Development of Dextre

SYSTEM ACCEPTANCE REVIEW REPORT

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The McGill Robotics Mars Rover team have been working to redesign and manufacture the mechanical, electrical, software, and science systems of our new and improved rover, Dextre. The team has made incredible advancements this year and is now beginning full system testing in preparation for the upcoming University Rover Challenge.

I. Mechanical Systems

The mechanical system is divided into six sections: arm, drive, chassis, sampling and suspension and with a collective goal of improving rigidity and reducing the overall rover weight.

Figure 1. Full render of Dextre using Autodesk Inventor.

A. Arm

Dextre's robotic arm has a total of six degrees of freedom and the ability to handle any five kilogram payload. This is made possible with a 120:1 harmonic drive located at the base as well as two four-bevel gear differentials which transform two degrees of freedom into one transmission system. In order to improve dexterity and versatility, four sets of timing belts and pulleys were integrated onto the arm to evenly distribute the weight and conceal the motors. A new end effector has been designed to entail adaptive gripping with free rotating joints and the ability to conform to any irregular shape, enabling the arm to grasp tools and service switches.

B. Drive

After extensively testing past drive systems, the team is now concentrating on achieving further vibration dampening and developing greater traction. In order to address plastic deformation experienced in the previous assembly, the metal plates were replaced by box channels. This higher moment of inertia resulted in a sharp decrease in torsional and bending stresses.

The six 10.0-inch diameter wheels feature fifteen spring steel treads. By reducing the tread lengths to 6.5-inches, the wheels experience much smoother movements as a result of increased frequency and greater contact area between the treads and terrain. Moreover, each of the wheels is driven by brushless DC motors encased in custom housings and hidden within the wheel to maximize height clearance. The corner wheels are also equipped with individual steering units allowing Dextre to freely rotate with absolute position monitoring while performing Ackermann, swerve, point, AND translational steering.

C. Sampling

To further enhance the performance of Dextre's sampling system, two motors with encoders are located on the sampling rig and used to track the drill speed and depth. Due to the success of the past coring system, Dextre features a similar flange design with an improved soil capturing mechanism. With the use of high-torque brushed motors equipped to an impact driver, a hardened cutting tip, and speed and positions control loops, the auger is capable of drilling up to 20 cm. deep in compact soils.

D. Chassis

The newly designed electrical box is not only compact but also features direct access ports to the onboard electronics. By using aluminum welded tubes for the frame as opposed to steel, the final weight totalled to just 1.706 kg. To minimize loss of strength at stress-critical and welded locations, the frame was first heat treated followed by gradual cooling to prevent deformation The main camera will be secured onto two servo motors to create a simple yet effective 2-axis (pan-tilt) gimbal system and will be attached to an aluminum mast.

E. Suspension

The modular rocker-bogie system of Dextre has been designed specifically for the extreme traversal task. In the case of navigating complex terrains, the rockers work in tandem with the bar differential to minimize pitch oscillation and ensure all six wheels remain in contact with the ground.

In order to address recurring deformation and cantilever concerns, the suspension brackets and links were completely redesigned using aluminum support beams with increased width and added steel ribs. The new links not only alleviate unwanted deflection, but also enable an even faster conversion between six and four wheel drive configurations.

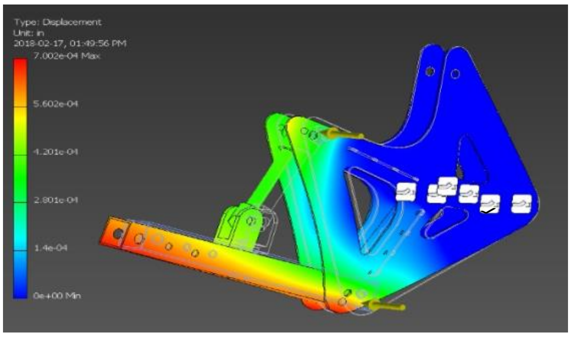


Fig 1. Extensive Finite Element Analysis conducted on the suspension brackets to optimize strength-to-weight ratio.

II. ELECTRICAL SYSTEMS

The electrical division is divided into five sections: power & controls, drive, arm, science, and communications & perception with a common goal of improving modularity, mobility and reliability.

Figure 2. Custom-made PCBs for the electrical system.

A. Power & Controls

Dextre's power subsystem consists of two 24V LiPo batteries each with a 8000mAh capacity, stepped to 19.2V, 12V, and 5V to power the motors, sensors, antenna, and computer. A current and voltage monitoring chip was added to ensure better safety, however in the case of an emergency, an easily accessible kill switch was further mounted to immediately cut the power of all active systems.

Dextre also features a single centralized power board to support fuse monitoring and an embedded microcontroller. The size of the past boards was significantly reduced by removing the large relays. Additionally, load-sharing functionalities were added to ensure uniform power draw from both batteries. Along with the added benefit of improved battery life, this feature has contributed to the development of a consistent battery charging workflow.

B. Drive

In order to accommodate the significantly downsized electrical box, the drive PCBs were moved out and distributed across four individual housings. Dextre's drive subsystem connects to the main computer through an Arduino Micro and consists of six Maxon EC90 flat brushless motors. These are slotted in four newly-designed backplanes, each capable of accommodating two brushless motor drivers coupled with a custom brushed motor driver board. The brushless motors are driven by off-the-shelf

Afro ESC 20A controllers and are easily swappable in the case of unexpected failures. Dextre's drive systems have also been fitted with encoders to report the brushed motors' absolute positions through SPI and compute the angle of the steering system.

C. *Arm*

Dextre's arm subsystem consists of seven brushed Maxon Motors of which five incorporate breaks allowing the arm to lock in any position. These are coupled with both absolute and incremental encoders to output measurements of the arm's angular position. The driver boards have been fitted with new connectors to create an effortless board swapping mechanism as well as Arduino Megas to handle the SPI communication of absolute encoders. The arm electrical system substituted the past Tiva boards with Arduino Megas to combat the unreliability previously faced with Tivas as well as to better incorporate SPI into the system. The PCBs have also been separated into two links to simplify wiring harnesses across the rover allowing each joint to perform full rotations with no impediments. To further simplify control systems, each motor is equipped with current monitoring to allow for future implementation of torque-based control loops on top of the existing position control loops.

D. *Communication & Perception*

In order to maximize the field of view while upholding the high demand of data transfer rates, the previous USB cameras were replaced with six wide-angle IP-based cameras. With the use of PoE encoders and Zipstream technology, the command station is able to stream HD videos from all six camera units simultaneously. The rover also makes use of a tilting Li-DAR to detect up to 30m with a +/- 30mm accuracy, a STORM32 stabilizing system to compile 3D maps of the surrounding environment as well as an AHRS coupled with a GPS antenna to reference global positioning. To ensure high quality streams, the rover is further equipped with a 2.4GHz omnidirectional antenna capable of transmitting up to a range of 200 meters at 400 Mbps.

E. *Science*

A new backplane was designed to work in tandem with an Arduino Mega microcontroller by routing various sensor ports and mechanical components. The backplane serves as the foundation for the science system by distributing power to the terminals and supporting the four servos used for the probe, camera, soil compartment and rock containers. Attached to the backplane are auxiliary power boards including the on rover science board (ORSB) and a brushed drive controller for sensor data conversion of motors.

III. SOFTWARE SYSTEMS

The software division consists of four primary sections: arm, autonomy, science, and command station.

A. *Arm*

Dextre's arm control pipeline has been completely redesigned to optimize efficiency and incorporate inverse kinematics. These major improvements allow for the precise manipulation and fast trajectory execution of the arm to fluidly perform panel servicing and extreme retrieval tasks. Advanced control methods such as planar and axial movement and rotation are also possible as a result of this new system. A realistic simulation environment has also been created to test the new algorithms and help train operators.

B. *Autonomy*

By utilising data generated from the LiDAR, Dextre is capable of constructing maps of the surrounding environment and further apply advanced pathfinding algorithms to avoid unplanned obstacles while travelling autonomously.

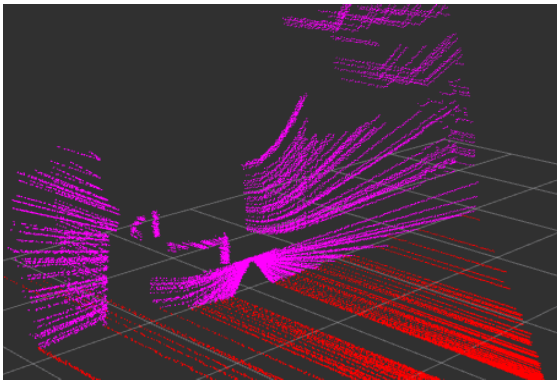


Figure 3. A generated 3D point cloud of random objects placed in front of Dextre for the autonomy task.

An AHRS attached to Dextre provides further data encompassing the precise orientation and instantaneous velocity of the rover. This information is merged with the corresponding data obtained from an optical flow camera and information from the wheel encoders to correct deviations and errors. The final algorithms have been tested using modified simulations in Gazebo and will soon be subjected to real-world environments during full integration testing.

B. Command Station

This year, the control interface has been ported from Python to C++ to enable faster camera feeds and enhance connectivity between Dextre and the command station. Moreover, to improve operation speeds, Dextre's live status (camera feeds, motor status, arm position, orientation of the GPS, sampling data) is always accessible and can be easily tailored. In addition, each button has been mapped either onto the keyboard and/or joystick to further improve convenience.

IV. Testing & Operations

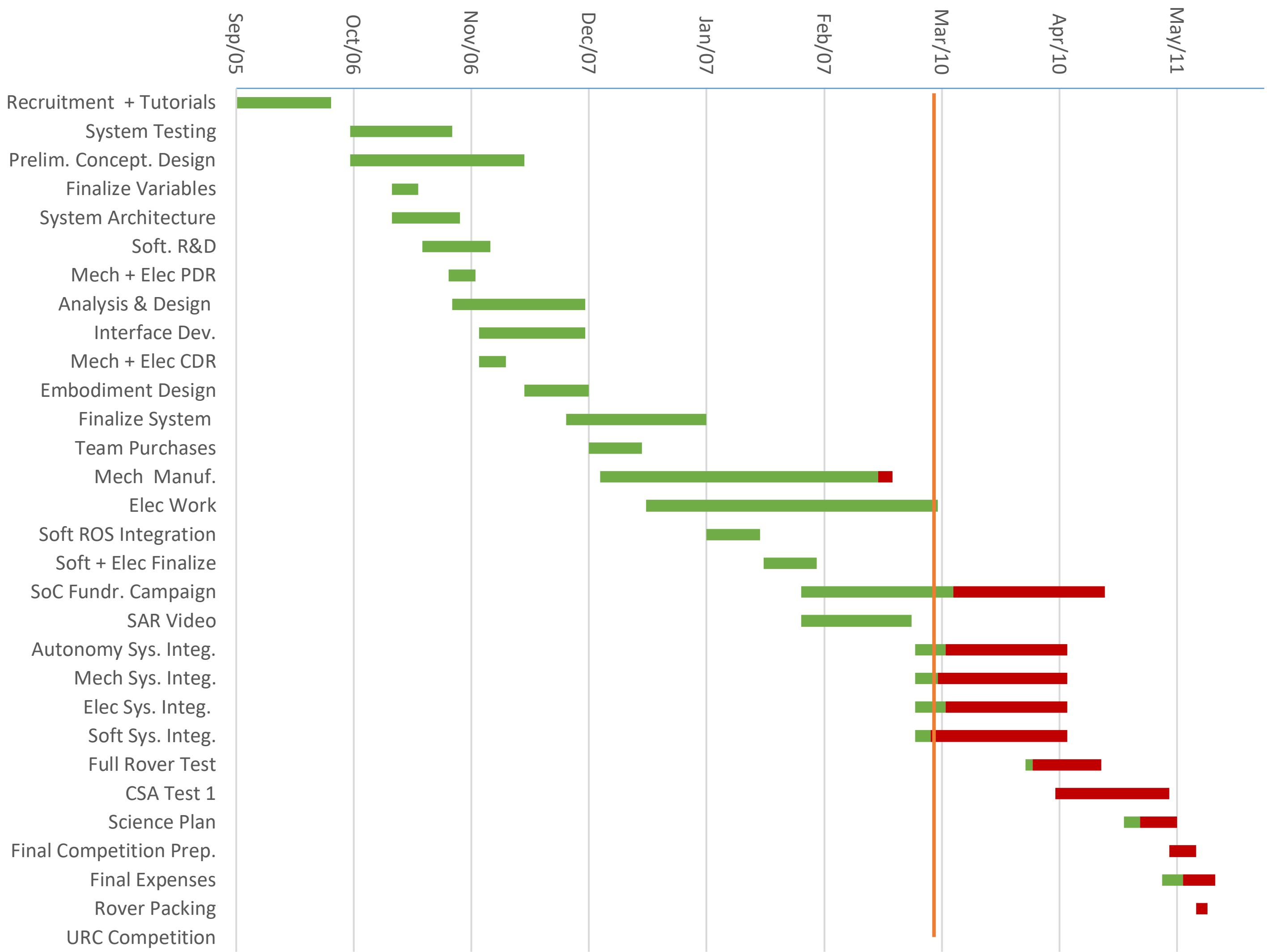
Following the new member recruitment, each division conducted component-level tests by experimenting with software algorithms, electrical boards and harnesses, and prototypes of the mechanical components. The past rover, Calliope, was subjected to extensive tests early in the year to improve systems that failed previously. In addition, the mechanical division performed stress analyses on Finite Element Analysis to simulate and design for worst-case scenarios. System-based tests are also conducted regularly to ensure the seamless integration of new designs.

The team will soon begin full integration tests on the Mars simulated terrain located at the Canadian Space Agency. In order to simulate, on new systems, tasks such as sampling and autonomous traversal, the team built service panels and gates equipped with buttons and switches. New operators will also be trained to carefully maneuver Dextre at the simulated terrain to prevent unwanted casualties.

V. Conclusion

After an upsetting performance at the 2017 University Rover Challenge, McGill Robotics has completely redesigned the past systems by pinpointing errors that resulted in system failures at competition. In order to ease communication and work efficiently, establishing an effective team structure was top priority.

By combining the knowledge and ambition of both returning and newly recruited members, along with an abundant number of sponsors, the team managed to successfully design Dextre while staying on budget and schedule. After months of hard work, the team is looking forward to competing at the upcoming 2018 University Rover Challenge in Utah!



BUDGET

Category	Total (CAD)
Sponsorships (in-kind, monetary)	$6,144.86
McGill University Funding (DTFC, EUS)	$7,282.10
Competition Expenses	-$2,037.55
Electrical Components (boards, wires)	-$2,692.73
Science Components (spectrometer, chemicals)	-$1,000.00
Mechanical Components (motors, metal, fasteners)	-$2,941.02
Expected Income (Seeds of Change campaign, sponsors)	$833.33
Expected Mechanical (additional fasteners and metal)	-$500.00
Expected Electrical (PCB)	-$400.00
Final Balance	**$4,688.99**

The McGill Robotics Mars Rover team, with the help of sponsors, fundraising campaigns, and university funding, will have the funding required to travel and compete in the 2018 University Rover Challenge.

VII. SCIENCE PLAN

The science plan aims to discover potential findings for sustainable life by gathering soil and environmental readings and conducting detailed geological and microbial tests. The retrieved soil sample will undergo a preliminary on-board analysis followed by a comprehensive bench analysis.

A. On-Board Analysis

The rover will first detect areas containing erosion through the use of custom erosion detection algorithms. Upon identifying evidence of water erosion, two images including a wide-angle panorama of the surrounding and a high-resolution close-up of the excavation site will be taken and further processed to evaluate the chemical and physical conditions required for microorganism growth. The rover will subsequently acquire a soil sample during which, GPS coordinates of the site are sent to the operator.

The rover is further equipped with a sampling system capable of drilling up to 20 cm deep. As the sampling rig rotates into the soil, the drill tip remains engaged with the core but as the drill is lifted, both the flange and twistable membrane mechanism will self-lock to hold the soil contained within the inner liner in a sealed and undisturbed core compartment. Two load cells have also been placed on the sampling rig to measure the weight, before and after, the coring procedure; the difference between the measurements provides the weight of the recovered soil sample. Simultaneously, a probe will be inserted into the excavated site to detect subsurface humidity and temperatures. In addition to using an anemometer to monitor real-time wind patterns, various probes attached on the ORSB will take environmental readings such as pressure and as well as UV, TVOCs, and CO_2 levels to help evade areas of higher UV dosage and detect potential organic impurities.

B. Bench Analysis

The biological tests will be performed by evaluating beakers filled with a 1:1 ratio of soil sample to water. The four qualitative tests to be performed include Sudan III, Ninhydrin, Benedict's reagent, and carbonate testing to evaluate fat content, presence of amino acids, reducing sugars, and calcium carbonate content, respectively. A NPK test to discover the macronutrients essential for life, along with the detection of any fats, amino acids, and carbohydrates from the aforementioned tests will indicate potential signs to support life.

The solutions used throughout the bench analysis procedure including Ninhydrin, Benedict's reagent ($CuSO_4$), 1% Sudan III stain, and hydrochloric acid (HCl) will be kept in commercial off-the-shelf packaging Due to the extreme corrosivity of HCl, the acid will be kept away from metals and stored according to its respective MSDS.

During the stratigraphy analysis, geological strata will be studied using images captured from the rover. The soil sample is first analyzed using a NIR spectrometer to determine the characteristics of minerals present. By compiling an IR spectra library of Utah soils, the science team can directly compare the results to the library and verify the compounds (OH bonds) present within the soil.

Based on the captured panoramic images, a sedimentary layer analysis including the examination of sedimentation and surface soil patterns will be performed to predict the soil properties and existence of water. The close-up images of the soil surface will allow for further detection and examination of evidence for life including: desert pavements, ripple marks, riverbeds and sulphate patches.