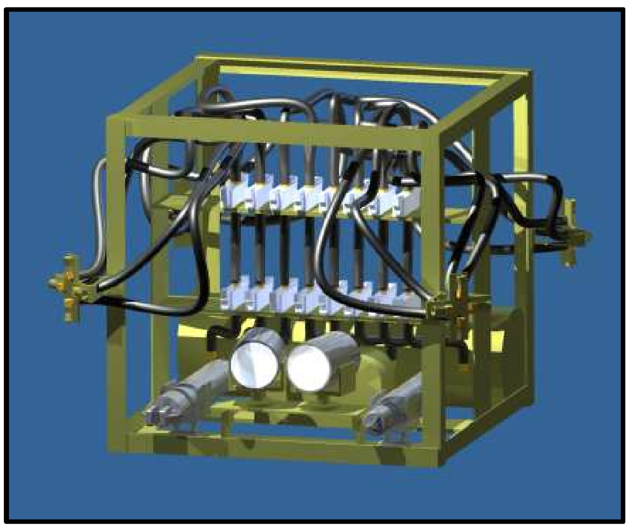
Deploying the EVROV will be quick and simple. With the optional docking station outside the spacecraft, the chance of accidental decompression will be lessened. It will have its batteries charged and nitrogen tanks filled at the docking station, as well as allow for the astronauts to download and upload programs to the EVROV. From there, it will be ready when needed and will save precious time.

Need Statement

Space walks, or as NASA calls them EVA's (Extravehicular Activities), have been performed since March 18, 1965. A Russian cosmonaut exited the Soyuz space ship for about 12 minutes. The dangers were not fully understood, and Alexei Leonov's space suit over inflated. He was unable to reenter the spacecraft. After some quick thinking and a little luck, Leonov got away with a minor case of decompression sickness. [4]

Alexei Leonov

There are abundant dangers are in the harsh vacuum of space. The space suit is the only thing separating the astronauts from the extremes of space. It provides them with their only life line, with no "safety nets." If the suit is punctured by a micro meteor while working outside the space vehicle, the astronaut will be in great peril. The unlucky astronaut could die instantly of anoxia, or if they manage to survive, they could suffer from decompression sickness. There is also the possibility of being separated from the space craft and literally being "lost in space." Because of all these dangers, EVA's are NASA's last resort. They are usually only planned late in missions when problems are discovered. [5]



With the EVROV, all these dangers can be avoided. No longer will the mission specialist have to risk life and limb performing relatively simple tasks. The EVROV will be perfectly capable of picking up objects, making use of tools, and conducting visual reconnaissance. If a job is out of EVROV's capabilities, and a specialist must be used, then it will prove valuable as another method of monitoring the mission giving the astronauts inside the space craft and mission control on earth a third-person view of what the mission specialist is doing and enabling them to keep an eye on any possible dangers. The EVROV will be equipped with stereoscopic vision allowing the operator to have an enhanced perception-of-depth over traditional monitors. This will allow for the operation of the EVROV and its manipulators to "feel" much more natural to the pilot. The EVROV will also be robust enough so that in the event that a mission specialist is separated from the space craft, it will be able to perform an astronaut EVA rescue.

Another advantage to using the EVROV will be its ability to save the astronauts countless hours of time. One spacecraft could deploy multiple EVROVs, making the competition of the task much faster. In the entire history of EVA's, there has only been one EVA that utilized three astronauts simultaneously, but most EVA's only use one. [6] Picture having three or four EVROVs working on a single task, each with a skilled pilot, the task will be done quickly and with much less risk to human life! The EVROV will also be extremely fast to deploy as it will have a docking station (optional) in the exterior of the space craft, or space station. There, its batteries will be recharged, nitrogen tanks refilled, downloads and general programming can be accomplished. This will eliminate the need to use an airlock and reduce the chance for inadvertent decompression of the space ship. From its exterior dock, it can be instantly fired up and perform whatever task is at hand. Compared to the current procedure of suiting up an astronaut, getting the airlock pressurized and having to follow the "camping out" guidelines[7], an EVA docking station will save many man-hours! The EVROV will in some cases eliminate the need for astronaut EVAs and in turn reduce the amount of time astronauts spend in the vacuum of space.

Oceanic ROV example

The EVROV system can be utilized by the International Space Station or any other space faring vehicle that is used in space where work is done outside the vehicle. It is even possible that the system can be installed on unmanned vehicles where the pilots can be on Earth while they work on vehicles in orbit with a fleet of EVROVS.

The idea of the EVROV is predicated on the ROVs that have been used in oceanographic research for the past 20 years. ROVs have been used for missions similar to what the EVROV will be used for. They have arms to manipulate items, cameras to be able to see underwater, thrusters to maneuver underwater. It is safer to send an ROV into the depths of the ocean than it is to send a person. Likewise it is safer to send an EVROV into the harsh environment of space than it is to send an astronaut. ROVs are meant to help divers in the ocean just like the EVROV will help astronauts in space.

Oceanic ROVs are used for multiple tasks. Different ROVs are built and used for various reasons or tasks. Some ROVs are used for science explorations; they can pickup rocks and plants from the ocean floor, as well as take pictures and videos. Other ROVs are used for safety reasons, like escorting divers underwater water. In case a submersible gets stuck or breaks down, an ROV is sent to investigate so the operators can figure out what to do.

Sending ROVs into the ocean instead of divers decreases risks of anything happening to the diver. Divers won't risk decompression sickness, or get hurt by an animal. Also, ROVs can be sent to depths that humans aren't able to dive to. As you can see, the EVROV is much like the ROV, but for space.

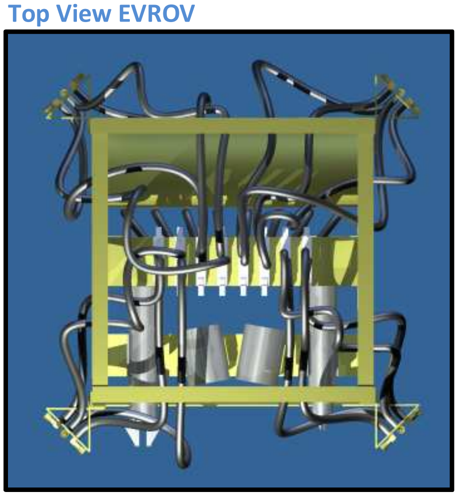
Oceanic ROV example

Concept Details

EVROV Design Rationale

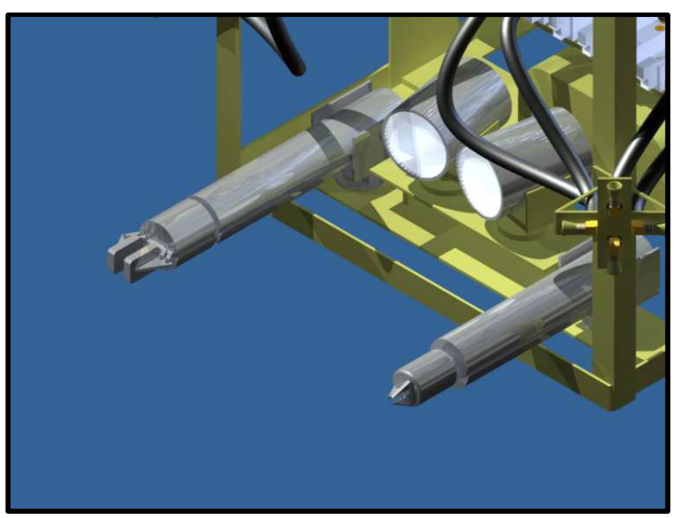
The EVROV design is based on the "form follows function" philosophy of architect Louis Sullivan[8]. The craft will look like what it is supposed to do. The frame of the craft will consist of a cube made of 90 degree angle titanium. This will give us more mounting points for the components and simplify the construction of the frame as well as minimize the cost. The absence of gas in space will make the EVROV's aerodynamics irrelevant to the maneuverability and speed since it will be operating in the vacuum of space. The EVROV will have its components placed symmetrically in the frame by mass so that the center of mass is at the center of geometry as well. This will allow the thrusters to maneuver the craft accurately and without causing it to tumble out of control. The craft will be powered by on-board batteries that are rechargeable via an optional external docking port on the main space craft.

Top View EVROV



The EVROV's primary operating functions are its propulsion and vision systems. To begin with the craft will have a nitrogen pneumatic propulsion system that will consist of a storage tank, thrusters and solenoids which will be used to activate the thrusters. The solenoids will be connected to the thrusters using special tubing that is space worthy. The thrusters will be arranged in a cluster that will point in four different directions, two horizontal and two vertical, all at right angles to each other in one plane. The thruster clusters will be mounted at 45 degree angles to the square geometry of the EVROV frame. From our underwater ROV experience in the past we call this vector drive. The vector drive will allow the EVROV to go in any direction horizontally, depending on what combination of thrusters the pilot engages. As far as the vision system is concerned, the craft will have two high definition cameras in the front as drive cameras. They will be mounted in parallel to each other at the average distance of the space between human eyes, about 3 inches. This will enable the pilot to have 3-D stereo vision[9]. The pilot of the EVROV will be able to drive it with depth perception making its movements more accurate and safe. The EVROV will be controlled by the operator station in the space craft via wireless radio communications. The absence of a tether will allow the EVROV to have maximum maneuverability and to be able to go almost anywhere it can physically fit.

The EVROV will have multiple additional capabilities. It will have two 4 degree range of motion arms to pick things up and hold tools. The craft will have a storage bin for the arms to place items in. It will also have an array of sensors like temperature, distance, infrared etc.. In addition to the sensors, all the data collected on the craft will be stored on board for download later. The craft will also have lights and additional auxiliary non stereo vision cameras. All in all the EVROV will be designed a lot like a traditional ROV that is used in ocean exploration, only it will have accommodations made for the space environment.

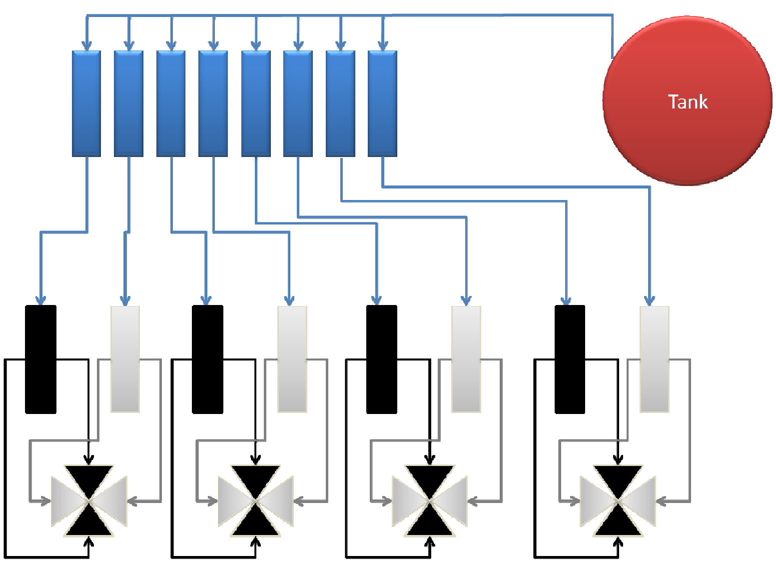


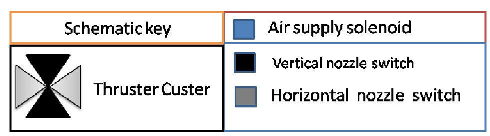
Nitrogen Based Pneumatic Thruster System

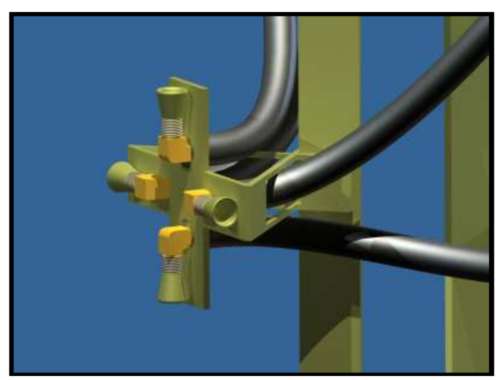
In the hostile conditions of space, a rugged and reliable propulsion system is needed in order to be effective. The EVROV will be equipped with a pneumatics propulsion system which uses nitrogen gas to affect the desired motion. Nitrogen's low expansion and contraction property in extreme alternating temperatures makes it the appropriate compressed gas for the pneumatic propulsion system[10]. The pneumatics system will be comprised of a pressurized tank of nitrogen which will feed into a thruster distribution manifold where the gas will be sent to the desired thruster in order to affect the given motion as commanded by the pilot. The nitrogen tank storage pressure will be 3000 psi. It will then be regulated as required by pressure regulators that can be set via the pilot through the operator controls. The thrusters will be engaged by pneumatic solenoids that allow the regulated nitrogen gas to then be expelled at the desired pressure and duration.

With the vacuum of space and no friction, any minuscule force applied to any object can lead to significant unwanted motion. The center of mass distribution of all the EVROV's components, if not done properly, can add to the instability and cause many difficulties when operated. An unbalanced EVROV will roll, pitch and yaw undesirably when operating. Due to this fact, having the thruster distribution manifold and thruster clusters at center of mass is critical in order to have a stable craft. The EVROV will be equipped with four distinct groups or clusters of thrusters. Each cluster will contain four nozzles positioned at right angles to each other in one plane. There are four groups of thruster clusters on the four exterior corners, at center of mass vertically, and distributed symmetrically in the horizontal geometry. The positioning of the thruster clusters will be at a 45 degree angle to the geometry of the square of EVROV frame. The position of the thruster clusters for the vertical control is dependent on the symmetrical positioning based on the horizontal geometry. This allows for vertical control, regardless of the 45 degree positioning. The combination of 45 degrees and symmetrical geometry placement of each thruster cluster will allow the EVROV to be able to go in any direction based on the combination of thrusters activated. The direction the EVROV travels will be the sum of the vectors of the thrusters.

The following diagram illustrates the "schematics" of the pneumatic thruster control.





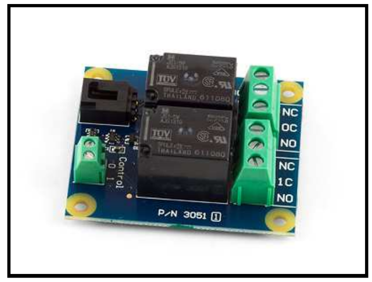


Thruster Cluster

EVROV Control System

Every functional aspect of the robot is controlled and monitored by the robot's control system. Without one a robot is simply a piece of "eye candy", but with it the robot is a highly capable tool. To control our EVROV we chose to use a Phidget control system.

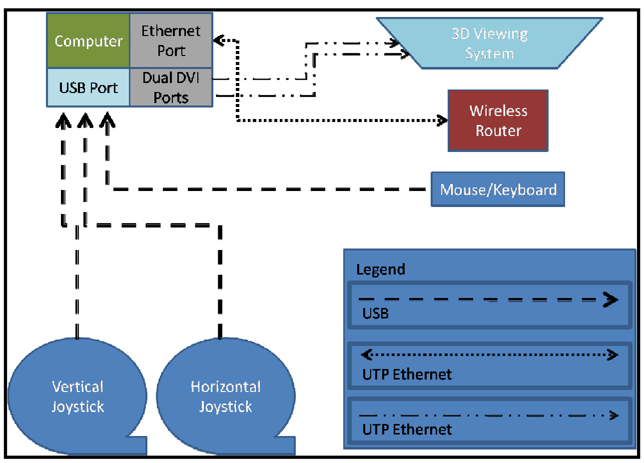
The main advantage and reason why we chose the Phidget control system was because, it uses a standard computer as its central processing unit, it is cost effective, and easily programmable. Through Phidget, all the different components such as the Analog I/O board, motor speed controllers, temperature sensors, and dozens of others all communicate to the computer via Universal Serial Bus (USB)[11]. That means that we don't have to use any other robotics specific hardware, which tends to be more expensive. Since Phidget is based on using a regular PC all the open source applications on the web will aid us in programming. The Phidget system is very flexible when it comes to programming. This system may be modified once it gets past the preliminary stages due to radiation and temperature extremes in space but we are basing our design on this system for now.



Phidget dual relay switch

The control system configuration on EVROV will be very simple. There will be a small computer located on the robot called the Robot Controller (RC). This computer will be processing most of the data, such as the firing the solenoids, vision processing, controlling the arms, temperature readings, nitrogen tank pressure, and much more. All of these different components will communicate to the RC via USB interfaces.

The operator interface (OI) is where EVROV's pilot will operate and monitor the robot's activities. The main component to the OI is the computer. This computer is solely responsible for sending user input to the RC as well as receiving the video feed from the RC. The main means of user input will be through joysticks. One joystick will control vertical movement and another joystick will control all horizontal movement. The pilot will be outfitted with stereoscopic goggles or glasses, which will allow the pilot to receive a three-dimensional view from EVROV's perspective. The RC will communicate to the Operator interface using common place wireless routers and wireless bridges, in other words wireless internet technology. We chose to do this because it is extremely easy to setup, easily expanded, and it is an inexpensive way to achieve the bandwidth we need for the stereoscopic viewing system. It also supports duplex telecommunications which is a must for an EVROV.



Operator Interface

The computers on both the EVROV and at the operator station will be using the Intel® Core™2 Quad Processor Q9650 running at a factory-set 3 GHz and equipped with a 12MB L2 cache! That's four cores running at 3 GHz, which means true multitasking! This processor is very efficient, with the majority of its 95W power consumption going to actual processing[12].

To harness the power of this processor, we will mount the "beast" on a GIGABYTE ATX Intel-based motherboard. This motherboard has 2 oz. of heat-sucking copper, and the BIOS comes preloaded with Easy Tune 6 for easy and safe over clocking. The motherboard also has no shortage of PCI and PCI Express slots[13].

Space Worthiness

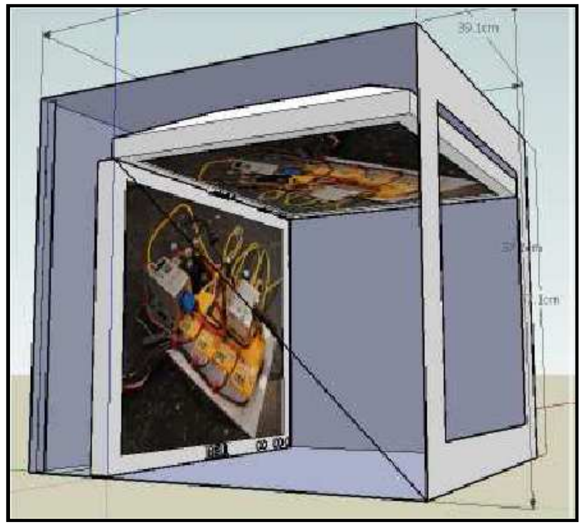
Decades of space exploration has taught us a thing or two about its harsh and unique environment. Solar radiation and drastically varying temperatures are just two of the major problems of building a craft. The EVROV will make use of the years of experience pioneered by others who have designed crafts able to tolerate the radiation and temperature issues.

The EVROV will be bombarded by a vast array of elements from the sun and other cosmic events. Energetic plasmas, particles, and other forms of radiation are just some examples of the types radiation stress that the EVROV must be protected against[14]. If the craft is not protected, the craft can experience unpredictable consequences from small discrepancies in data to loss of control of the craft. Designing electronics to withstand the hardships of exposure to these elements is called "radiation-hardened" or "rad-hard"[15]. The team will learn about "hardening" the components that are sensitive to the effects of radiation and use this technology to alleviate the problem.

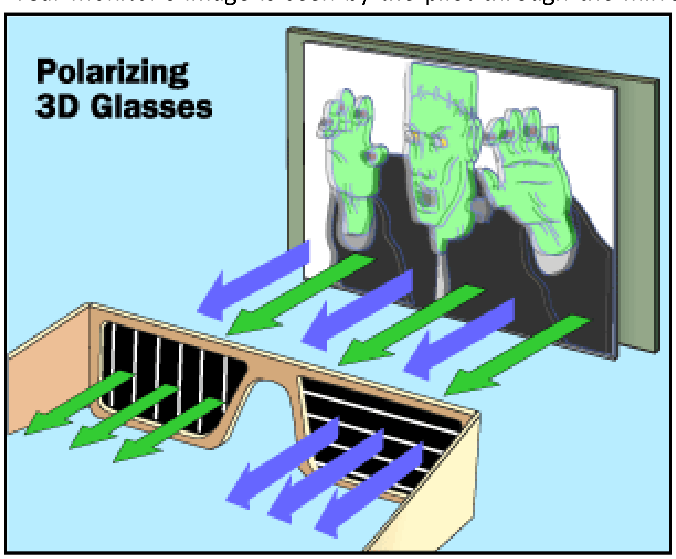
Protecting the EVROV from the drastic temperature variations in space is crucial to the functioning of the vehicle. Outer space temperature can range from -100˚C (-148˚F) in the shade to 120˚C (248˚F) while exposed to the direct sun light[16]. This poses a severe problem to the function of our vehicle since many of the components on board are thermally sensitive. Extreme heat can melt electrical connections and in turn short circuit components. Conversely, extreme cold temperatures will prohibit all functions from components such as the electronics and computer that will be used on the EVROV. An effective way to solve this thermal sensitivity issue is to wrap all of our sensitive components with heater jackets, which consist of two layers. The innermost layer that will be in contact with the actual component is electrically insulated but thermally conductive. This is very important for it will prevent any of electrical components to be harmed by the heating elements in the jacket. This will only take care of the extreme cold problem of the EVROV. Adding a last layer of gold foil will reflect the sun's radiant heat to prevent our electrical components from heat damage. The solution is simple but effective[17].

Operator Vision System

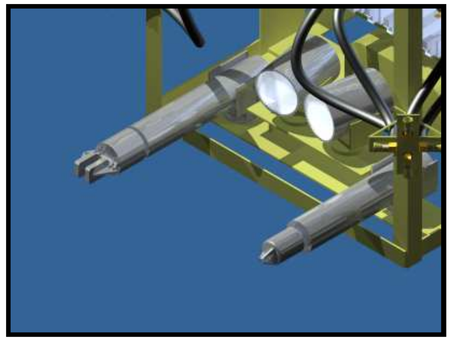
In the field of robotics and remotely operated vehicles (ROVs), one element has not lived up to its maximum potential: the vision system for the operators of such robots. The operator currently uses a flat screen that projects a two -dimensional version of what the robot sees. Depth-of-field is nonexistent, and the operator must use other visual cues to determine whether or not they can grab or manipulate objects. The goal of our EVROV vision system is to give the operator something that they never had in tele-operating such robots — three-dimensional (3-D) stereoscopic vision. The operator will be able to determine if the robot can actually grab something or not. It will save the pilot precious time during missions. Using the 3-D video system we can recreate a realistic "vision" of what the robot sees and project it to the pilot of the EVROV. This enhanced vision allows the pilots to better "fly" the EVROV in delicate tasks without ramming or bumping into the objects that the pilot is trying to manipulate. The 3-D visual system computer at the operator station provides the ability to process the video and display it in real time to the pilot as well as to the mission specialists on earth.



We researched 3-D video systems and found the perfect design in WIRED magazine, in an article about a 3-D system called the Vizard[18]. The EVROV utilizes a "Two camera" system which is fed to a computer via wireless technology located at the pilot station where two identical LCD monitors are situated in a special setup. LCD monitors are needed to create this 3-D effect because of the fact they give off light in a polarized manner. The two monitors are situated in a way that they form a right angle to each other. One monitor is placed on top of a housing facing down and another is placed in the rear facing in, so they are both facing toward the inside of the housing. They are positioned so that the tops of the displays are in contact, forming a 90-degree angle. A 50 percent teleprompter mirror is then placed between the two LCD monitors with the reflecting side up, bisecting the right angle of the two monitors at a 45-degree angle. The front of the housing is open so the pilot can see the rear monitor. The rear monitor's image is seen by the pilot through the mirror with its polarity unchanged, and the top monitor's image is bounced off the mirror, due to the reflective side facing up. This rotates the polarity of the light from the top monitor by 90 degrees. There are two images created with their polarity perpendicular to each other. The video feed to the top monitor is also inverted horizontally so that left and right appear the same direction when both images are viewed through the mirror. Viewers wear special polarized glasses with the same variance in polarization, in other words, one eye sees only the horizontally polarized image, and the other eye sees only the vertically polarized image. While the viewer's eyes see separate images, their brain does the rest of the work visualizing the 3-D image. The images are offset just as if your eyes were the cameras. This method makes for a very realistic 3-D effect[19].



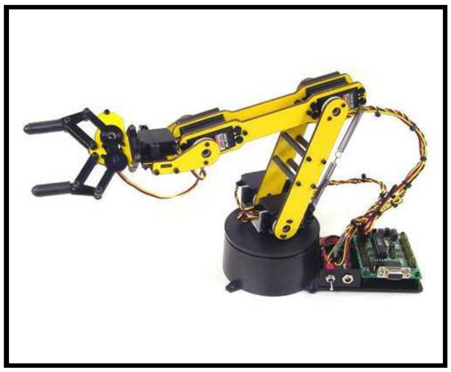
Manipulator



EV-ROV will be equipped with dual manipulators. Each will be specially designed to manipulate different shaped objects. One tri-grabber will be for oddly shaped objects such as a diagonal bar, spheres, or anything else of that sort. That arm will be accompanied by a parallel grabber. The parallel grabber will specialize for handling objects that are slender and perpendicular to the operators view. The parallel grabber will be located to the right extreme of the front end of the robot, and opposite of the tri-grabber. Each arm will have four degrees of motion relative to the robot; Rotation, Horizontal/Vertical, left/right, open/close claw.

Each arm will be completely retractable meaning that when traveling the arms can be totally inside the EV-ROV frames. This will prevent any possible entanglements as well as keep the center of mass in the center of geometry. Traveling this way will make the EV-ROV more efficient. In the event that the ROV must transport an object in its manipulators and the arms cannot be retracted we will employ a three axis accelerometer. These will give us the ability to compensate for displaced mass caused by the arm and its contents.

The pilot will have very intuitive control over the arms by using a scaled model of each arm that will house the pilots arm, somewhat like an exoskeleton. Every movement the pilot does with his arm will be mimic by the arm on the ROV. This method of control will prove to be very intuitive. Overall the different arms along with our control method will give the pilot have more flexibility when operating the EV-ROVs arms.



An example of a type of manipulator for the EVROV

EVROV Docking Station (Optional)

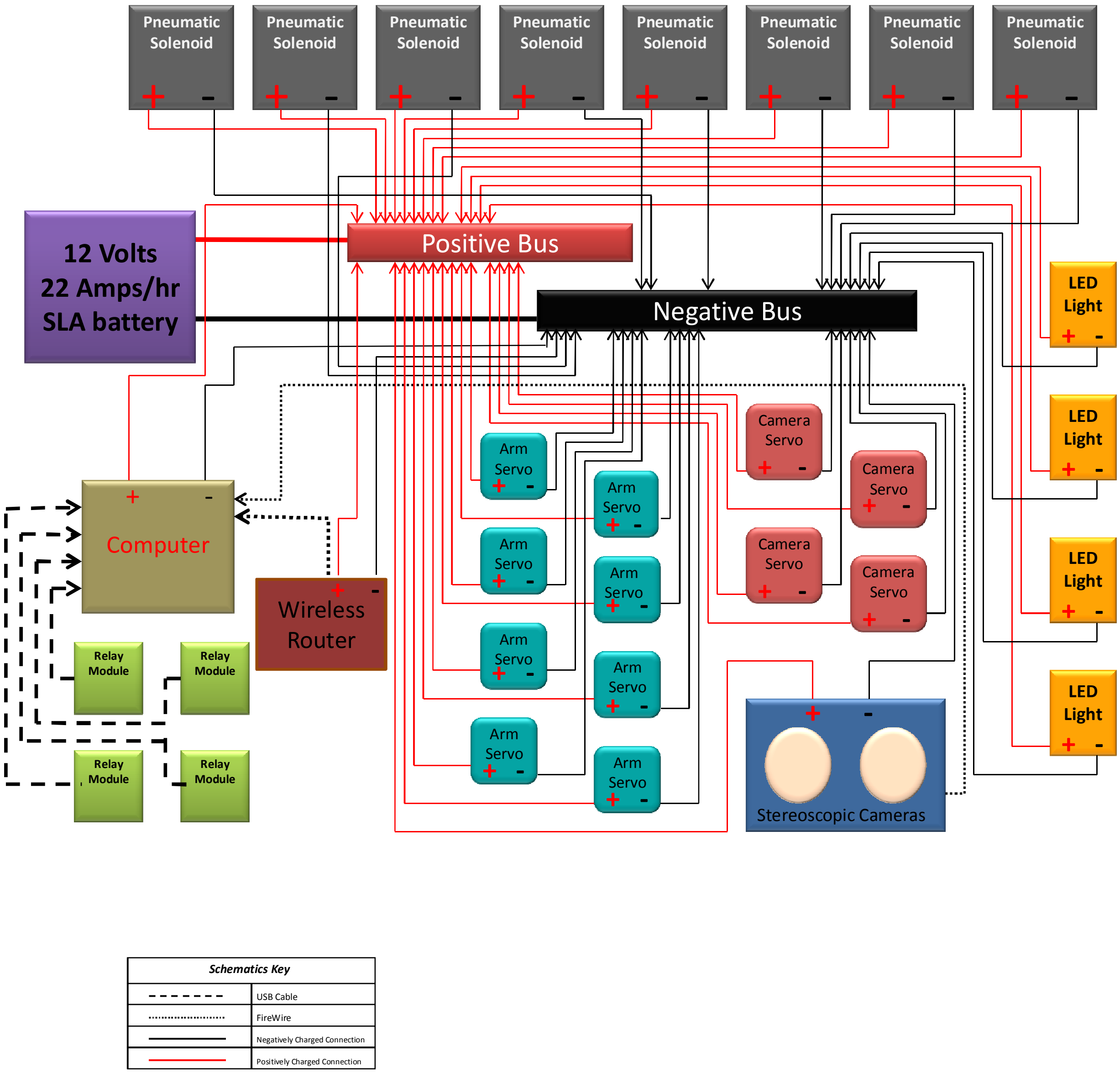
In keeping with our mission goal of reducing or eliminating unnecessary EVAs by humans we will design the EVROV to be stationed outside of the space ship, eliminating the need to open an airlock every time the EVROV is in use. This docking station will supply the robot with power, nitrogen supply, and it will also allow the operator to retrieve information from the robot itself as well as uploading new programming. An Airlock can be used to retrieve the EVROV if there is a need for the astronauts to physically work on the craft itself.

The docking station will have a funneled-shaped entry so that the pilot can maneuver the robot and it can be somewhat guided by the funnel so that all of its connection ports line up correctly once docked. The docking station controls will be accessible from within the space craft, so an astronaut can service the craft.

The docking station functions will include recharging the on board batteries, maintaining the EVROVs environmental controls, nitrogen gas refill for propulsion, downloading data and loading computer programs. So while the EVROV is docked it receives all its power from the space ship or space station. From the docking station, it can be deployed rapidly once all its systems are charged.

While the docking station has many advantages it does cost more, however, the EVROV can still used by any space craft or space station as long as they have an airlock. The EVROV servicing can then be done by the astronauts in person. It will reduce the cost significantly and the EVROV still keeps most of its benefits.

Appendix A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Camera Servo
Camera Servo
Camera Servo
Camera Servo
Stereoscopic Cameras
Schematics Key
USB Cable
FireWire
Negatively Charged Connection
Positively Charged Connection

Appendix B

Footnotes and References

1. **Footnotes**