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A Simple Tele-Robotic Lunar Excavator

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Abstract— **An excavation tele-robotic system is developed to excavate and collect lunar regolith. The excavator has been developed by the team BRACU ChondroBot consisting students from BRAC University for NASA's 2nd Annual Lunabotics Mining Competition (LMC) 2011. Considering the requirement of NASA and calculating the load, friction and power the mechanical excavator was designed and built. The dimension of the excavator is 1.45m × .74m × 1.48m and the weight is 80 kg. It consists of two excavation arm and one pulley system depositor bucket. Two conveyer belt type wheels are used to drive the robot. Efficient control and communication is always a big challenge for a Tele-robot. In our developed system hardware can be operated both manually and remotely through a web browser by logging in from any computer without direct visual and auditory access to the hardware. A unique control circuit, graphical user interface and communication module for two terminals are also developed for remote access.**

Keywords- Lunar excavator, Tele-robot, bucket-ladder, obstacle detection.

I. INTRODUCTION

This paper describes the successful design and construction of an excavator system called Chondrobot within the design specifications as mentioned by NASA. NASA is promoting the development of mining equipments that are efficient to collect and handle regolith on lunar surface. With this objective and also to promote the interest in space activities and Science, Technology, Mathematics, and Engineering (STEM) fields, NASA has been arranging the yearly Lunabotics Mining competition since 2010 where students from any levels from all over the world can take part to design and implement an excavator system for its use.

This paper discusses the technical specifications and development process of the excavator called ChondroBot. First, 3D Computer Aided Design (CAD) of the planned lunar excavator and a demo paper model is developed. Different components of the system are designed and developed module by module and then integrated into one whole system. The excavator system designed is very cheap as its mechanical part is constructed fully using locally available recycled materials.

The rest of the paper has been organized in the following manner: Section II gives a brief description of device structure and operation including system specifications as outlined by NASA; Section III describes the overall system architecture, identifies the key system components followed by a detailed description of each of the system components, their design, function and interfacing among them; Section IV describes the testing of system, and validation and verification of the different system requirements carried out at different times during the development and implementation phases of this work; Section V concludes the findings of this work.

II. SYSTEM DESCRIPTION

A. Basic Structure

Figure-1(a) shows the 3D model and 1(b) shows the photograph of the excavation system constructed at BRAC University. It consists of two excavator arms made by bucket-ladder system where a pair of chains circulates around a rigid frame. To maximize the collection, closely spaced custom shaped aluminum digger scoops are mounted directly on the chains. The excavated regolith is collected in a bigger bucket (collection bucket) placed at the other end of the excavator arm. The collection bucket is connected to a motor to pull the bucket up and dispose the collected soil into the collection zone. The excavator arms and the bucket are supported by a frame made from hollow steel tubes welded together.

The excavation hardware is about 1.50m high, 0.75m wide and 1.50m long, and weighs about 80 kg. To ensure that the excavation hardware is usable for an actual lunar mission, it does not employ any physical processes (e.g. suction or water cooling), gases, fluids or consumables that would not work in the lunar environment.

B. Operation

The excavation hardware can be operated remotely without direct visual and auditory access to the hardware. Data and video originating from the excavator during mining can be used to operate it. An on-board computer is used to send the various command and control signals through a micro-controller to the motors and other sensor circuits of the excavator. The on-board computer can be

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accessed and run through a web browser by logging in remotely from any computer. Thus this tele-robotic vehicle can be operated remotely from anywhere in the world. Wi-Fi wireless communication has been used to communicate with the excavator.

Once in the mining zone, upon receiving the appropriate signal, the excavator arms will start rolling, pushing the digger buckets through the lunar regolith, which in turn will collect the regolith, roll all the way up the excavator arm and, while going down, pour the collected regolith into a large custom-made bucket placed beside the excavator arms. After the collection of required amount of regolith, the excavator will move back to the deposition area where it will deposit the collected regolith into a collection bin. The large bucket containing the regolith will be lifted up by two motors attached with the bucket through strings in a pulley system copikol. The figure-2 shows a full cycle of the operations of the excavation hardware.

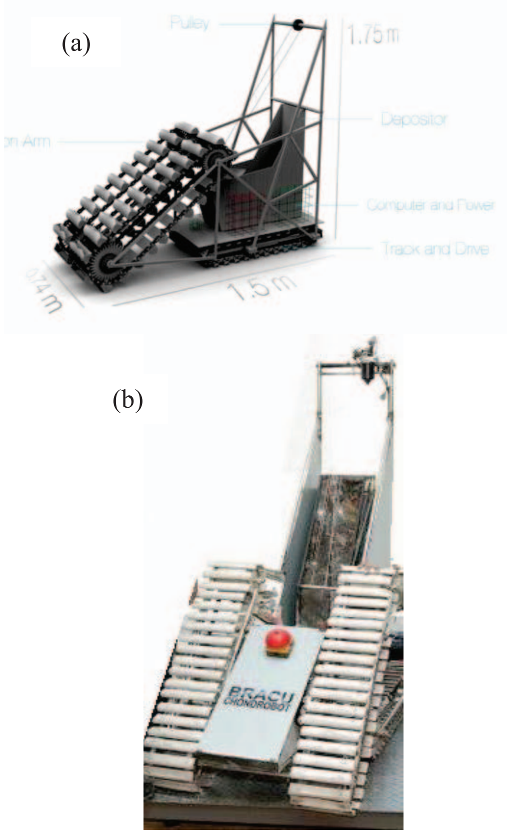

Figure 1: (a) The 3D and (b) the actual ChondroBot lunar excavator

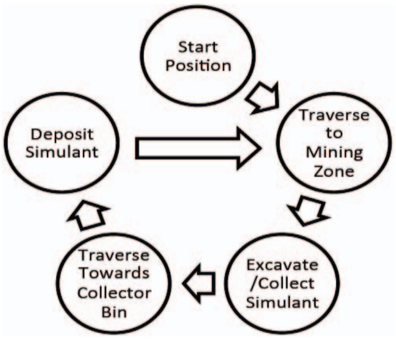

Figure 2: Operation Cycle of ChondroBot

III. SYSTEM ARCHITECTURE

The overall hierarchy of the excavator can be given by the figure-3, where we see that the communication and controls subsystems are separate. This is due to the design of the system where the communication relays the operator commands to the controls subsystem.

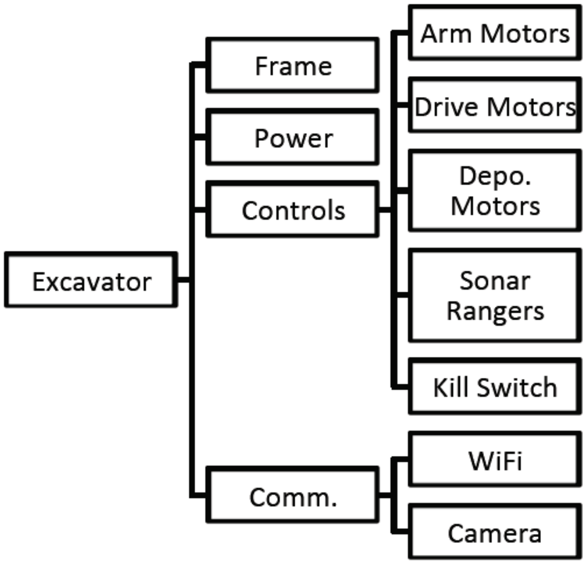

Figure 3: Overall system architecture hierarchy

A. *Interfaces*

The interfacings were determined while designing the system. Each subsystem is interfaced with one or more subsystems. The nature of interfaces are a combination of mechanical, mechatronic or electrical. The table-1 describes different types of interfaces of major components.

B. *Key Components*

The ChondroBot excavator system has been divided into several subsystems that have been built individually. The following are the key components of the excavation hardware:

1. Structural Frame or Skeleton
2. Drive Subsystem
3. Excavating Arms Subsystem
4. Depositor Subsystem

5. Controls Subsystem
6. Communications Subsystem
7. Power Supply

Each of the subsystems is comprised of several electrical, electronic and mechanical components. The details of each of the key components have been described separately in the following sections. Each of the subsystems is interfaced with one or more other subsystems. The nature of interfaces among different subsystems is shown in Table 1.

Table 1: The interfaces of the system

Type	Interface	Solution
Mechanical to Mechanical	Frame to Drive	Adjustable Post with Bolts
	Frame to Excavation Arms	Adjustable Post with Bolts
	Frame to Depositor Bucket	Hinges
Mechanical to Mechatronic	Drive to Motors	Timing Belts
	Frame to Motors	Bolts and Screws
	Excavation Arms to Motors	Timing Belts
	Depositor to Motors	Strings and Pulleys
Electrical to Electrical	Command Center to Excavator	Wireless Access Point
	Network to Controls	On-board Computer
	Batteries to Relay	Emergency Stop Button
	Camera to Command Center	On-board Computer

1) *Structure and Frame*

Steel pipes or hollow tubes have been used to construct the skeleton, or the frame of the excavator. The pipes used have a diameter of 20mm and thickness of 1.2mm. The frame is welded together in places where no adjustments are required. In rest of the places, bolts were used so that the frame is adjustable in different conditions which makes it possible to dismantle the excavator for the purpose of transportation. The cross-section of the pipes at the base was transformed to oval shape for making the joints more rigid. Extra frame tubes were put in the frame after initial testing revealed that the welded joints could come off when there is heavy stress. Several tests were done to check the rigidity and strength of the frame. The frame has been tested to carry weight up to 120 Kg without difficulty.

Figure 4: Frame and drive subsystems

2) *Drive Subsystem*

The drive system is comprised of several large and small sized components, which will enable the excavator to traverse through the terrain. The drive subsystem contains the following key components.

a) Track: The track is made with standard bicycle chain and aluminum pipe. Two chains were riveted on two ends of a pipe sliced together. This ensured that the inside of the halved-pipes provide a grip to the ground. There had been several trials before perfecting this chain system. Previous designs were not stable, as gears welded were not properly aligned with the frame and sprockets.

b) Wheels: The steel wheel sprockets initially installed were not properly aligned with the chain for which the chains were falling off the sprockets. Lightweight nylon wheels with a groove wide enough to hold the chain were used. The wheels were made from a cylindrical block of nylon shaped with lathe machine.

c) Drive Sprockets: Gears have been welded to the drive sprockets of the drive subsystem. The motors are connected to the gear with a strong timing belt. The sprockets are connected to a steel pipe with bearing, which interfaces with the frame using bolts.

d) Motors: All the motors used in the excavator are of same type. They are high-torque, low RPM motor system used for automobile windscreen wipers. The motors run in 12 volts. It takes 2A–8A of current to operate in different conditions.

3) *Excavation Arms Subsystem*

This subsystem consists of two excavation arms independent of each other. Primarily, we considered using a

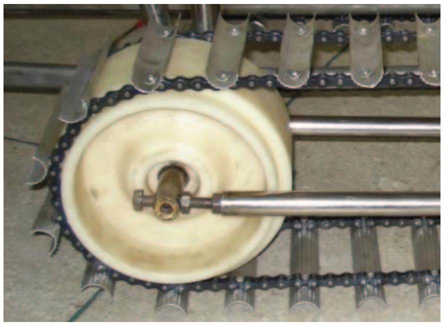

Figure 5: Section of the drive's track

Figure 6: Motor connected to sprockets with timing belt

Figure 7: Excavator Arm

large digger arm. However, it caused the excavator to bump and the design was modified. The excavation system uses a track similar to the drive system. Instead of the sliced pipes used in the drive system, custom shaped aluminum digger buckets have been used in this system. There are 52 buckets in each arm with a total of 104 buckets on the excavator.

4) depositor subsystem

The depositor subsystem is responsible for storing the collected simulant and to deposit them to the collector bin when it reaches the deposit zone. This subsystem is comprised of a large custom--made bucket of stainless steel sheet, two high-torque motors, and a pulley system. The bucket is supported by a frame made from hollow steel tubes, which have been welded together.

Figure 8 illustrates the transformation of the aluminum plate to create the small buckets.

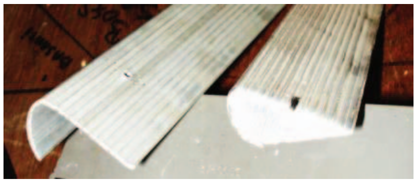

Figure 8: The bent sheet of aluminum (*left*) has been folded to make the bucket (*right*)

Figure 9: The whole depositor subsystem

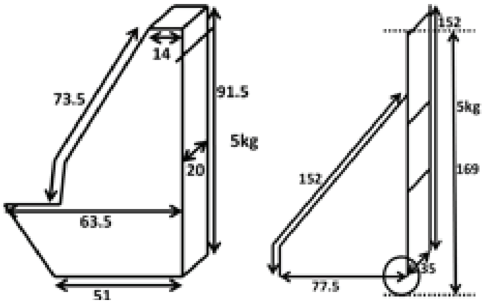

Figure 10: Physical dimensions of depositor subsystem

The shape of the bucket is made in such a way that it can easily go between the excavation arms and rotate approximately 100 degrees upwards to release the collected simulant. The shape also ensures that the height of the excavation hardware does not go over 2 meters when the bucket is lifted upwards. The system uses pulley system with two motors, which could lift up to 15 kg of mass. The initial design used a bearing as a hinge. But later a custom hinge was made, by inserting a smaller tube through a larger one. This eliminated the alignment problem caused by the welded bearing. The string used to pull the bucket is the same one that is used in Motorcycle brakes.

5) Controls Subsystem

The control subsystem is the brain of the excavator, which commands all sensor and actuator components on board. It is the most important and sensitive part of the excavation hardware. The initial plan was to have a common system for controls and communication, where the microcontroller directly communicates with the Wi-Fi router. However, due to unavailability of many components, the components were separated. An onboard computer relays the commands from the Mission Control Room to the microcontroller (PIC16F877A) via serial port. The on-board computer used in the system is a laptop computer with its displays and other unnecessary components removed.

The code is written for the excavator works in two parts. The lowest level in the control system is the microcontroller. The microcontroller program, written in C, runs a cycle and reads one byte of data from the on-board computer's serial buffer. The on-board computer runs an apache server that executes PHP commands. A 3rd party module of PHP allows the operator to read and write from the computer's serial port.

The front end of the program has been written in PHP and JavaScript. This program is run through a web browser, which is accessed through remote login from the Mission Control Room computer. The main reason behind using this is to explore the possibilities of remotely operating the tele-robotic vehicle from anywhere in the world.

The microcontroller sends command to a motor driver circuit, which relays the digital signal to the motors. For reducing the complexity, two motors (one of drive system and the other of the excavation arm) of the same side are connected with the same relay. This means that both the tracks are synchronized and contribute towards the translational and rotational motion of the excavator. Fig. 10 shows the schematic diagram to drive the motor in forward and reverse direction controlled by micro controller using two relay. Instead of one motor two motors are used in parallel connection.

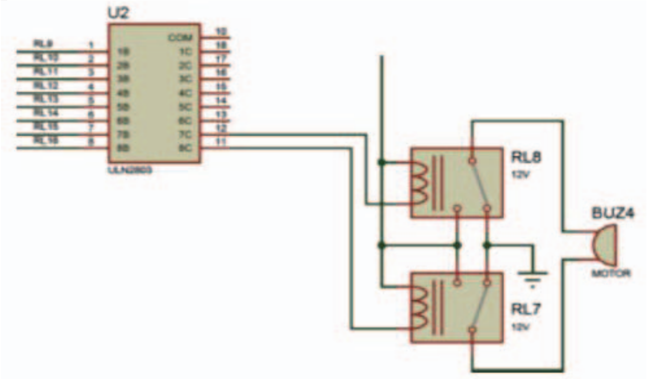

Figure 10: The motor driver circuit connected with a motor

6) *Communications Subsystem*

According to the official rules of Lunabotics mining competition, Wi-Fi wireless communication has been used to communicate with the excavator from the Mission Control Room. The laptop, which works as the Mission Control Room, connects to the excavator via a Wireless Access Point (WAP) or Wi-Fi router. The wired interface of the router extends to the laptop's Ethernet card. The excavator's on-board computer, on the other hand, connects to the router wirelessly via its Wi-Fi network card. The Mission Control Room is then able to login to the Operating System in the on-board computer remotely. This is how the excavator operator can get the full control of the computer in the excavator and operate through it. The webcam attached through the computer displays the video in the on-board computer, which can be viewed by the remote operator at a frame rate of about 10 frames per second (fps).

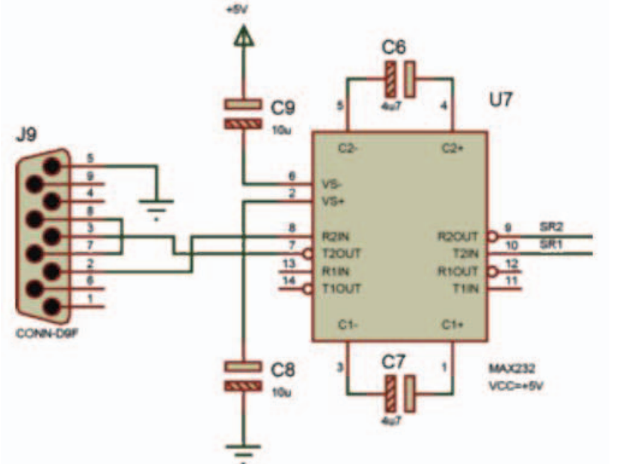

Figure 11: The serial communication interface

This method of communication ensures a reliable connection. It also enables us to use any computer as the Mission Control Room. Fig. 11 shows the interfacing between computer and micro controller. Serial port of computer is used for communication and MAX232 used for interfacing. The MAX232 IC is used to convert the TTL/CMOS logic levels to RS232 logic levels during serial communication of microcontrollers with PC. The controller operates at TTL logic level (0-5V) whereas the serial communication in PC works on RS232 standards (-25 V to + 25V). This makes it difficult to establish a direct link between them to communicate with each other.

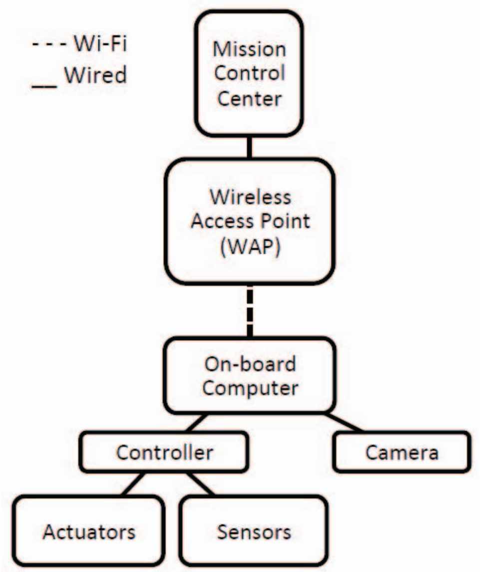

Figure 12: Communication system hierarchy.

7) *Power Subsystem*

The major consumers of power are the six motors requiring 3A–4A current each on average. At full load, they consume about 5A of current. A single lead acid battery which can provide 18A of current for an hour is used as a source of power in the current design. The emergency stop button or the "kill switch" is to be connected to the batteries via a relay. The "kill switch" is designed to manually turn off the power instantly under emergency situation.

IV. TESTING, VALIDATION AND VERIFICATION

During the design implementation process each subsystem has been verified multiple times to make sure the implemented design is correct and the developed system will meet all the requirements defined for the system. Dimensions and weights of the different components have been noted down during the development process so that the total system does not exceed the maximum allowable weight or dimension. Among other requirements that have been verified after the integration of the total system includes:

- the control circuit is equipped with the emergency stop button so that all the power can be turned off instantly;
- the communication method follows the standard specified by the competition's rule;
- the system does not employ any physical process those are not applicable in lunar like environment. For validating the system a lunar like environment was made using the sand which has some property similar to BP-1[4]. The environment was equipped with obstacle and craters to test if the robot can pass them. The wireless access point was established to test the communication procedure. After testing the whole system, it was concluded that:
- Conveyer type wheel need more power especially on turning, so there is a tradeoff between Speed and power.
- communication requires bandwidth approximately 3Mbps but it would be better if less bandwidth could be used;
- the excavator arm is capable of collecting 8kg of regolith in one minute; and
- the system is capable of completing the full cycle (from starting zone to collecting and then depositing) in 5 minutes.

V. *PERFORMANCE EVALUATION*

Mechanical, control and communication worked successfully in Chondrobot. In plain surface it could run with 120 kg extra payload in 5kmph speed and could operate in every direction perfectly including U turn. In BP-1[4] simulate it runs with 3kmph without any extra load. In this environment it can take only 20 degree turning. With a single lead acid battery chondrobot can operate for one hour in plain surface and 38 minutes in BP-1[4] simulate. Communication requires bandwidth approximately 3Mbps, the excavator arm is capable of collecting 8kg of regolith in one minute and the system is capable of completing the full cycle in 5 minutes.

VI. *CONCLUSION*

This specific robot named Chondrobot attended in NASA Lunabotics Mining Competition(LMC) 201**1**. It was verified in real lunar simulate environment. Before going to lunarena it passed the NASA's specification [3]. It experimented twice in the BP-1[4] simulate. It could work properly in forward and backward movement. Communication also worked perfectly. It could collect a significant amount of regolith. There are a lot of scopes to improve this excavator. Wheel is the main challenge of this environment. So, more experiment is needed in wheel design. The size and shape of depositor bucket can be modified. We used pulley system for deposit bucket but linear actuater can also be considered for this kind of operation. There are also some scopes to improve dust tolerance system.

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