

Hybrid Robot Crawler / Flyer for use in Underwater Archaeology

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Abstract— Remotely operated crawlers are specialized vehicles that allow for underwater intervention by staying in direct contact with the seafloor. The crawler offers a very stable platform for manipulating objects or for taking measurements. Additionally, crawlers lend themselves to long-term work. Crawlers are already well established platforms for various environments. For example, planetary rovers have successfully proven themselves in missions to the moon and mars.

At Florida Institute of Technology a hybrid remotely operated crawler has been developed for archaeological and scientific activities within coastal regions of the ocean. This hybrid vehicle combines a standard 40-cm high, 53-cm wide, 71-cm long remotely operated vehicle (ROV) flyer with a 1.0-m high, 1.52-m wide, 2.8-m long remotely operated vehicle crawler for multiple research activities such as underwater archaeology documentation and artifact removal. Named the RG-III, the hybrid vehicle is currently designed to operate in depths down to 100-m. The vehicle is controlled by a remote control cable from the beach or boat and is equipped with video, still cameras and robotic grippers. Capable of carrying most environmental data gathering instruments the crawler is also able to “fly” when necessary by filling flotation bladders and using its four mounted thrusters. This capability allows the vehicle to jump from one side of a shipwreck to another or to fly over sensitive regions such as reefs. The ROV-flyer piggy-backs on the ROV-crawler and can separate to become an “eye-in-the-sky” to observe from above the activities of the ROV-crawler.

Index Terms — Remotely Operated Vehicle, ROV, Remotely Operated Crawler, Robotics, Underwater Archaeology, Marine Archaeology, Nautical Archaeology.

This work was submitted on June 12, 2013 and was supported in part by the Harris Corporation.

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I. INTRODUCTION

The RG-III is the third generation of modifications to an undersea recovery crawler / vehicle under development at Florida Institute of Technology in Melbourne Florida. The RG-III (Fig. 1) is a high-powered remotely-operated vehicle with the ability to take on a wide range of underwater archeological projects. RG-III's underwater capabilities include the recovery of lost valuables with sensitive structures, visually examining underwater scenarios, high maneuverability at depth, and the ability to translate its position while neutrally buoyant in the mid-level depths. RG-III will soon be operational in coastal waters to depths of 100-m allowing the vehicle to collect and retract archaeological artifacts or other objects of importance.

Design modifications to the RG-III include the addition of a flying remotely operated vehicle (ROV) with a tether management system (TMS). The ROV expands the RG-III's underwater view as well as being a second vehicle to gather data, such as pressure, sea conductivity, and temperature at various depth measurements. The robotic arm on the ROV is able to collect small objects that are inaccessible to the RG-III crawler's robotic arms.

The RG-III's main goal is an underwater mechanical system able to grapple small and large objects from the sea floor for research, exploration or salvage. This system is designed to advance the research possibilities of marine / nautical / ocean

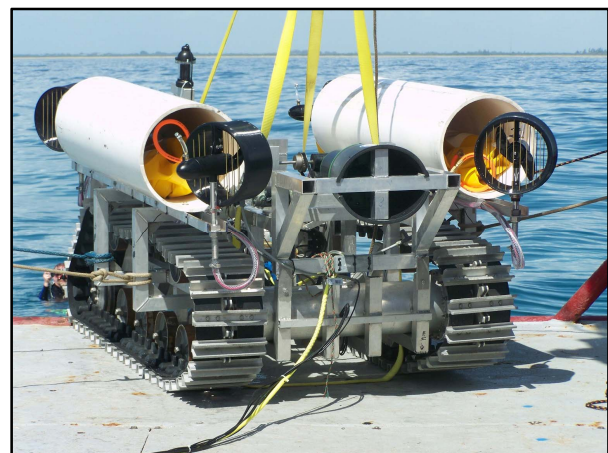


Fig. 1: RG-III Crawler

archaeologists and scientists by overcoming the underwater limitations generally experienced in underwater archaeological exploration.

II. MOTIVATIONS

Shipwrecks are abundant with great numbers still to be discovered. Back in the 1970's treasure hunting was at an all-time high when people started noticing the value of historic artifacts. The act of treasure hunting has died down over the last few decades due to lawsuits with individual states, the federal government and with other nations, but the act of underwater archaeological analysis and recovery is beginning to flourish as technology advances with new techniques and methods of searching for and recovering artifacts deep underwater. Whether it is the underwater archaeologist striving to obtain information about some underwater artifact or marine salvage specialist trying to recover materials from a sunken ship, both are in serious need of remotely operated vehicles – especially in deep waters i.e., over 30-m depth. The RG-III is a remotely operated crawler vehicle with the capabilities of lifting anything from 100-kg to just a few grams under extreme depths and currents. Systems such as these are in high demand due to the fact that they are able to operate at greater depths, possess less human liability, and have longer working hours than any commercial diver. Marine salvage and ocean cleanup organizations will find it a benefit to use RG-III due to its effectiveness in removing debris from the ocean floor.

Underwater vehicles are important for exploring the harsh underwater environments that may be unsafe for divers. A crawler with a grabber arm capable of moving and lifting solid underwater waste and materials is a great asset to any underwater recovery mission [1]. The RG-III's main goals are to lift a 100-kg object, such as a lead ingot, and drop it into a lift container, and be able to recover artifacts that are under a layer of overburden. One of the accessories soon to be added is a sand blower to remove sand from buried objects and surrounding area. Attached to the crawler is a remotely-operated vehicle (Tomcat) allowing the operator to have an aerial view and to explore the seafloor from a distance.

The RG-III crawler can either be deployed with diver assistance or on solo missions with guidance via live video feeds on both the RG-III crawler and ROV Tomcat. RG-III has a rugged frame and heavy lifting capabilities to recover large objects. The crawler is able to maneuver on or above the sea floor by lifting itself and flying to another location. The crawler can be used for recovery efforts and transportation of tools and equipment. Ports and harbors are also key locations that could benefit from the use of RG-III where the crawler is ideal for recovering submerged items [1].

III. CUSTOMER REQUIREMENTS

The initial requirements of the RG-III crawler system are:

- 1) The vehicle must be capable of lifting a metal bar weighing 100-kg (dry weight) from the seafloor at a depth of 30-m.
- 2) The vehicle must be capable of placing the bar in a 1-m

1-m metal basket while operating at a depth of 30-m.

- 3) The vehicle must be capable of turning right and left making a full circle within a 10-m dia.
- 4) The vehicle system must include a camera that is separate from the vehicle to observe and monitor the vehicle activity from a surface vessel.
- 5) The vehicle must have the capability to lift itself, i.e. without surface support, over obstacles as tall as 20-m that are on the seafloor and successfully returning to the seafloor on the other side of the obstruction
- 6) The vehicle must be able to join/connect a flying remotely operated vehicle. This ROV will act as an eye-in-the-sky for all operations.
- 7) The vehicle must include a blower motor capable of removing sand at a rate not less than 10-cm³/min and relocating that sand to a location not less than 2-m from original position.

These goals are complex and require the construction of numerous mechanical systems and the integration of mechanical-electrical intelligent systems where micro-controllers and controlling software must be developed and integrated.

IV. BACKGROUND

ROVs have been around since the 1950s when the British Royal Navy developed “the ROV Cutlet to recover practice torpedoes” [2], and since the Royal Navy's ROV numerous oceanographic and space institutes and companies have built remotely operated flying and crawling vehicles for a variety of purposes. At the Florida Institute of Technology (FIT), the Department of Marine and Environmental System's Ocean Engineering program acquired a small defunct flying ROV (Tomcat) from Harbor Branch Oceanographic Institute in 2011. Simultaneously, students at FIT developed an undersea crawler as a senior design project. The crawler made its first sea trials that summer in 2011 (Fig. 2). In 2012, with funding from the Harris Corporation the crawler began its transition to its current configuration (i.e., the RG-III) where the Tomcat ROV is incorporated into the system. With the addition of a number of enhancements and the solving of performance issues such as maneuverability and grappling accessories, this hybrid vehicle has been brought to a professional level.



Fig. 2: 2011 Sea trials

V. DESIGN

The complete upgraded crawler design can be seen in Fig. 3. The main components of the systems' design are divided into seven different categories: 1) frame and motor housing, 2) propulsion, 3) tether management system (TMS), 4) buoyancy System, 5) manipulator arm, 6) power distribution and control, and 7) ROV (Tomcat).

A. Frame and Motor Housing

Modification and strengthening of the frame was necessary after cracks were discovered in several welds of the motor support. Analysis using ANSYS showed where deformation was greatest, which matched known weld failure points. Adding ribs to the outer frame support between the main frame of the crawler and the motor housing frame made of 1/4" 6061-T6 aluminum solved this issue.

The motor housing frame was loaded with 91-kg on each support. The maximum deformation for the original design had a max value of 0.066458-in (1.6880332-mm) (Fig. 4). With the added support ribs the deformation was decreased to 0.043935-in (1.115949-mm) (Fig. 5).

The maximum stresses on the original design were very conclusive and the areas with the max stresses were also the areas where the welds were cracked. The maximum stress of the original design was 20011-psi (1407-kg/cm²) (Fig. 6) which is not past the yield point but still high enough to fail under repeated fatigue. With the added ribs on the revised design the maximum stress was decreased to 9317.7-psi (655-kg/cm²) (Fig. 7). This value is far lower and will allow for a stronger and safer design.

The factor of safety of the original design was greater than 1 so by design it should not have failed however, after fatigue from multiple uses over time failure occurred. For the revised design we more than doubled the factor of safety from 2.0294 on the original design to 4.3504 on the revised design. This allows for a design that will be able to withstand repeated uses during operation.

B. Propulsion

The "flying" propulsion system of the crawler consists of four Minn-Kota electric trolling motors, each capable of 30-lb (13.6-kg) of thrust. Equation (1) determined how much thrust would be required to move the entire system [3].

$$F_D = \frac{1}{2} \rho v^2 C_D A \quad [3]$$

Where:

F_D is the drag force, ρ is the mass density of the fluid,

v is the velocity of the object relative to the fluid,

A is the reference area, and C_D is the drag coefficient

Due to the complexity of calculating a drag coefficient for the crawler, an estimated value was chosen based upon a simplistic model of a solid rectangular shape with the same length and width dimensions of the crawler. With a drag coefficient value of 1.05 and frontal surface area of 1-m², in order to achieve a speed of 0.5-knots against a 1-knot head on current, a drag force of 55-lbs (25-kg) needs to be overcome.

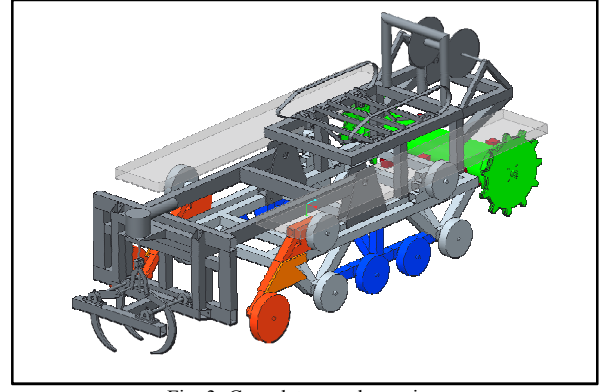


Fig. 3: Complete crawler design

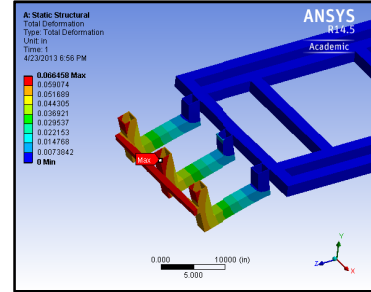


Fig. 4: Deformation of original frame

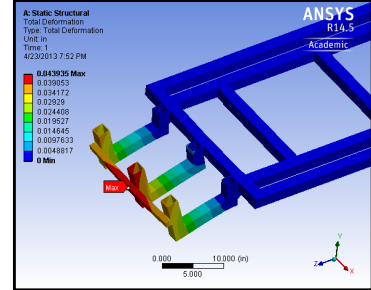


Fig. 5: Deformation of revised frame

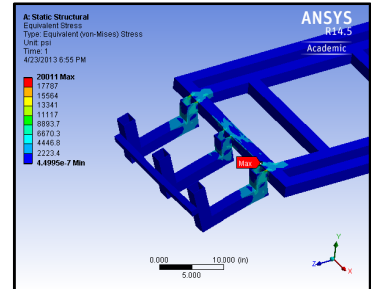


Fig. 6: Von Mises stress of original frame

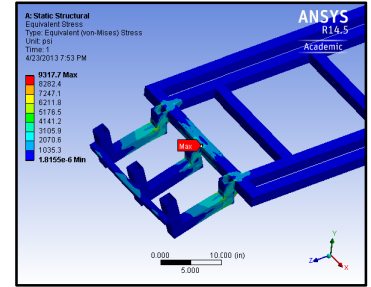


Fig. 7: Von Mises stress of revised frame

Four trolling motors provide enough thrust to move the vehicle and by incorporating a Rice nozzle duct to house the blades, the propeller system increases the overall performance of the motors to be used [4].

C. Tether Management System

The RG-III enhancements include the integration of an ROV (Tomcat). These two systems are linked by a tether management system (TMS), which contains power, data, and video cables to run and control the tomcat's motors and camera. The Tomcat is the "eye-in-the-sky" for searching and observing, providing an unobstructed view of the area. For the ROV to piggy-back on the crawler, a landing platform with an automatic fastening system was developed. The system allows the tomcat to detach and reattach from the crawler and safely stores the tether while the two are attached.

The TMS is comprised of three components: a latching device, tether-reeling device, and a housing device for the tether. The latching component has 4 L-shaped latches that are stationed on each side of the landing platform, which when activated opens and closes to release or constrain the Tomcat ROV. Only when deploying and retrieving, the ROV must be attached to the RG-III (i.e., reduce the risk of tether entanglement) (Figs. 8 & 9).

The TMS reel system is composed of 2 rollers that roll in unison via a timing belt pulley attached to an electric motor with an integrated gear reduction that runs off of 12-V DC at 155-RPM. The timing belt pulleys from McMaster Carr are 2.1-in (5.3-cm) and the roller axle pulley 3.1-in (7.9-cm). The equation (2) was used to determine the rpms of the axle.

$$\frac{RPM1}{RPM2} = \frac{D1}{D2} \quad (5)$$

Using the motor's RPM and the diameters of both pulleys the RPM of the axle is found, where RPM1 is the motor's RPMs and D1 the diameter of the motor's pulley. The axle was determined to spin up to 98 RPM allowing the rollers to safely spool in the tether without the tether pushing out to the sides of the rollers.

The housing for the TMS incorporates an outer cylinder with a hole in the center, at the front right behind the groove in the rollers. As the tether is rolled into the cylinder, the tether's cable follows its inherent natural coil from transportation and storage.

D. Buoyancy System

One of the primary requirements of the RG-III is to "fly" to other locations. Consequently, a buoyancy system is integrated enabling the crawler to become neutrally or positively buoyant in the water column by the integration of professional grade, soft shell marine salvage bags. "A lift bag is an item of diving equipment consisting of a robust and air-tight bag with straps, which is used to lift heavy objects underwater by means of the bag's buoyancy" [6]. The bags used are known in the industry as either salvage tubes or lift pillows due to their cylindrical form.

The bags selected for the 2013 sea-trials are two 400-lb (181-kg) custom built salvage tubes by MatJack lift bags (Fig.

10). These bags have pressure relief overflow valves and solenoid hookup inflation inlet tubes installed. D-rings are attached for lifting or restraining the bags to the vehicle. The lift bags are attached to an aluminum 80-ft³ (2.265-m³) scuba cylinder that fills the bag with air. The scuba tank's 3250-psi (228-kg/cm²) working pressure exceeds the connected hoses and bag ratings so a first stage balanced ScubaPro regulator (Fig. 11) is used to step down the pressure down to an average of 140-psi (9.8-kg/cm²). The connectors that attach the hoses to the solenoids are inflator hose male connection rods.

The connection between the tanks and the solenoid valves is through a scuba inflator piece where the blockage bridge is removed and the Schrader pin deactivated (Fig. 12) to allow

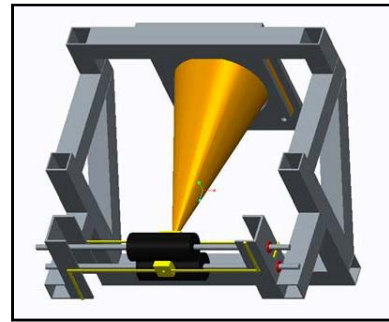


Fig. 8: TMS rendering



Fig. 9: TMS installed



Fig. 10: Matjack lift bag [7]

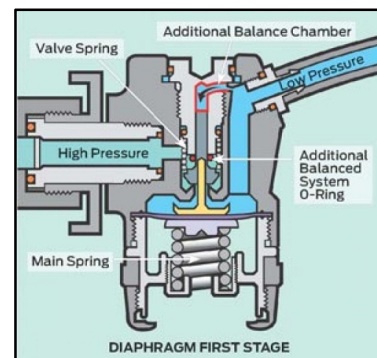


Fig. 11: First stage regulator [8]

more air to flow through the connection and hence decrease the time for the lifting to occur.

The solenoids used are air calibrated compressor solenoids (i.e., simple pin blockage solenoids primarily designed for air horn purposes) since they are designed to work under higher pressures similar to scuba cylinder working pressure. The minimum operational pressure is the low pressure outlet pressure of a scuba regulator, i.e., 140-psi (9.8-kg/cm²). Geerte's model MH442 (Fig. 13) is designed for a working pressure of 0 to 150-psi (0 to 10.5-kg/cm²) with a failsafe maximum of 250-psi (17.6-kg/cm²) and operate on 12-V and 0.25 amps of current. To make the solenoids waterproof they were imbedded in epoxy.

The lift bag size was calculated to gently lift the RG-III into positive buoyancy. For simplicity, the soft shelled lift bags were housed in PVC containment pipes for the 2013 sea-trials. Future designs will combine multiple fabricated corrugated aluminum cages with integrated syntactic foam thruster housings for a completely integrated buoyancy thruster system.

With all buoyancy systems, trim of the vehicle is an issue. Two methods are used with the RG-III: scuba weights are added to the front of the crawler, and customized syntactic foam added to the rear. Enough weight is added to make sure that a full lift bag results in a slow ascent. With the bags full, the expanding air due to decreasing the surrounding pressure is exhausted through the overpressure relief valves attached to the bags, making the ascent safe and controllable. Currently, retrieving the crawler carrying a heavy object is not an option.

E. Manipulator Arm

In its current configuration the vertical lifting manipulator arm is the main tool on the RG-III. It is used to lift and transfer heavy underwater objects to a lift bag, which is then lifted to the surface. The movable main frame that the manipulator arm is attached to consists of 2-in x 3-in x 1/4-in (5-cm x 7.6-cm x 0.5-cm) 6061-T6 aluminum for strength and corrosion resistance. The moveable main frame is hinged near the center of the crawler to distribute the weight evenly over the entire frame and tracks. This aids in the stability of the crawler when a large object is added to the front. Fixed to the front of the main frame is a faceplate that allows different options to be added to the crawler (e.g., the manipulator arm in its current configuration) via a faceplate with four 3/8-in (0.95-cm) stainless steel bolts. Options soon to be added are: backhoe, chainsaw like cutter, two multi-degree-of-freedom robotic traversing arms that will work together, traversing metal detector, and sediment blowers.

The RG-III's focus was the design and integration of a manipulator arm (Fig. 14) capable of lifting silver or lead ingots weighing approximately 200-lb (91-kg). To accomplish this lifting capability a manipulator arm was designed that is actuated by a single 750-lb (340-kg) actuator. With this actuator, the output at the tip of each tooth is 50-lb (22.7-kg) for a total of 200-lb (91-kg) pinching capability with the four teeth. The design is simple with only one degree of freedom

and manufactured completely of 6061-T6 aluminum and 316-stainless steel. When the claw is fully opened the open-width is 24-in (61-cm). The frame of the manipulator arm is manufactured from 2-in x 2-in x 1/8-in (5-cm x 5-cm x 0.32-cm) 6061-T6 aluminum and all pivot shafts are manufactured from 316-stainless steel. Both are corrosion resistant and the stainless steel allows added strength where deformation and stress is greatest. Sacrificial zinc anodes (Fig. 15) are attached to the manipulator since there is an interface of two dissimilar metals (i.e., aluminum and steel). The zinc anodes protect the structure from corrosion caused by galvanic reaction.

The final manipulator arm design is simple yet effective with one degree of mobility. It is actuated by a single vertical Lenco Marine trim-tab with a 4.25-in (10.8-cm) stroke. The four jaws allow for greater pinching force when retrieving items from the seafloor. The four jaws also create a cradle if an item is to be lifted from below.

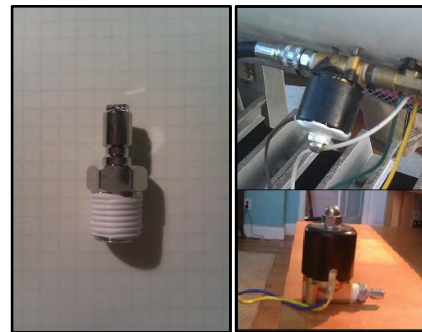


Fig. 12: Schrader valve Figure13: Solenoid

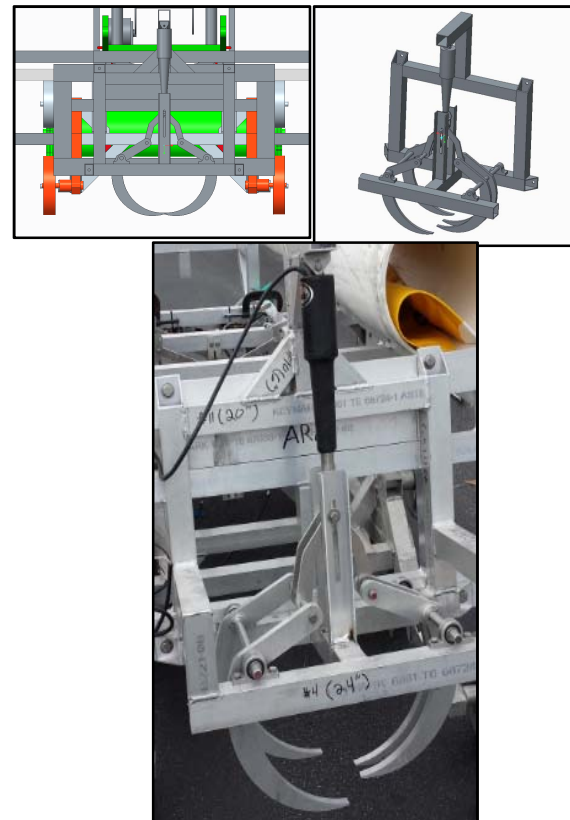


Fig. 14: Manipulator arm attached to crawler lift arm

The manipulator was tested in Ansys Mechanical 14.5 for the maximum deformation, maximum Von Mises stress, and minimum factor of safety. The analysis was completed in two parts: the manipulator arm frame and the manipulator arm claw. This allows better mesh refinement around specific areas of the design and allows for more accurate analysis of the component's design. Both parts of the manipulator arm were analyzed with a 750-lb (340-kg) bearing load applied to the bolt holes where the actuator is attached.

The maximum deformation (Fig.16) was found to be 0.17259-in (0.43837-cm), and with a design set value of 0.25-in (0.635-cm) for the maximum allowable deformation, the final frame design was proven to be within the allowable deformation limit.

The maximum Von Mises stress of the manipulator arm frame is 18290-psi (1286-kg/cm²), which is below the yield strength of the aluminum alloy. Additionally, the minimum factor of safety is determined as 2.2204, which is typical of most mechanical engineering designs.

Using the Ansys information, the manipulator design was optimized. The manipulator arm and frame is robust and able to withstand lifting forces over the targeted design limit. Next, the claw assembly of the manipulator arm was tested for maximum deformation. Again the maximum allowable deformation is 0.25-in (0.635-cm) and after testing the deformation found to be 0.18079-in (0.45921-cm), which is less than the maximum allowable.

The maximum Von Mises stress (Fig. 17) for the claw assembly is 29,430-psi (2069-kg/cm²), which is below the yield strength of the aluminum alloy, and the factor of safety is 1.0201. Greater than 1 is necessary for design integrity, but this value is a point of concern when the prescribed load is exceeded.

F. Power Distribution and Control

The crawler from the 2011 sea-trials was upgraded from a system with two track driving motors, two actuators, and a video camera that were controlled via analog from the surface along with all power conversion. The 2011 version used a 400-ft (122-m) tether of 18-gauge wire, resulting in a 48-V loss (due to resistance). With the many new systems to be added to the RG-III, including powering the ROV Tomcat, it was imperative to maximize the efficiency of a new power distribution and control system.

Numerous design ideas were discussed to implement the power delivery needed to be implemented along with their respective power requirements. Figure 18 shows the power lines for all systems where each individual line represents both a supply and return line. Not shown on the diagram are the data lines for the Tomcat as well as the video feed cables for both ROVs.

With this information an onboard power distribution center mounted on crawler, capable of converting a 240-V AC supply to all the necessary DC voltages was developed. This power distribution center reduced the size of the earlier version's tether, using AC instead of DC, which is preferred

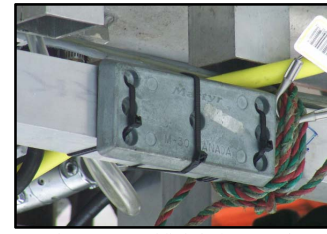


Fig. 15: Sacrificial zinc anode

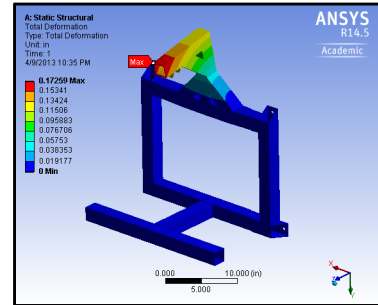


Fig. 16: Deformation of the manipulator arm frame

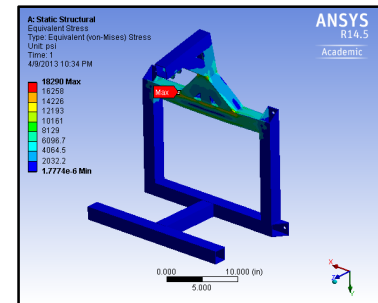


Fig.17: Equivalent stress of manipulator arm

for long distance transmissions when energy loss is a concern. The 240-V AC was converted to 180-V DC to drive the two track-motors and to 24-V and 12-V to power the other components. Figure 19 shows the Power Delivery Diagram of the power distribution system.

G. Control

The control system of the crawler is split into two categories: digital and analog. The digital microcontroller is set up as the primary control and analog is used for testing and as a backup control system. The digital system in the crawler uses Arduino micro-controllers for prototyping.

The analog system design consists of dual-pole dual-throw relays within the onboard power distribution constantly supplying the required power to the system. The relays are controlled by switches on the surface to complete the “ground” side of the relay circuit.

The digitally controlled system consists of a microcontroller communication network. On the surface, all controller inputs are gathered by a microcontroller via USB and transmitted to a microcontroller onboard the crawler. This acts as a central controller on the crawler that delivers messages to controllers attached to each of the onboard systems. Since all systems can be controlled by a single microcontroller, a modular approach was taken by implementing a dedicated controller for each

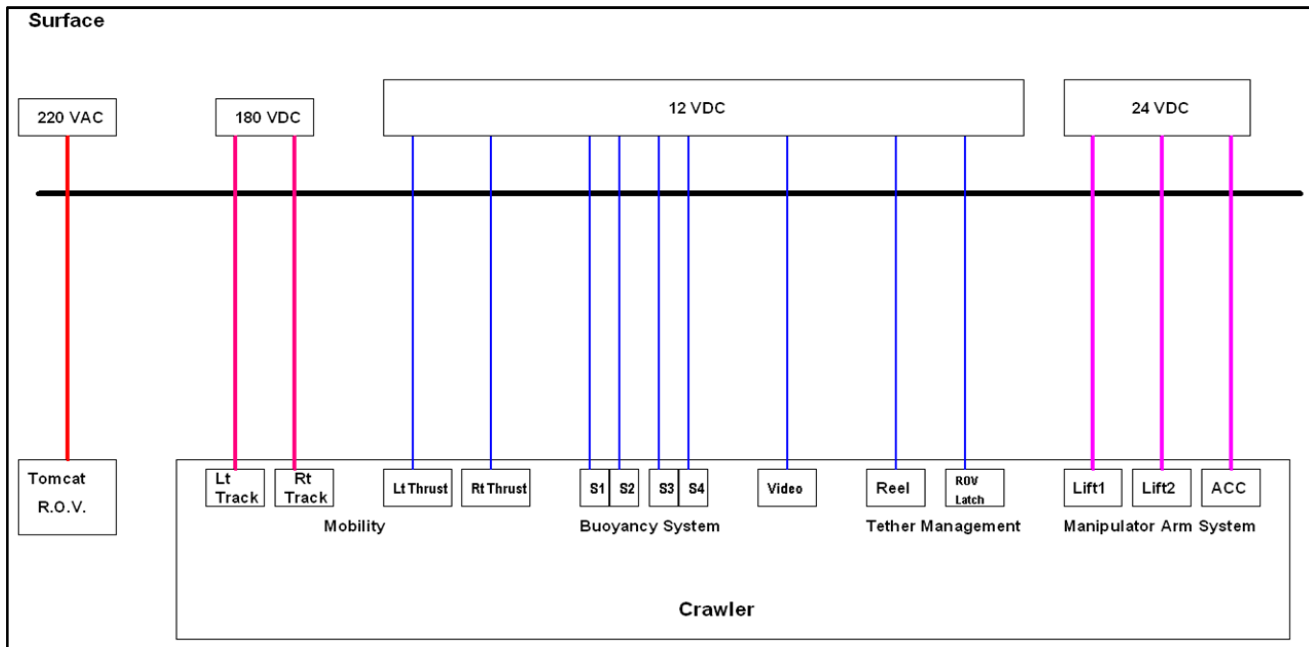


Fig. 18: Power Delivery Overview

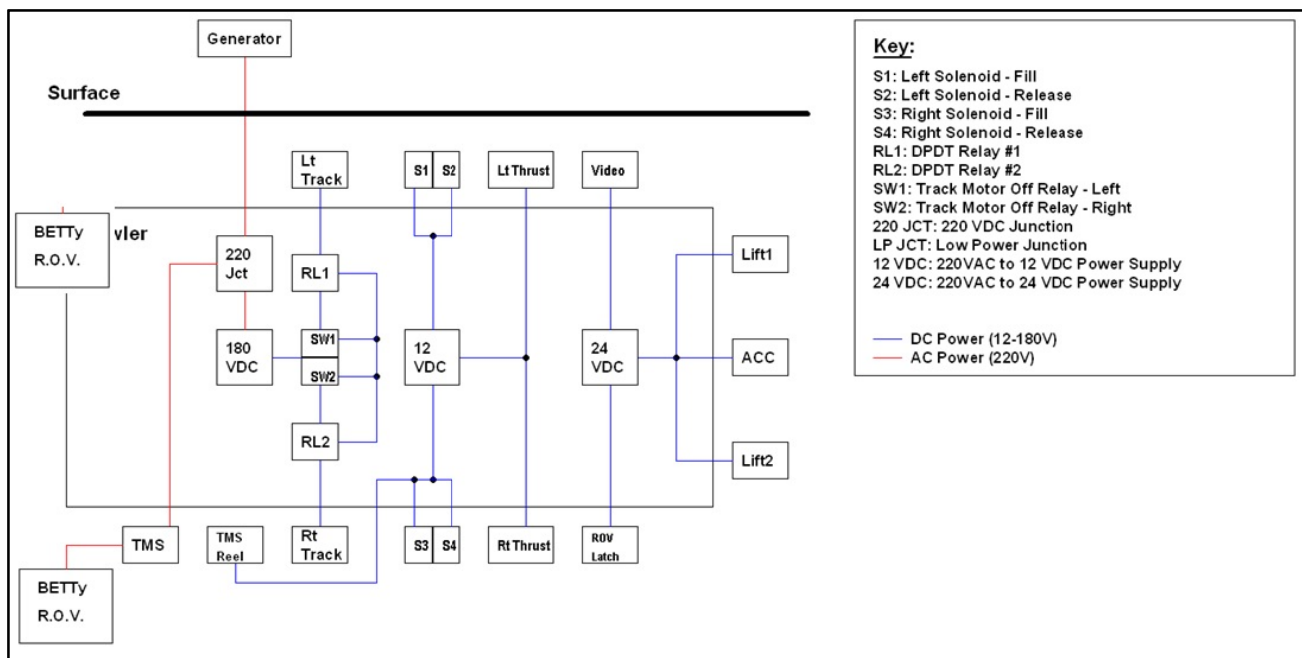


Fig. 19: Power Delivery Diagram

system. Each unit is configured in such a way that central communication tasks can be taken over if required. The DC systems receive power similar to the analog except the relays alter their position based on inputs from the microcontroller. The advantage of this arrangement is that the communication between the surface controls and RG-III is handled between two microcontrollers, which reduces the control of all crawler systems (not including Tomcat controls or video signal) to just two data lines through the tether. Microcontrollers also provide the ability to consolidate the controls into a single interface (e.g., USB video game controller) (Fig. 20).



Fig. 20: Vehicle Controller

H. Tomcat Tether

The ROV Tomcat tether system consists of two segments: a main tether between the surface and crawler along with a tether connecting the Tomcat to the crawler. The tether between the Tomcat and the crawler has two lines for power (supply and return), two for data communication, and two for video. These lines are attached to a junction on the crawler that sends the signals, unaltered to the surface via the main tether. The tether between the Tomcat and undersea crawler was donated by SeaBotix. The wiring diagram and pin connections for power and communication of the tether to the

ROV are shown in Fig. 21 where the ROV's female 9-pin connector mates with the SeaBotix 6-pin tether. The diagram specifies which pins and connectors are used. The SeaBotix tether is 60-ft (18.3-m) long and neutrally buoyant.

The main tether between the crawler and the surface is 310-ft (95-m) in length from Outland Technology (Fig. 22) with two sets of wires: twelve along the outer edge used for power transmission (22-AWG) and eight bundled in the middle used for data (24-AWG). For the digital control, this is the only tether used while for analog control this tether is used strictly for delivering power.

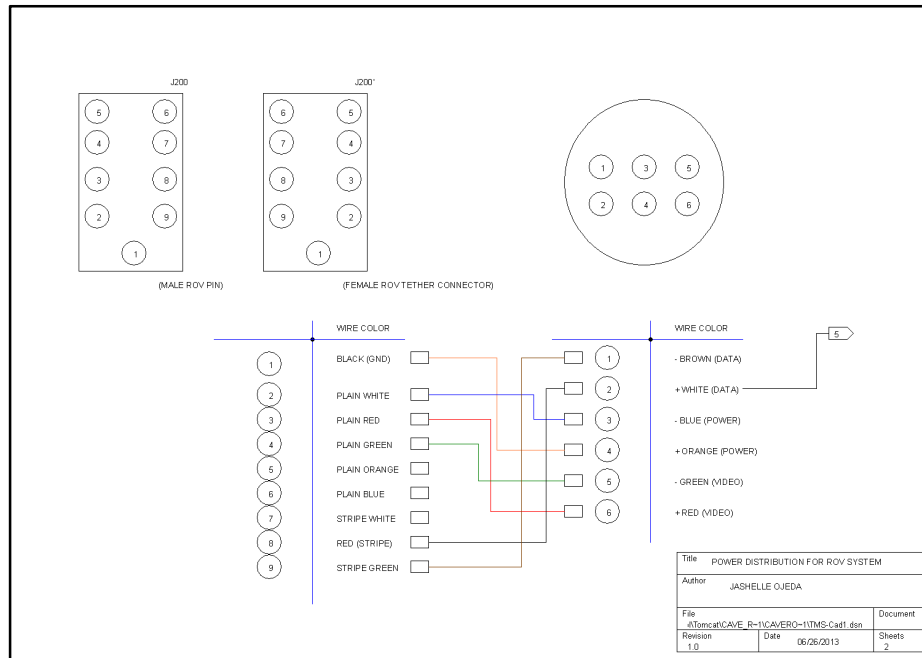


Fig. 21: Tomcat Tether

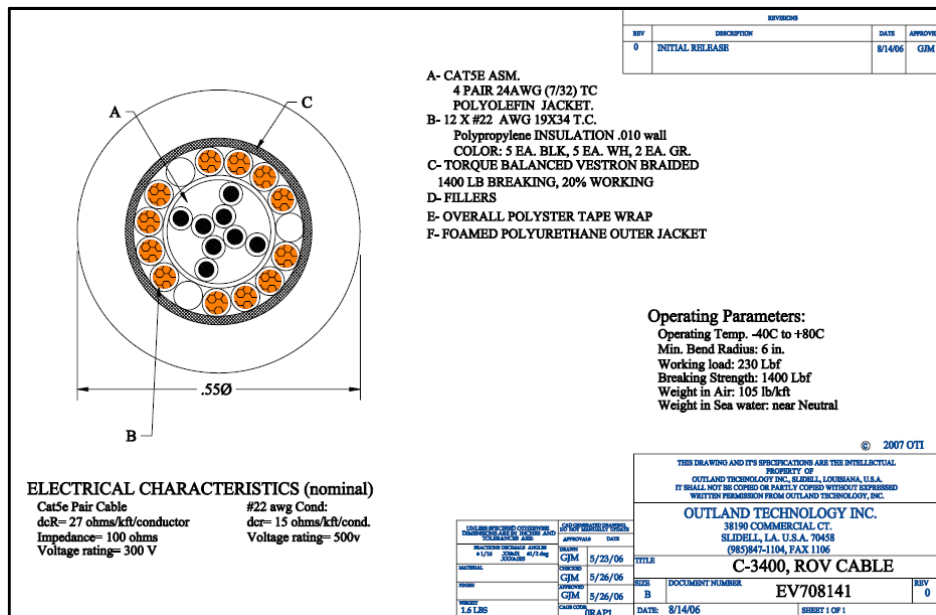


Fig. 22: Crawler Tether [9]

I. Tomcat ROV

Hardware and Components

The Tomcat remotely operated vehicle (a donation from Harbor Branch Oceanographic Institute) was re-engineered and converted from an analog system into a fully digital system using two microcontrollers; one for the surface controller and one for the underwater ROV. The surface controller uses an Arduino Mega 256 while the underwater portion uses an Arduino Uno. The two Arduinos communicate using the RS-485 protocol for serial 2-wire long range communication. Two Maxim Max-485 type level shifters are implemented on each side of the tether in order to step up the RS-232 serial signal used by the microcontrollers.

The surface controller uses two dual-axis joysticks from SparkFun electronics. These joysticks are nearly identical to those used in PlayStation controllers. The Arduino Mega reads four channels of analog values; one for each axis available on the joysticks. The right joystick controls the forward and reverse motion of the Tomcat. This joystick also controls the rotation of the ROV about the Z-axis. The Y-axis of the second joystick is used to control the vertical thruster while the X-axis is used to control the lateral thruster. This is the most minimal design possible for the operation of the Tomcat ROV (Fig. 23). Future additions include digital inputs to the Arduino micro-controller such as a pan/tilt device for a video camera, lights, and manipulator arm.

Once the RS-485 signal is relayed to the underwater controller the Arduino UNO interprets the values and sends pulse width modulated (PWM) signals to four Pololu high power MOSFET motor drivers. Each motor driver is capable of varying the voltage of each thruster from 0 to 24-V and also switch direction. The motor drivers are supplied with power from the Vicor VIPAK-C model power converter, which converts a 120/220-V AC signal into two channels of 24-V DC, each capable of supplying up to 12.5-Amps.

Each motor driver is then connected to an independent thruster through the already existing ports in the Tomcat pressure housing achieving four ways motion controls (Fig. 24). This is also the most minimal design possible for the ROV. Additional features in the future will include: pan/tilt camera motion, compass, lights, manipulator arm, and pressure sensor.

Software Code

The software code for both the surface and ROV controller is written in the native Arduino integrated design environment (IDE). The code for the two controllers uses a software serial package communication library called “EasyTransfer”. This library ensures that each data packet sent between Arduinos is received intact. Once the data transfer is proven to be robust this library will be replaced.

The code for the surface controller is where most of the computations and processing is done, allowing the ROV controller to be extremely quick. The Arduino Mega reads in

all four channels of Analog input and converts each value to a number between -255 and 255. This is a signed byte that is communicated to the ROV. Four of these transmitted bytes sent to the ROV specify each thruster’s speed. A significant dead-band has been introduced to each thruster to reduce sputtering. The bytes are transmitted at a 9600 Baud rate, which is relatively slow for this application. A higher Baud rate may be achieved through the elimination of the EasyTransfer library.

The ROV receives the transmitted signals and sets the PWM signal of each thruster accordingly. Additionally, if the sign of the byte is negative it flags a digital-pin, instructing the motor driver to reverse the direction of the thruster. This process is simplified by the nature of the Arduino as each thruster will continue function until a new series of control bytes is received.

VI. RESULTS

The **RG-III** underwent its first undersea trials on June 21, 2013 at 27° 26.5 N and 80° 13.5 W. The first test required the crawler to be placed in seawater for a trim check with no power. The following was determined:

- *A non-predicted failure in the design arose when the half full lift bag produced enough lift capacity to keep the crawler positively buoyant. The submersed weight of the system was overestimated and hence trimming weights would have to be used for a successful lift.*
- *The crawler was rear/aft heavy; therefore the arm and claw of the crawler were above the surface for most of the test. From calculations, this orientation was expected. Trimming weights were added to achieve a level system.*
- *The dump solenoids were located at the rear of the bag that was lower in the water column than the rest of the lift bag. The air inside the bag rose above the outlet and was unable to dump.*

When the crawler was brought back onboard, a full system’s check was completed in the dry environment. This system’s check with full power from the 240-V generator showed normal behavior until the “claw” check. As the claw was closing it was observed that the movement was not smooth. The jerkiness pinpointed a flaw in the electrical system, which upon further investigation determined that the crawler’s arm’s circuitry was shorted. The ground to the crawler was running as a power-pin, sending 45-V through the arm to the ship through the front claw actuator. A continuity check showed the power converter had blown and shorted due to a leak in the epoxy seal, causing the claw circuit and its actuator to short.

The buoyancy system of the crawler tested successfully both on land under electrical power and in the sea with manual inflation (power failure due to other causes). Divers used a scuba tank and a hose to fill the lift bags manually. The lift bags were filled at a constant rate to maximum pressure. As a result, the crawler surfaced without the aid of any lift system.

design should be used to obtain feedback from the environment underwater and used for automated controls such as depth or position. Multiple attachments will be made for the front arm of ROSCo to perform various tasks underwater.

The tether management system should introduce a larger housing for the extended tether length as well as introduce a guide to the rollers, allowing for better operation. One useful feature used in professional ROVs is the use of a turn counter to count the number of rotations of the ROV. This would enable to operator to rewind the turns in the tether to allow for a better spool within the TMS.

The Tomcat has much room for enhancements. Several features have been accounted for in the design, but not implemented are: pan/tilt of camera, lights, manipulator arm, and compass. Each of these components could be used to improve the overall effectiveness of the Tomcat.

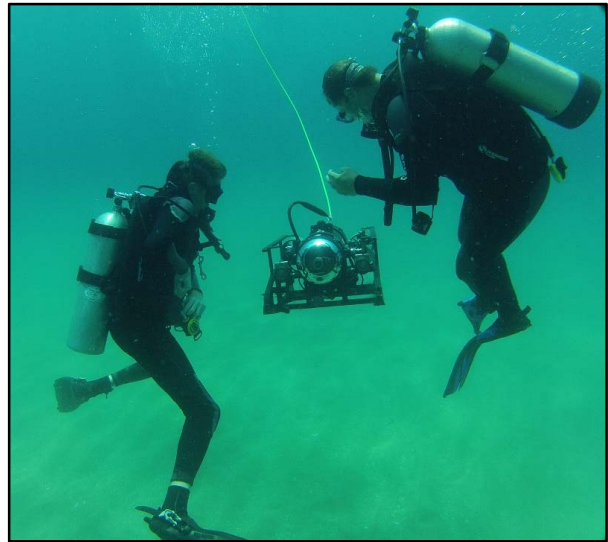


Fig. 25: Tomcat sea-trials

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