The ARTEMIS Project

Lunar Regolith Excavator Student Competition

ME Team #8 / ECE Team #1

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Lunabotics Mining Competition

- Designed to engage and retain students in STEM disciplines
- Provide a competitive environment in which may result innovative ideas and solutions that could be applied to actual lunar excavation

Max Weight	80 kg
Max Power Supply	40 V
Max Current	15 A
Min Excavation Material	150 kg
Max width/length	1.3 m
Max height	2.4 m
Max setup time	10 minutes
Operation time	30 minutes

Table 1. Competition Specifications

Figure 1. Artist's rendering of lunar excavation, taken from Lunabotics Mining Competition announcement

Needs Analysis Flow Diagram

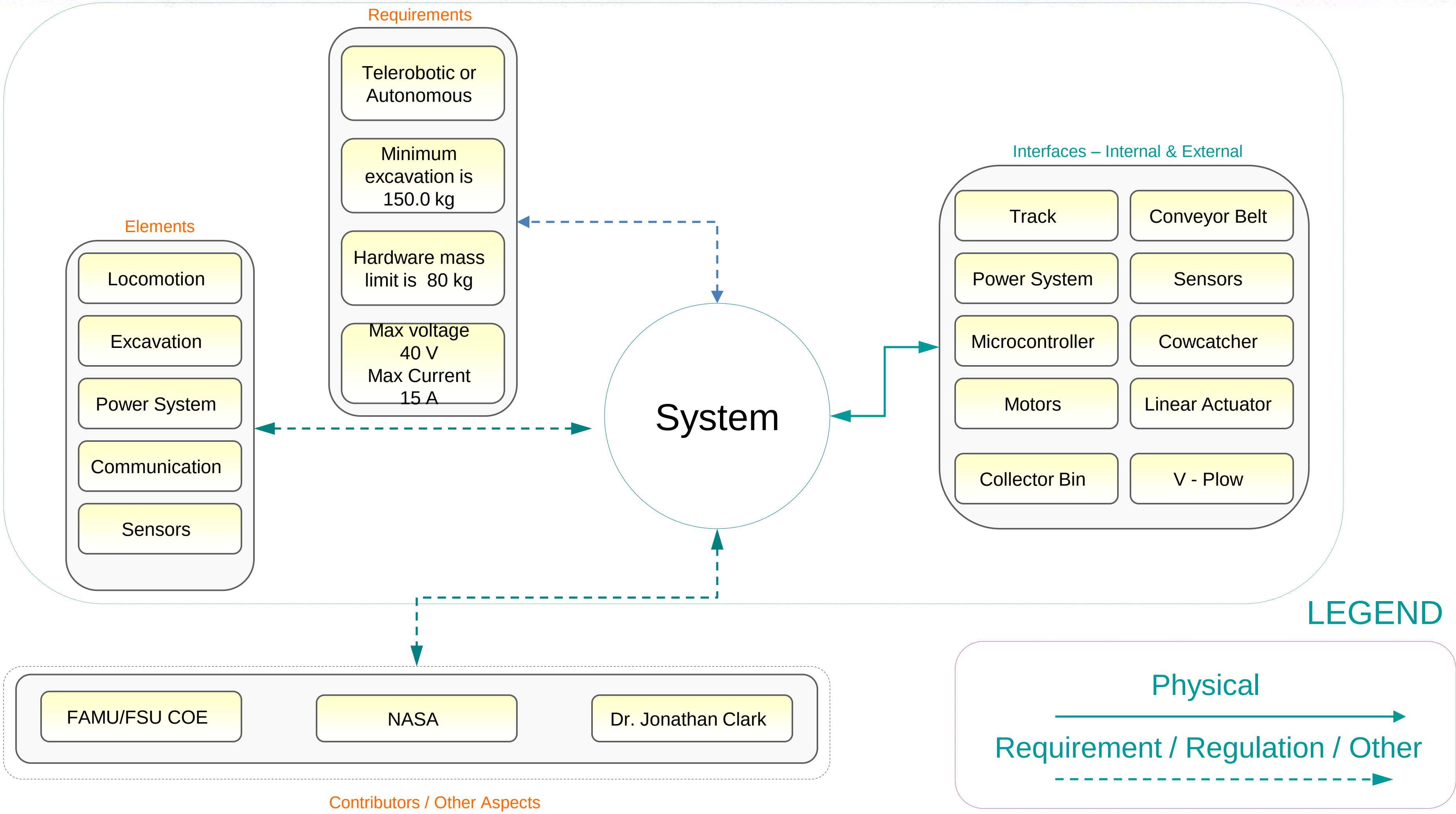


Figure 2. Needs analysis flow diagram for ARTEMIS Project

Robotic Platform Design

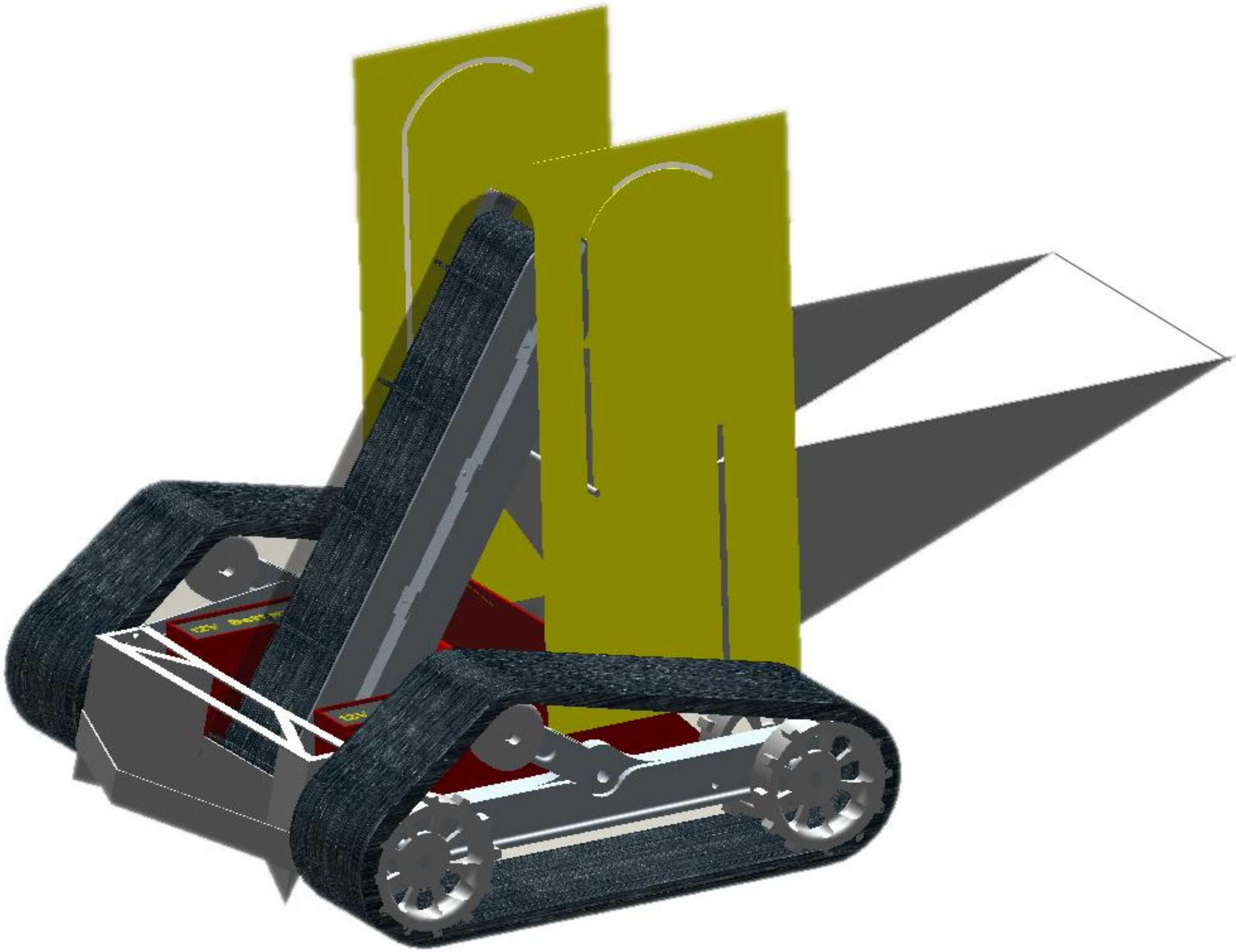


Figure 3. Robot design schematic

Circuit Block Diagram

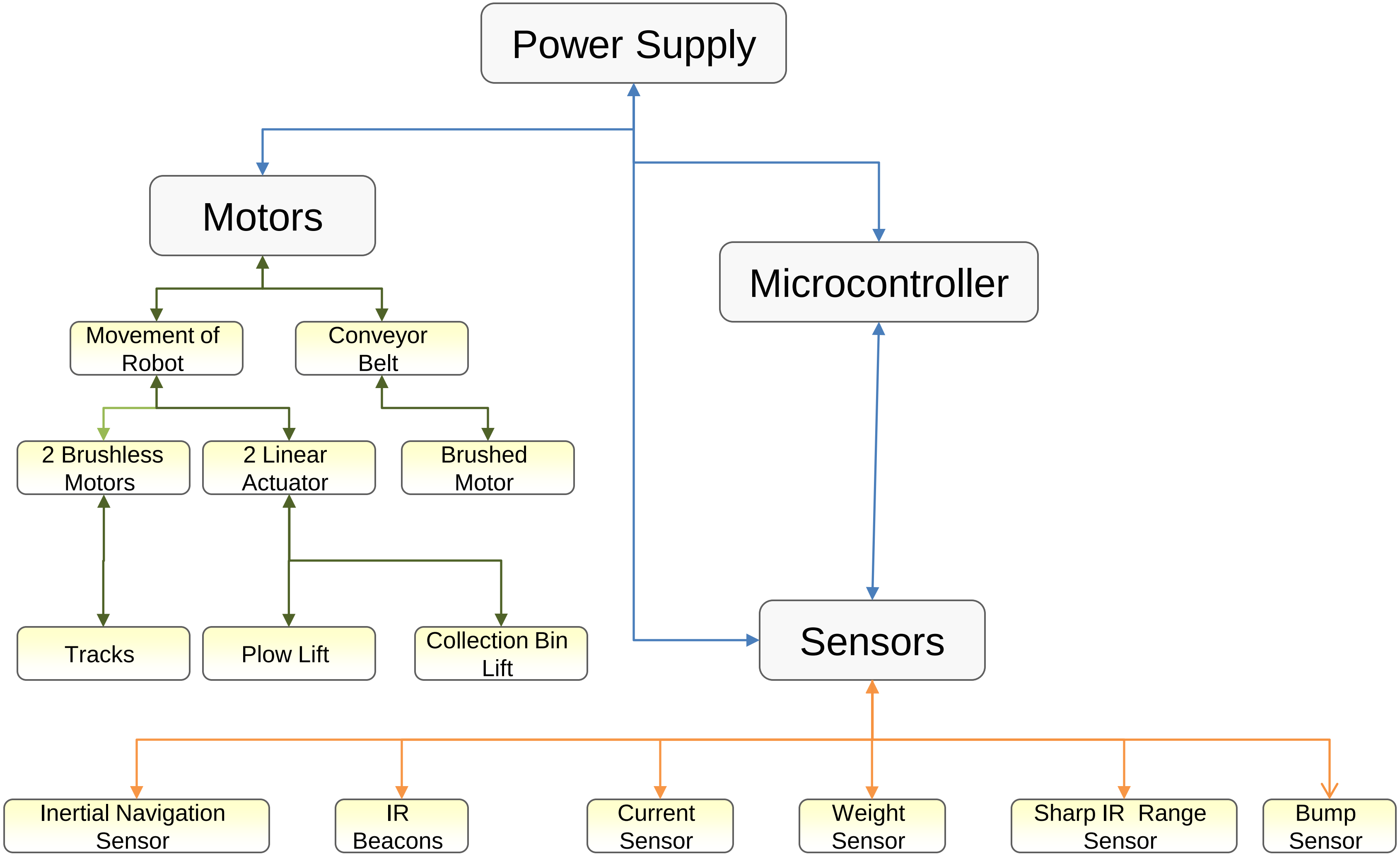


Figure 4. Circuit block diagram

System Breakdown

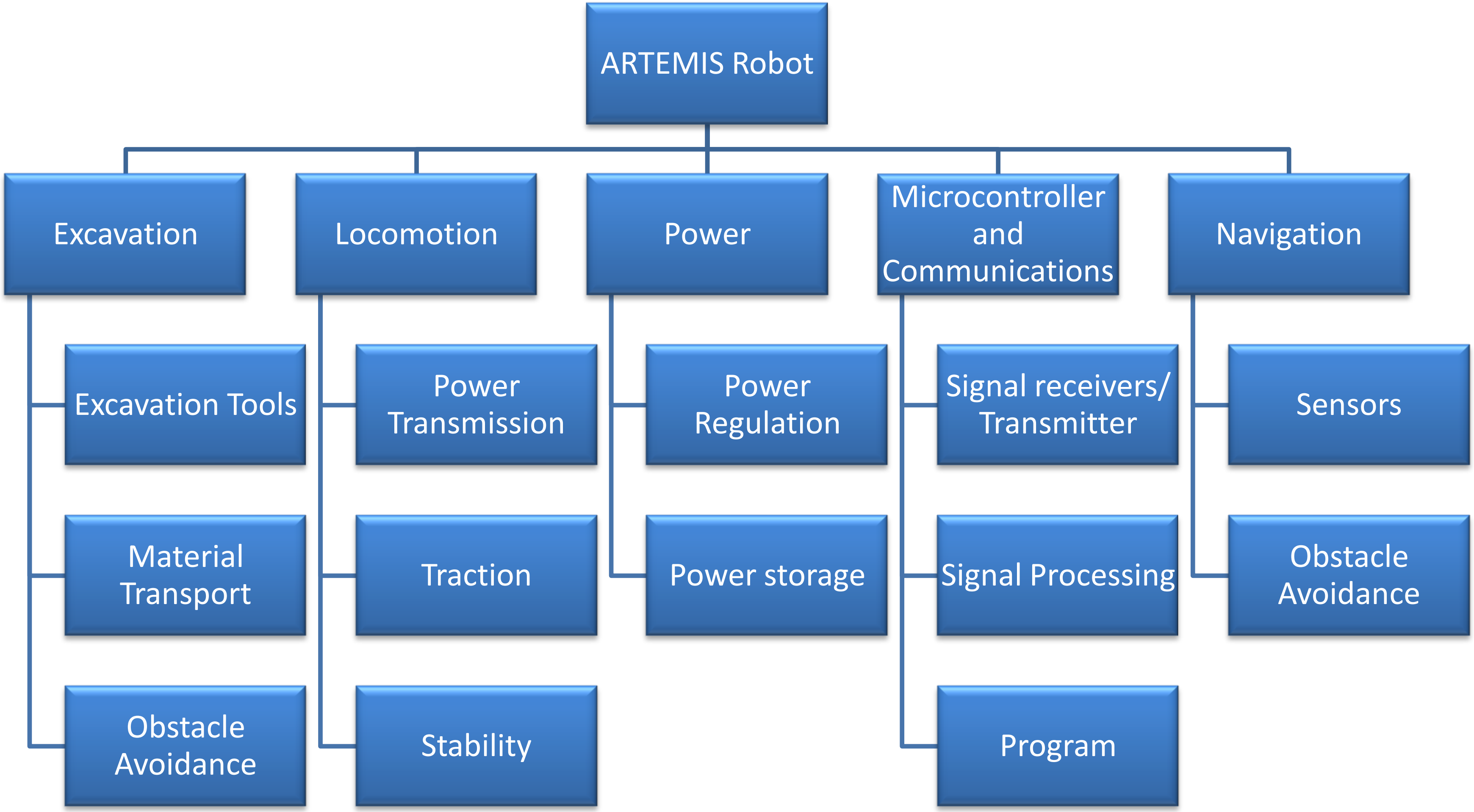


Figure 5. System breakdown structure

Concept Generation

- An initial design, overall design idea was proposed, then brainstorming for each subsystem
- Assigned specific qualities desired for final platform, then evaluated

Excavation

Locomotion

Power

Sensors

Communications
- Zigbee
- Bluetooth
- WiFi

Figure 6. Top 3 concepts for each subsystem

Concept Selection

		Concepts											
		Tracks		4 Wheels		6 Wheels		C-Legs		iSprawl Legs		Worm	
Specifications	Importance Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Traction	20.00%	5	1	2	0.4	3	0.6	0	0	1	0.2	4	0.8
Stability	10.00%	5	0.5	3	0.3	4	0.4	1	0.1	2	0.2	0	0
Maneuverability	15.00%	4	0.6	3	0.45	2	0.3	1	0.15	5	0.75	0	0
Speed	15.00%	2	0.3	4	0.6	3	0.45	1	0.15	5	0.75	0	0
Power	10.00%	5	0.5	3	0.3	4	0.4	2	0.2	1	0.1	0	0
Cost	10.00%	3	0.3	5	0.5	4	0.4	2	0.2	1	0.1	0	0
Simplicity	10.00%	2	0.2	5	0.5	4	0.4	3	0.3	1	0.1	0	0
Low Maitenance	5.00%	2	0.1	4	0.2	3	0.15	5	0.25	1	0.05	0	0
Dust Resistance	5.00%	2	0.1	4	0.2	3	0.15	5	0.25	1	0.05	0	0
	Score		3.6		3.45		3.25		1.6		2.3		0.8
	Selection	1st		2nd		3rd		-		-		-	

Table 2. Example Concept Selection Matrix for the Locomotion Subsystem

Note: House of Quality primarily used for weighting, comparison, and selection

System Overview

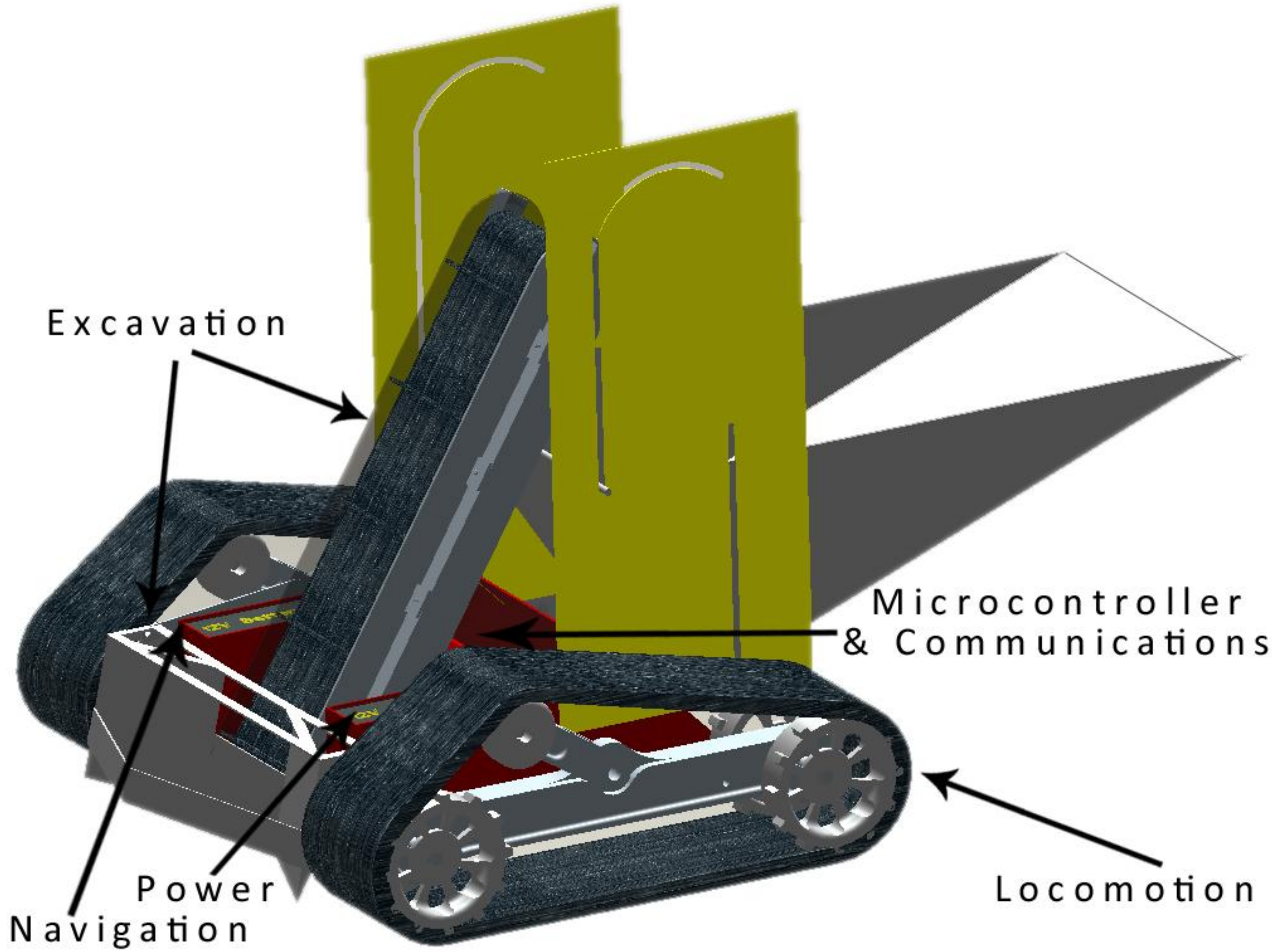


Figure 7. Overall platform design with subsystems

Excavation Subsystem Design

- Excavation Subsystem Components:
  1. Plow – piles regolith onto conveyor belt
  2. Conveyor Belt – transports regolith for deposit in bucket
  3. Bucket – holds regolith until delivery to holding bin

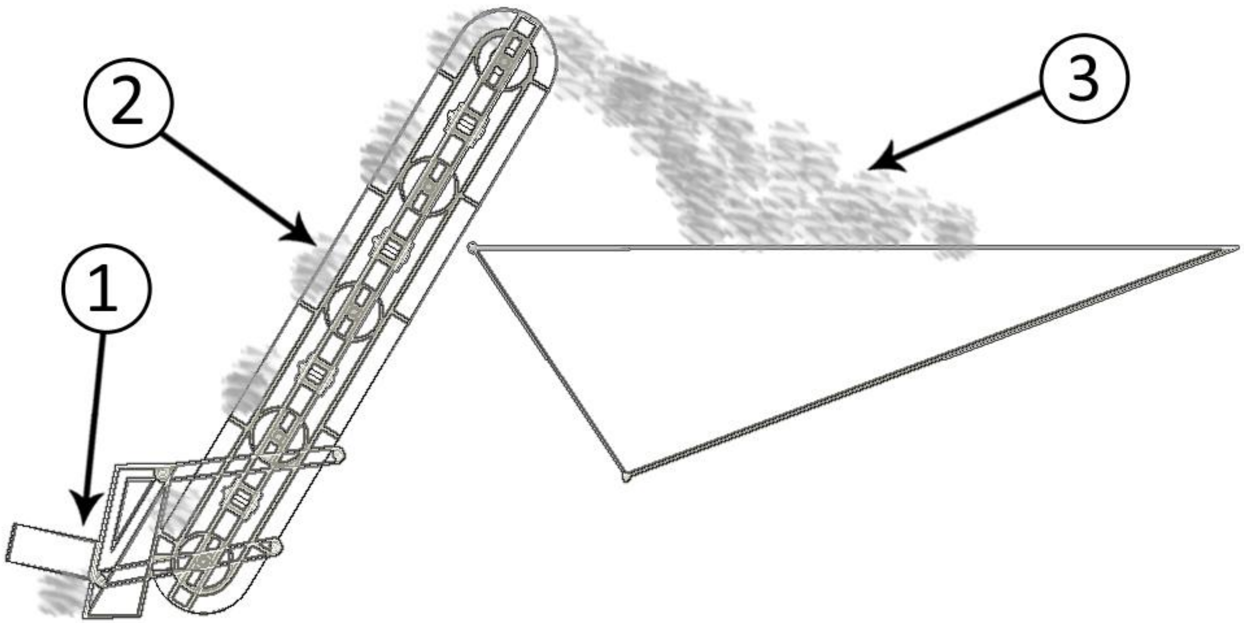


Figure 8. Excavation subsystem components and flow of regolith

Plow

- Integrated regolith channeling and rock deflection
- Coupled to conveyor for maximum efficiency
- Linearly actuated engagement
- Constrained angle using parallel 4-bar

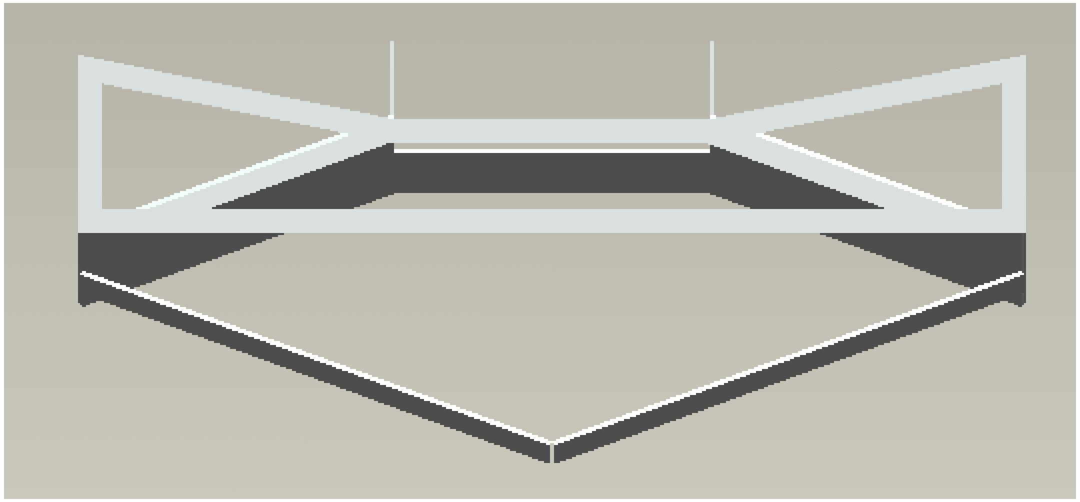
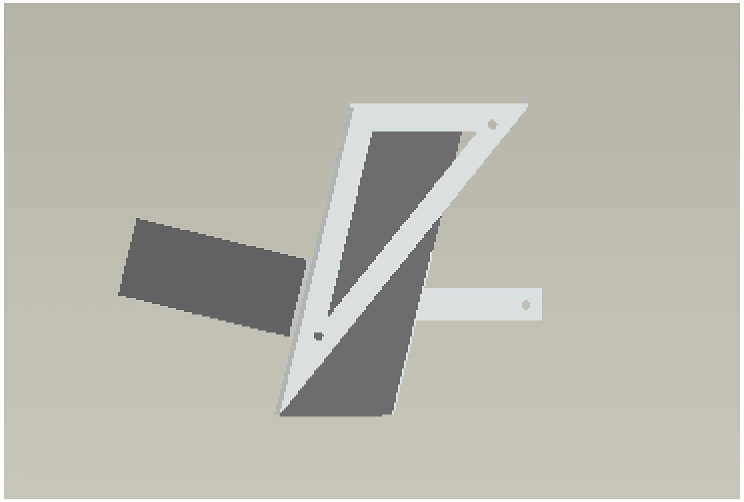


Figure 10. Top view of plow design



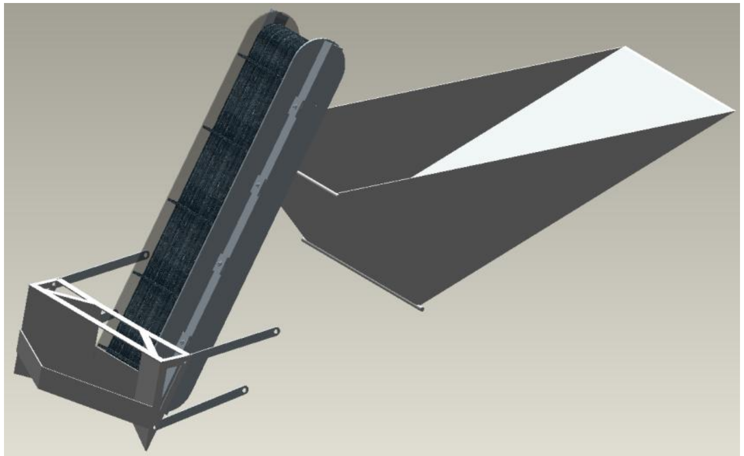
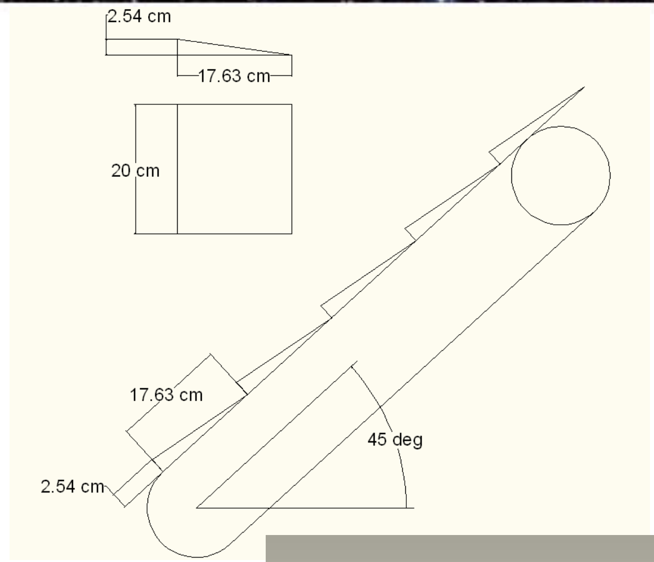


Figure 9. Side view of plow (top) and integration of plow (bottom)

Paddle Belt Conveyor

- Design Analysis
  - Assumptions and Constants
    - Inclination angle of 45 degrees
    - Uniform load distribution
    - Belt velocity of 1 m/s
    - Maximum regolith density of 1.91 g/cm^3
    - Each scoop excavates a volume of 448 cm^3
    - Belt coefficient of friction of 0.3
    - Bearing coefficient of friction of 0.0015
  - Results
    - Angular velocity of 26.2 rad/s
    - Angular acceleration of 13.1 rad /s^2
    - Max load of 4.28 kg
    - Required motor torque of 1.59 N*m
    - Total mass of 8.4 kg
    - Total mass of conveyor and load of 12.68 kg



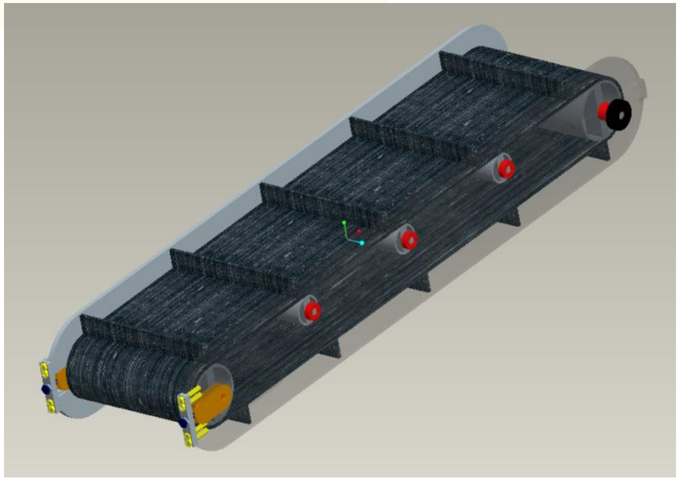


Figure 11. Design drawing of conveyor belt and isometric view of final design

Paddle Belt Conveyor

- Tensioning Mechanism
  - One mechanism per side
    - One DOF prismatic joint
    - Integrated bearing housing
    - Single bolt adjustment
      - Clockwise rotation
        - » Increase belt tension
      - Counter-clockwise rotation
        - » Decrease belt tension

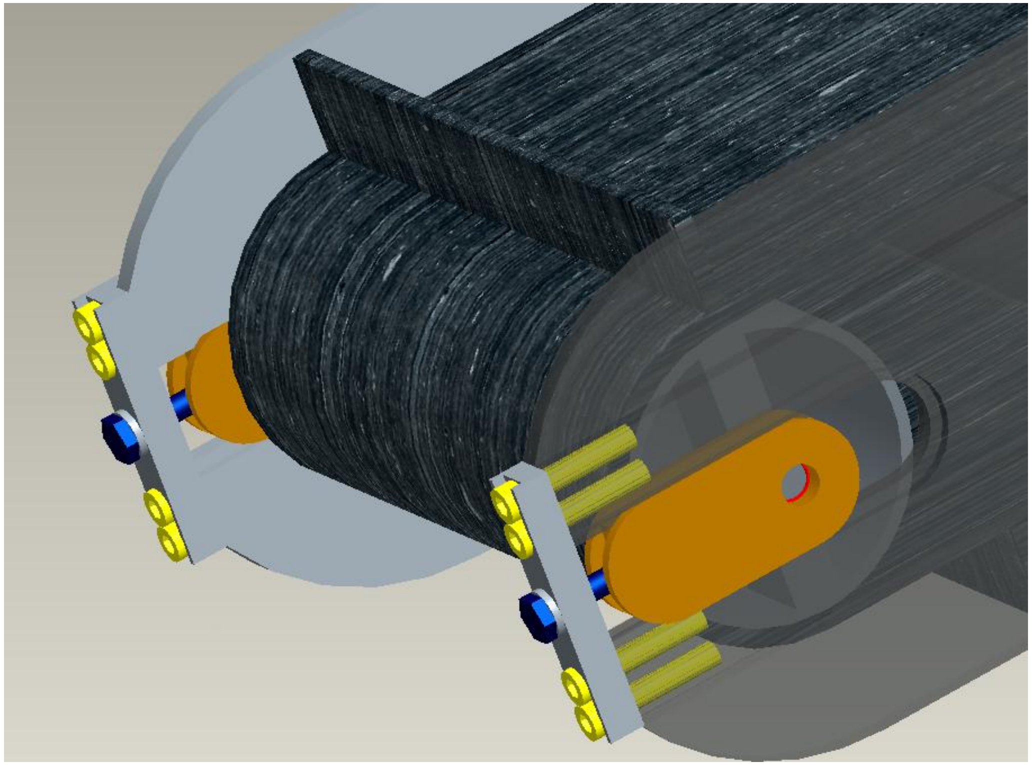


Figure 12. Tensioning mechanism on conveyor belt

Regolith Retaining Bin

- Density of Regolith – 1.5 g/cm^3
- Desired capacity – 100 kg
- Required Volume – 0.066 m^3
- Our Bucket
  - Capacity Volume 0.075 m^3
  - Height 0.3 m
  - Length 1.0 m
  - Width 0.5 m
  - Material Al 6061
  - Weight 9 kgs

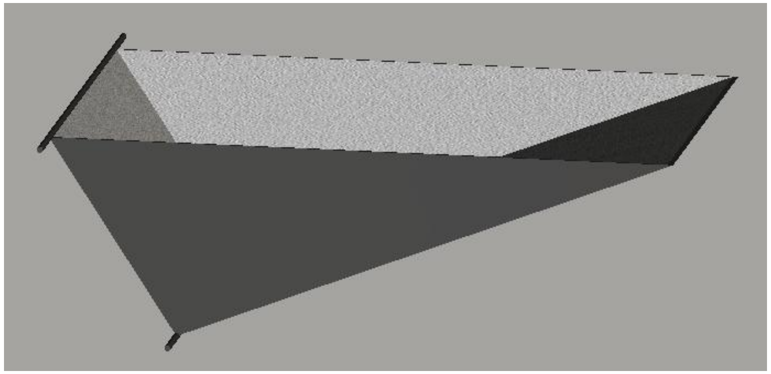


Figure 13. Isometric view of bucket design

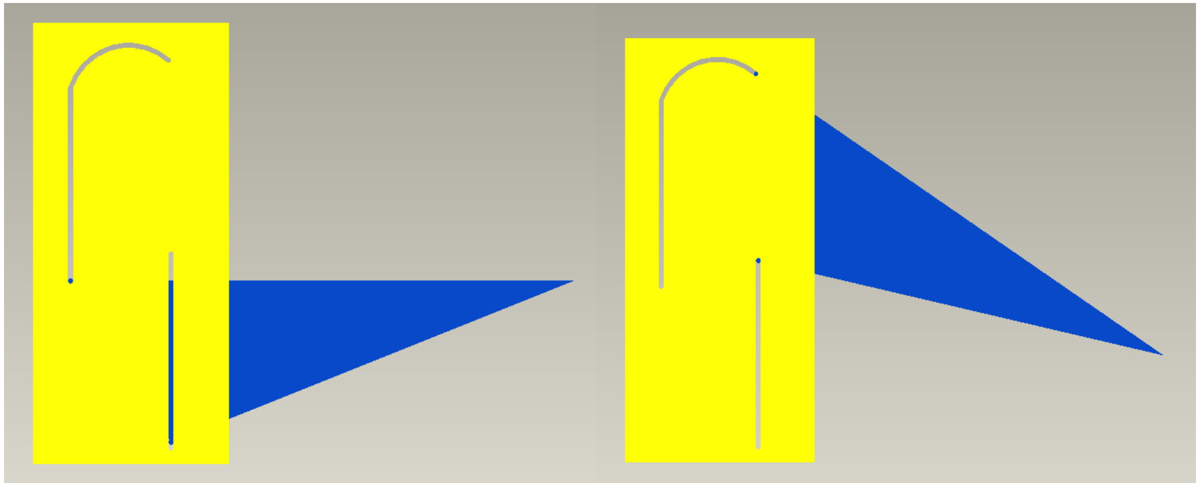


Figure 14. Example of bucket dumping from side view

Locomotion Subsystem Design

- Center Frame with torsion arm for tension
  - k=150 (Nm/deg)
- Motor housed in main body with drive shaft to rear sprockets
- Total mass of each track ~12 kg with tread

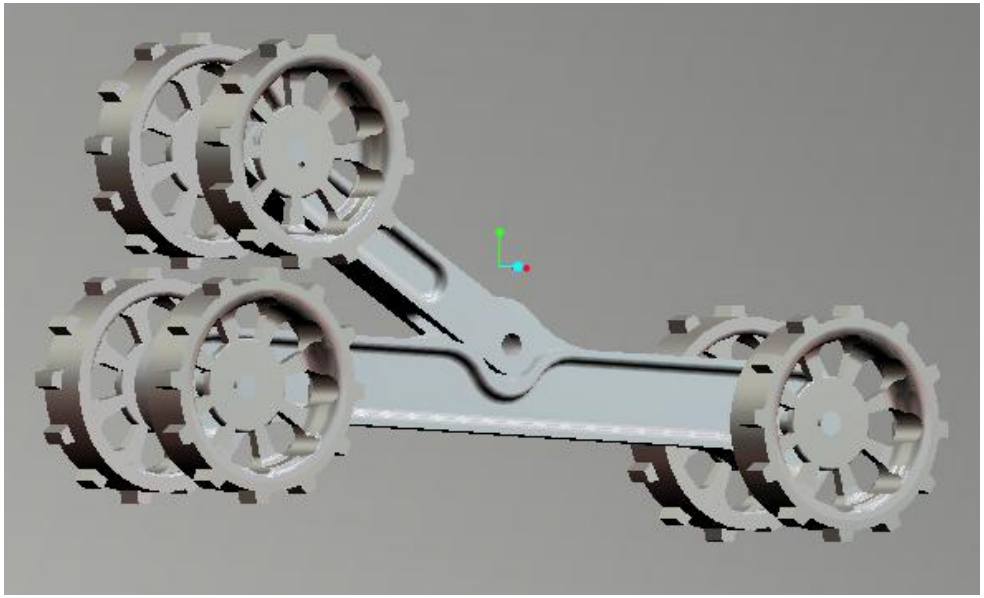


Figure 15. Isometric view of track frame

Locomotion Subsystem Design

- Chain Assembly
  - Variation of a bike chain
  - 15 cm tread surface at center
  - Individually adjustable connector links
  - Pin Joint allows large circular deformations

Figure 16. Isometric view of driving sprocket with example of treads

Power Subsystem Design

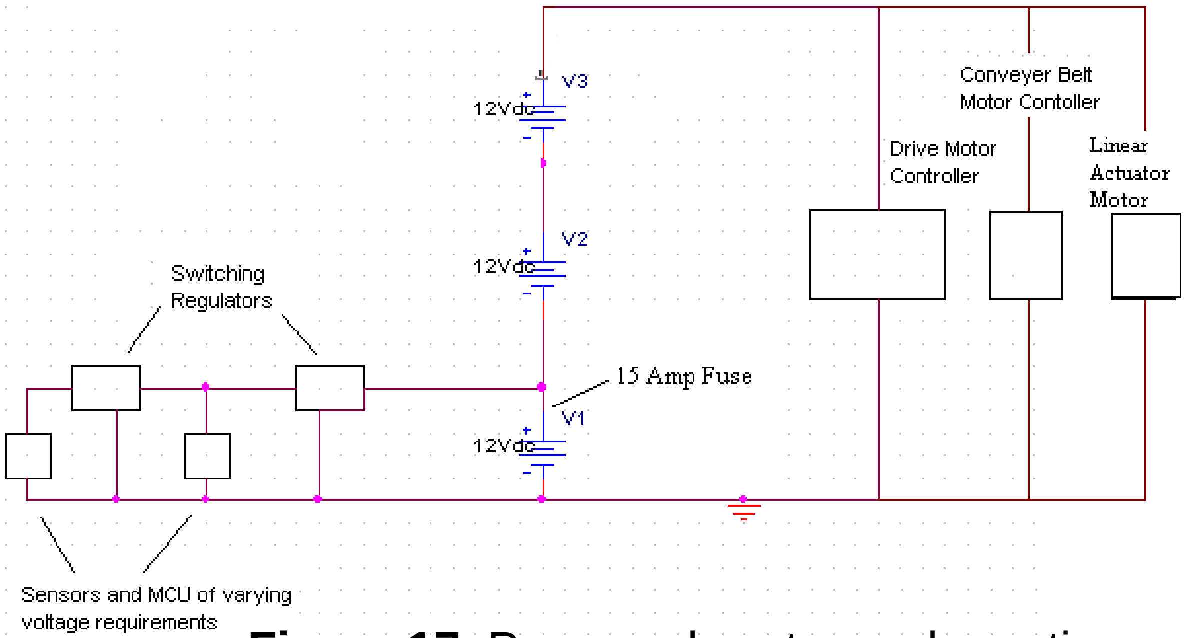


Figure 17. Power subsystem schematic

Artemis Power System Specifications			
Part	**Type**	**Weight**	**Price**
Switching Regulator	DE-SWADJ	N/A	$12 x2
Lead-Acid Batteries	Powersonic 12V 18AH	13.10 LBS x3	$51.95 x3
Accessories	Wires/Fuses/Switches/Capacitors	N/A	$50.00
	Total:	~40 LBS	$229.85

Table 3. ARTEMIS Power System Specifications

Power Subsystem Simulation

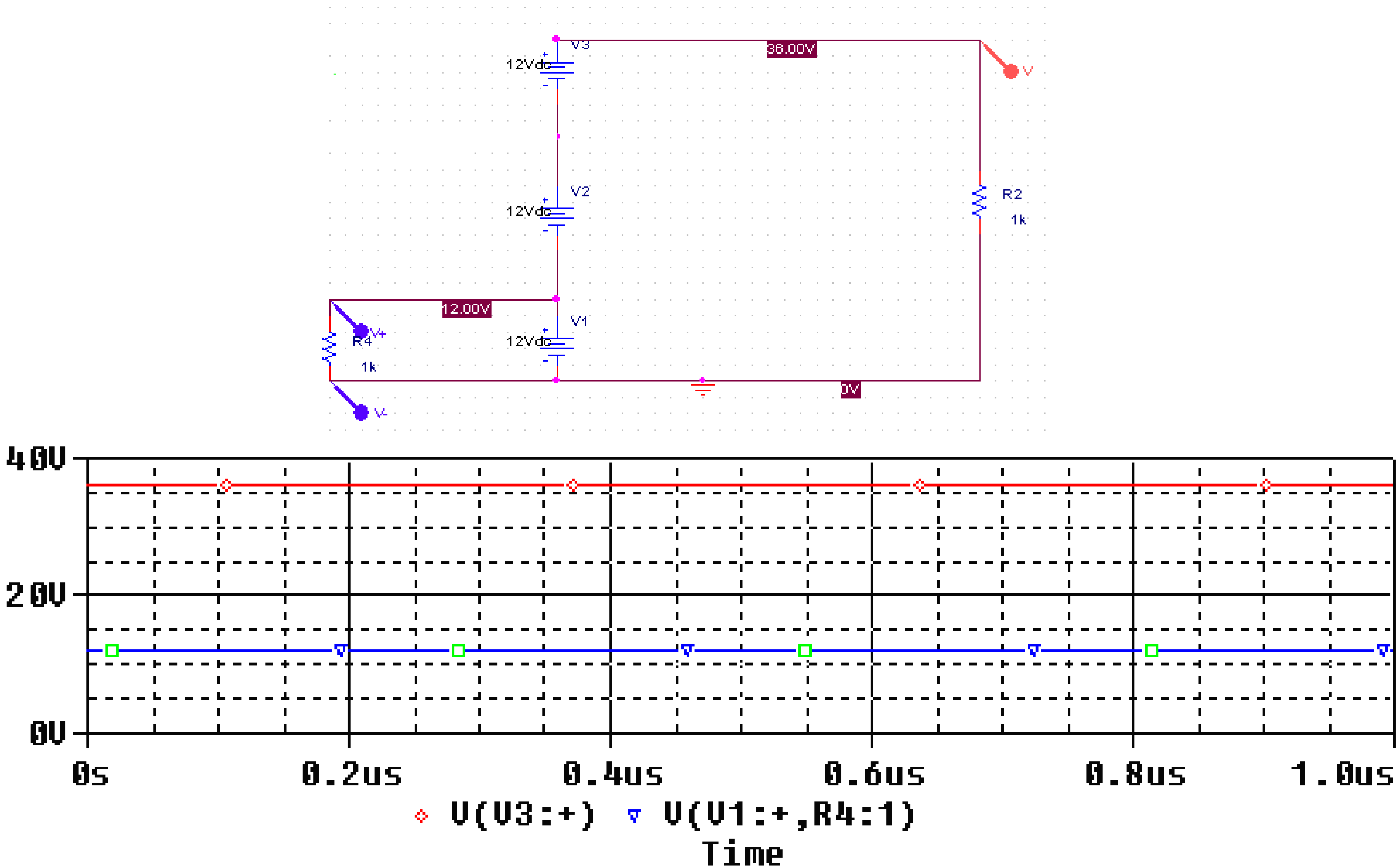


Figure 18. Schematic of power system simulation (top) and results (bottom)

Power Subsystem Overview

PHASE 1: Plow Engage
PHASE 2: Regolith Collection
PHASE 3: Regolith Deposit into Collector

Device	PHASE 1	PHASE 2	PHASE 3
Drive motor 1	ON	ON	OFF
Drive motor 2	ON	ON	OFF
Conveyor Motor	OFF	ON	OFF
Linear Actuator 1 (Plow Lift)	ON	OFF	OFF
Linear Actuator 2 (Bucket Lift)	OFF	OFF	ON
MCU/Sensors	ON	ON	ON

Table 4. Device operation according to sequence

Device	Maximum Allowable Current Draw	Maximum Power Draw
Drive Motor 1	5A	180W
Drive Motor 2	5A	180W
Conveyor Motor	2A	72W
Linear Actuator 1	2A	72W
Linear Actuator 2	10A	360W
MCU/Sensors	2A	12W

Table 5. Maximum device specifications in accordance to phase and 15A draw limit

Microcontroller

- 8 bit AVR vs 32 bit ARM vs Single-board Computer
  - AVR- slower, tons of support, very easy to program, 5V I/O
  - ARM- faster, more complicated, 3.3V I/O
  - Single-board- expensive, complete overkill
- Chose MCBSTM32, an ARM Cortex M3 board from Keil
  - 32 bit 72MHz
  - 2 SPI, 2 I2C, 3 UART, 16 ADC
  - 48 General I/O
  - Free, Donated by ARM

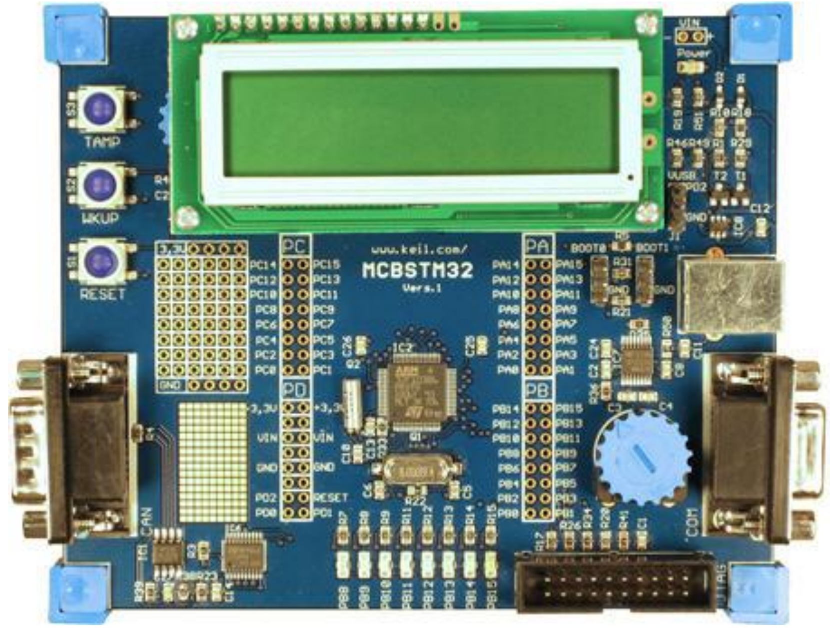


Figure 19. Example of ARM Microcontroller

Telerobotic Interface

- Remote operation of robot
  - At minimum: Start and stop
- Network provided which adds two second delay

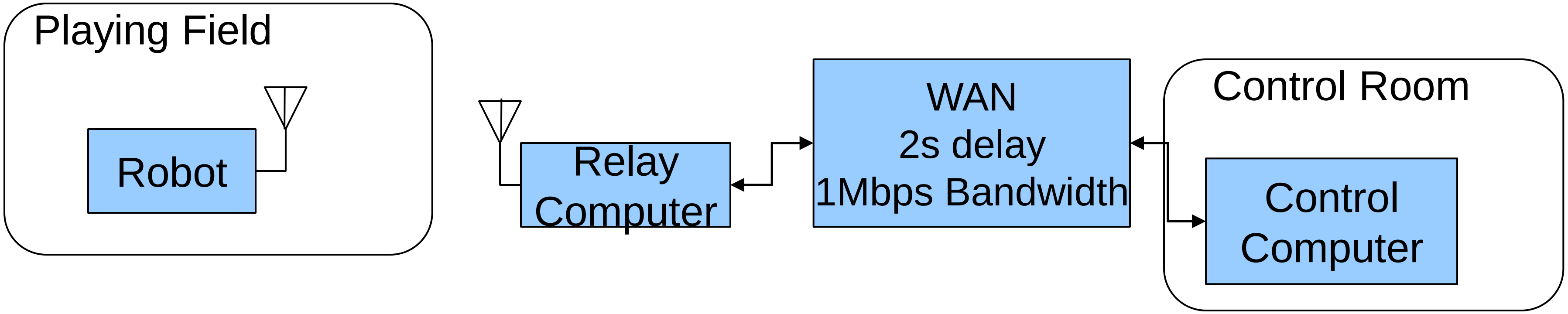
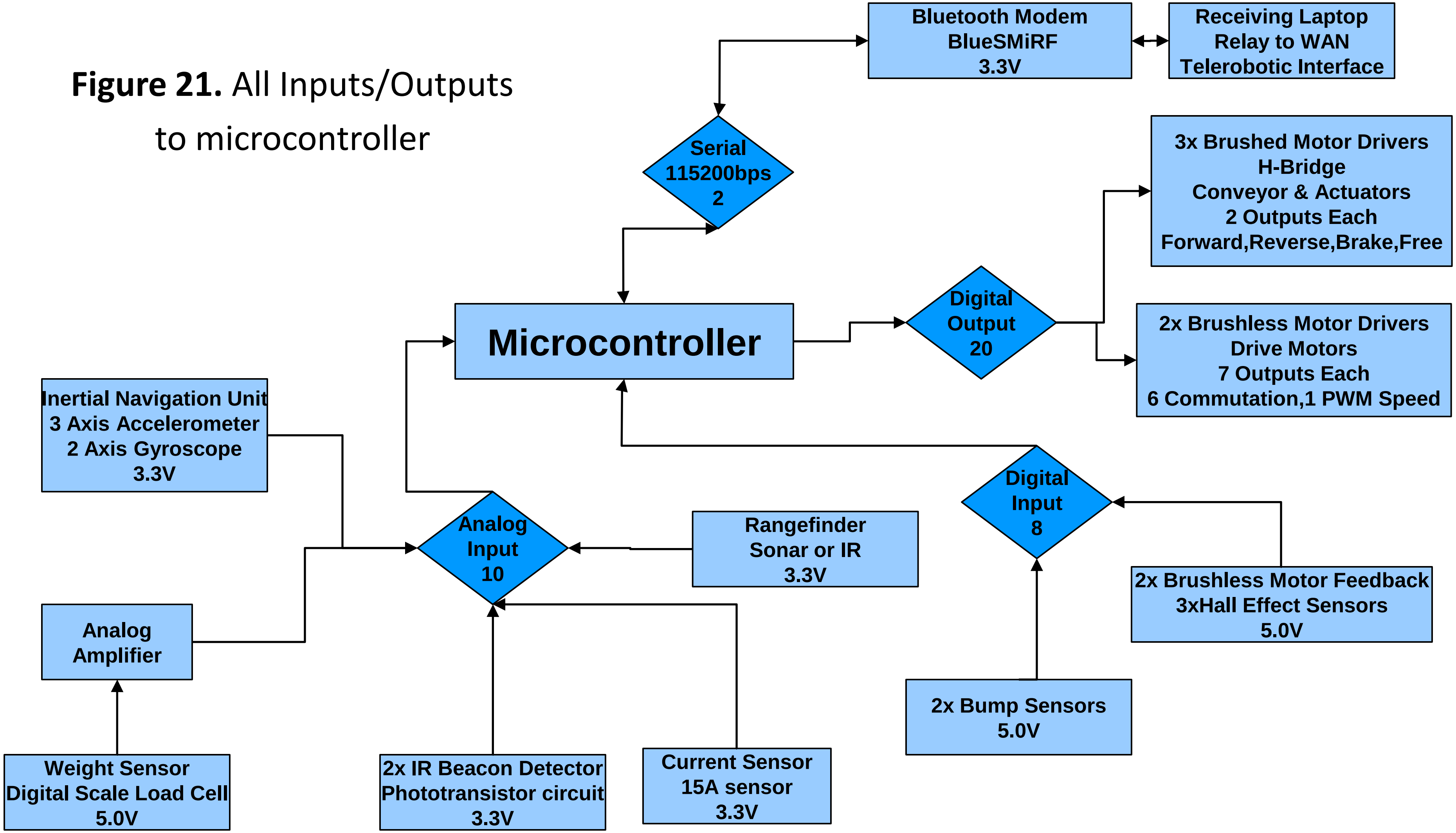


Figure 20. Diagram of communications during competition

- Link Robot to WAN Wirelessly
  - WiFi- 58Mbps, Complicated, High Power, Most Expensive
  - Xbee- 0.25Mbps, Simple, Medium Power, Cheapest
  - Bluetooth- 1Mbps, Medium Complexity, Low Power,Medium Cost

Interfacing Diagram

Figure 21. All Inputs/Outputs to microcontroller



Navigation Subsystem Design

- From start, proceed on random or preset course
- Once out of starting square, start digging
- When bin is full, move to center of area and face collector
- Move towards collector using beacons for alignment
- When at wall of collector, dump regolith
- Reset inertial navigation and repeat

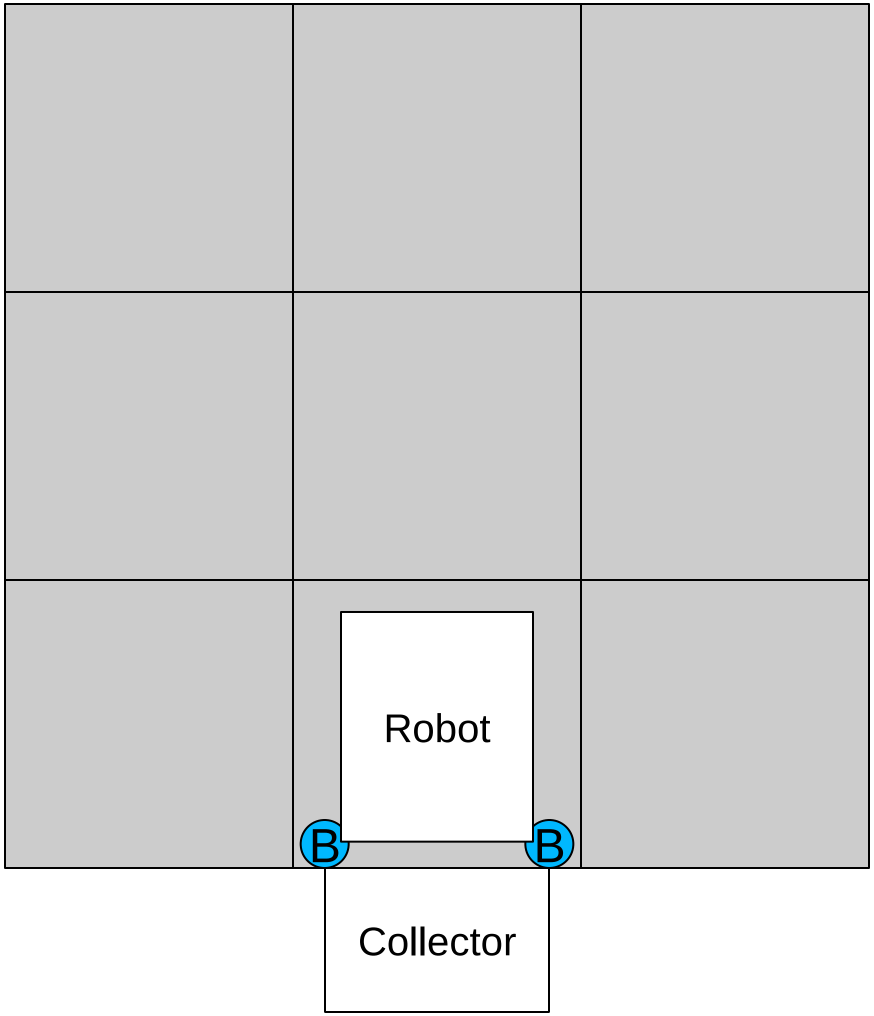


Figure 22. Diagram of Competition setup

Navigation Sensors Diagram

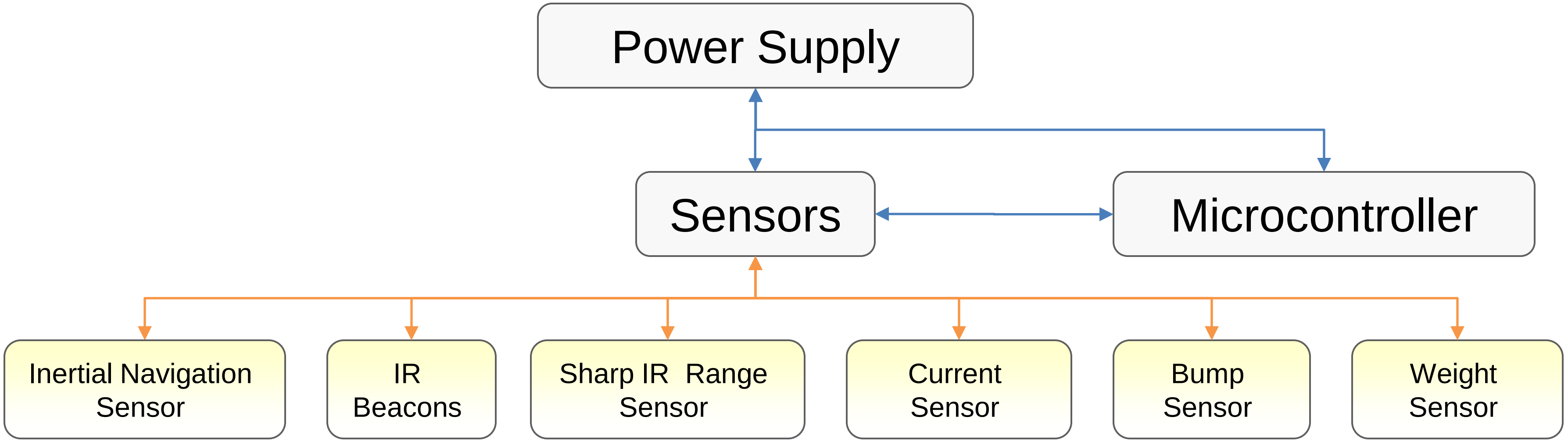


Figure 23. Navigation Sensor flow chart

Inertial Measurement Unit

Inertial Navigation Sensors

- Accelerometer and gyroscope provide position and direction sensing independent of the robots environment
  - Accelerometers measure acceleration in X, Y, and Z axis
  - Gyroscopes measure pitch, yaw, and roll

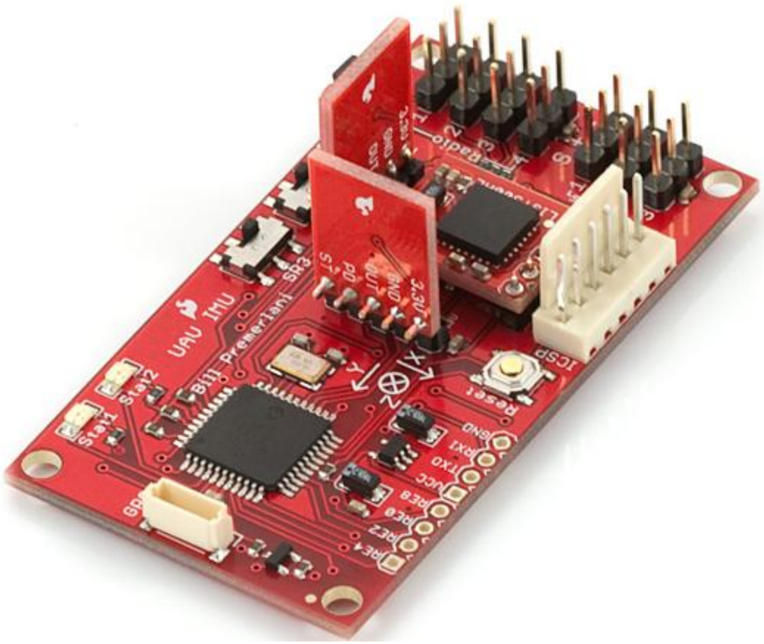


Figure 26. Three axis inertial navigation sensor

IR Sharp Sensor

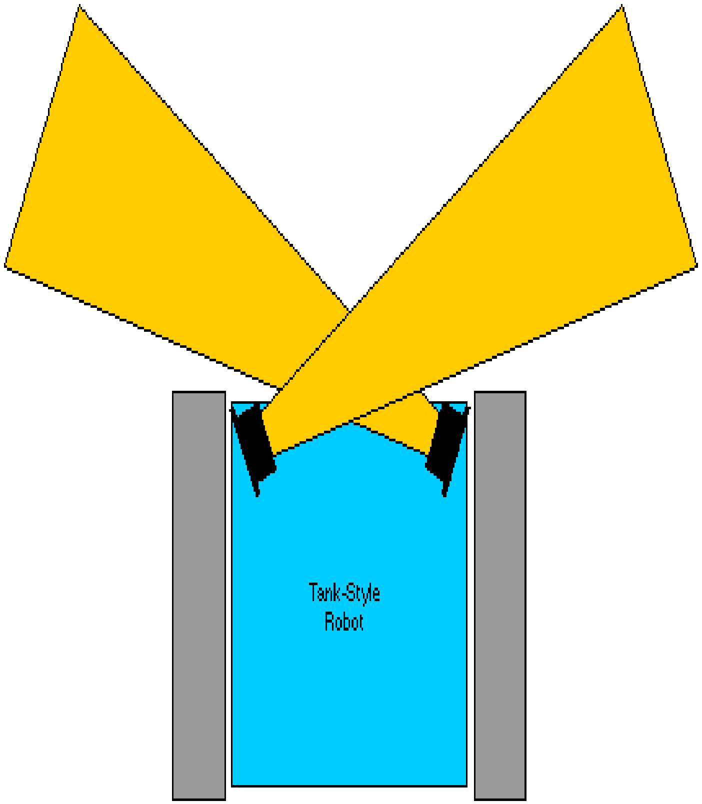


Figure 27. Configuration of IR Sharp sensors on platform

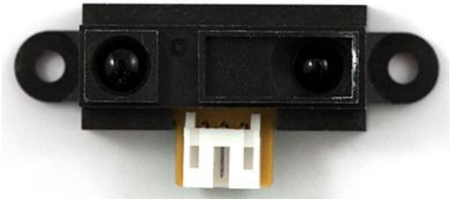


Figure 28. IR Sharp Sensor

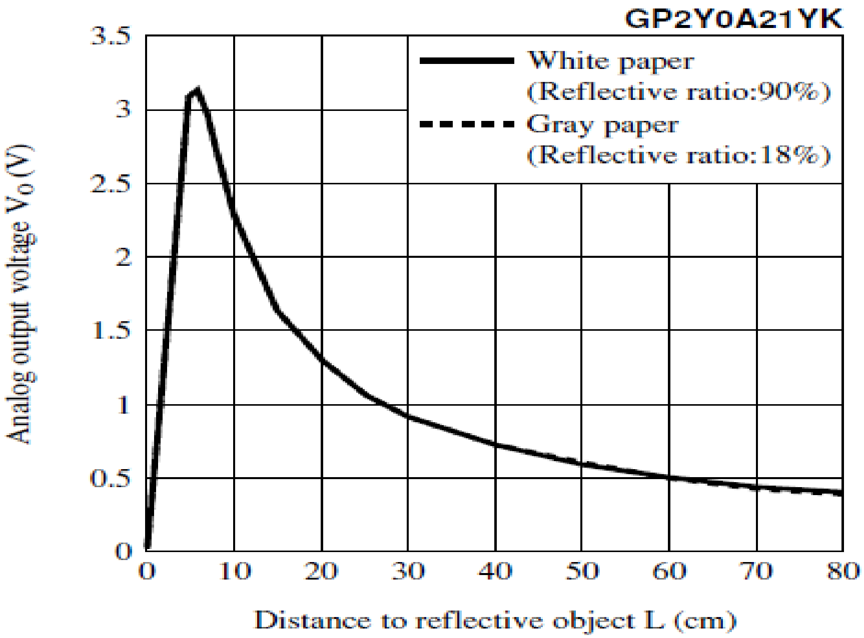
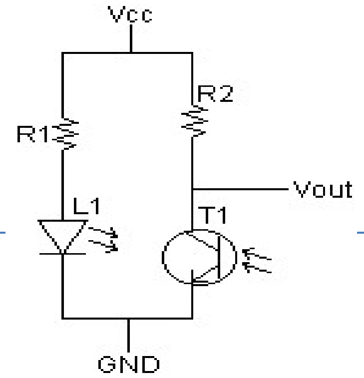
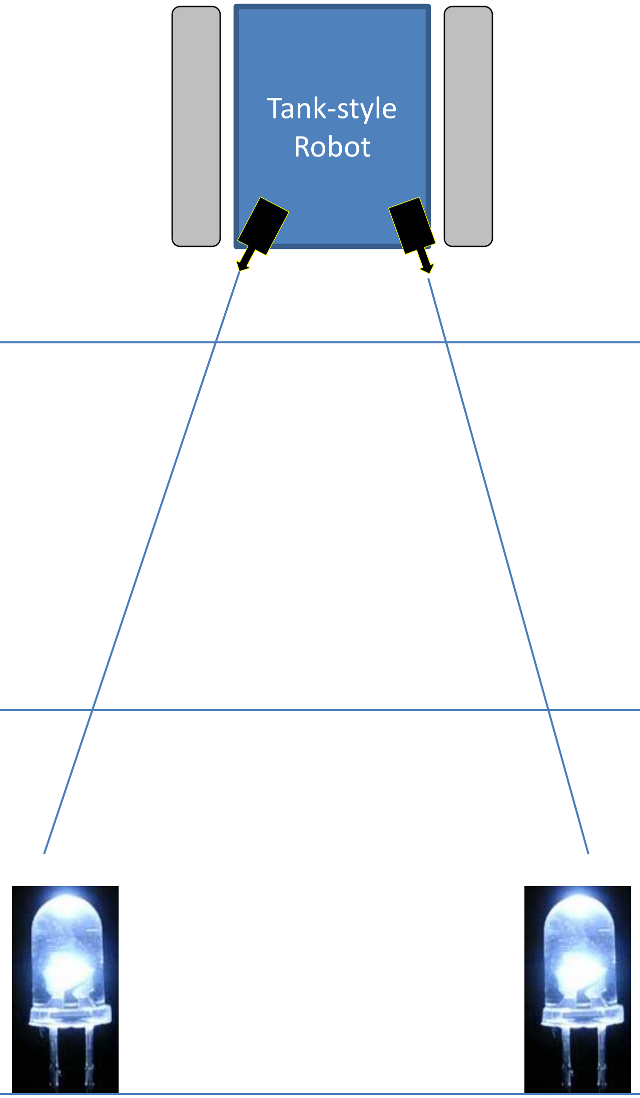


Figure 29. Analog output voltage vs. distance to reflective object

IR Beacon and Sensor

IR Emitter Circuit





Bumper and Weight Sensor

- **Tactile Bump Sensor Circuits**

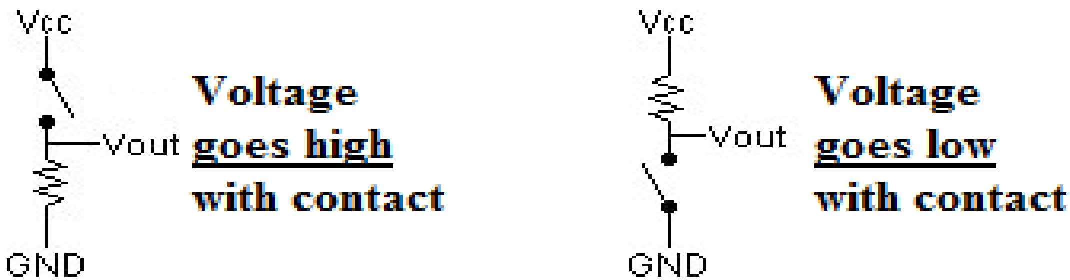


Figure 31. Bump Sensor Circuit

Figure 31a. Bump Sensor

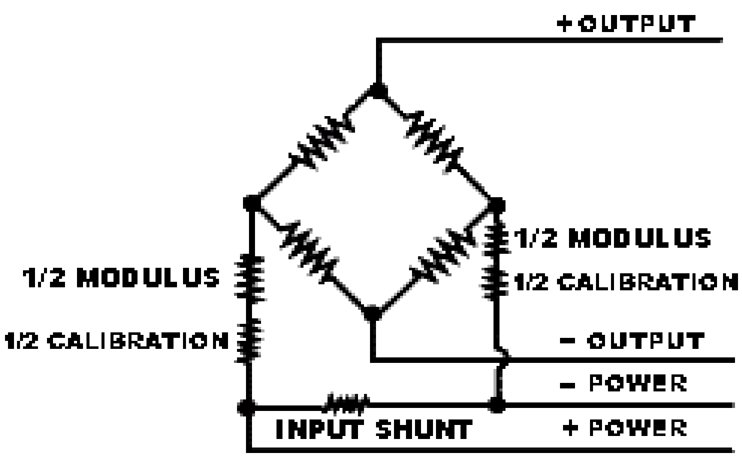


Figure 32. Weight Sensor Circuit

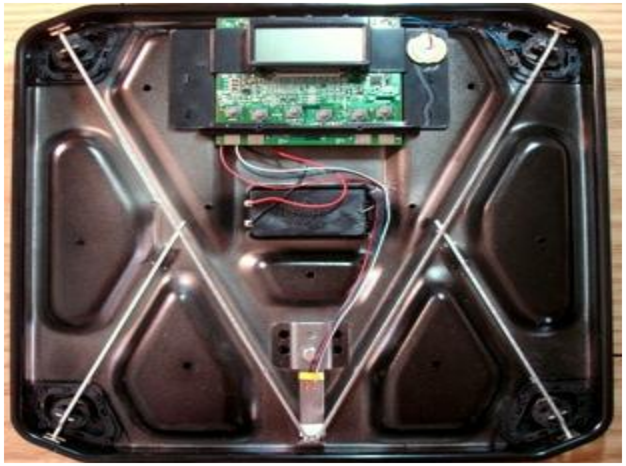
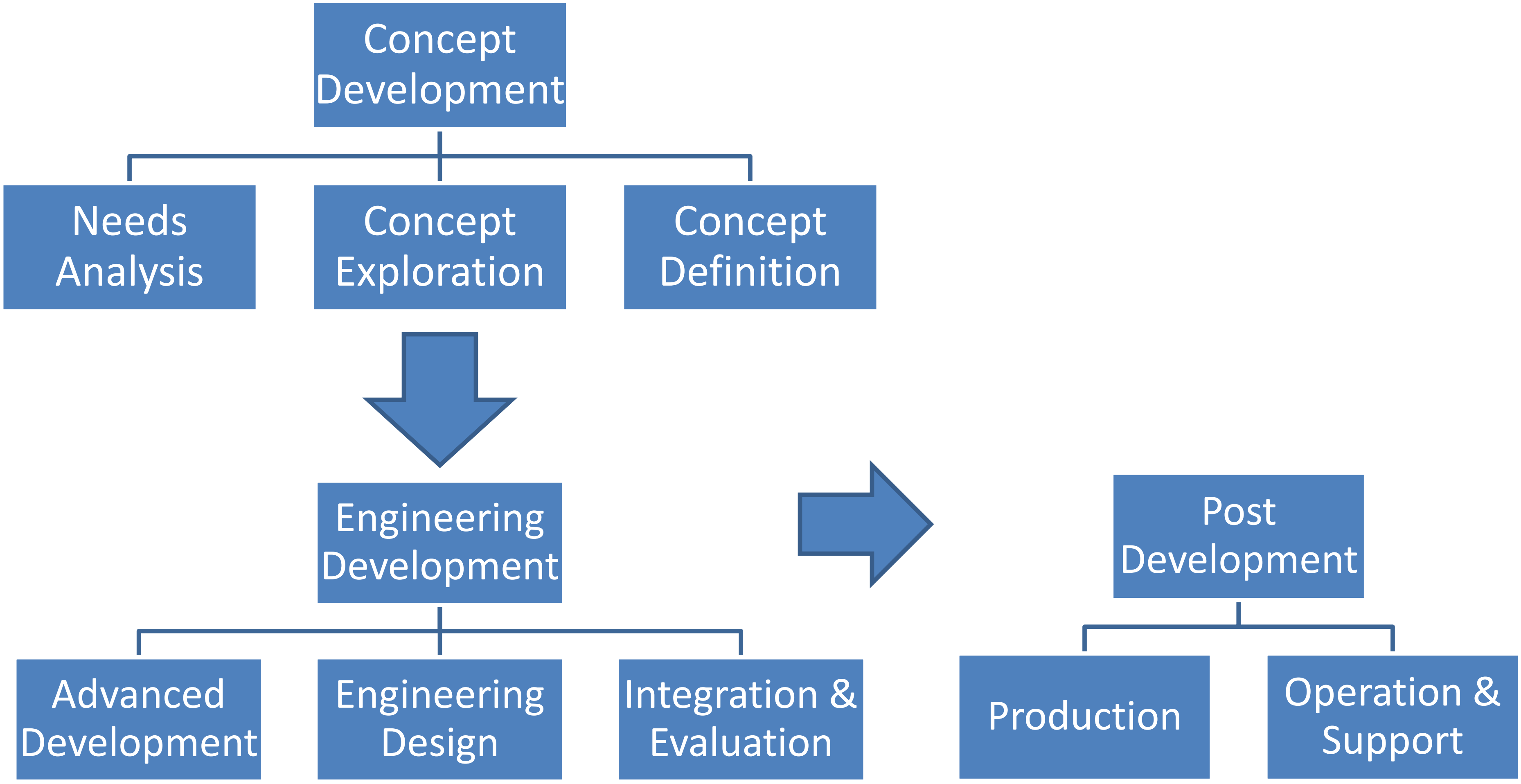


Figure 32a. Weight sensor in situ

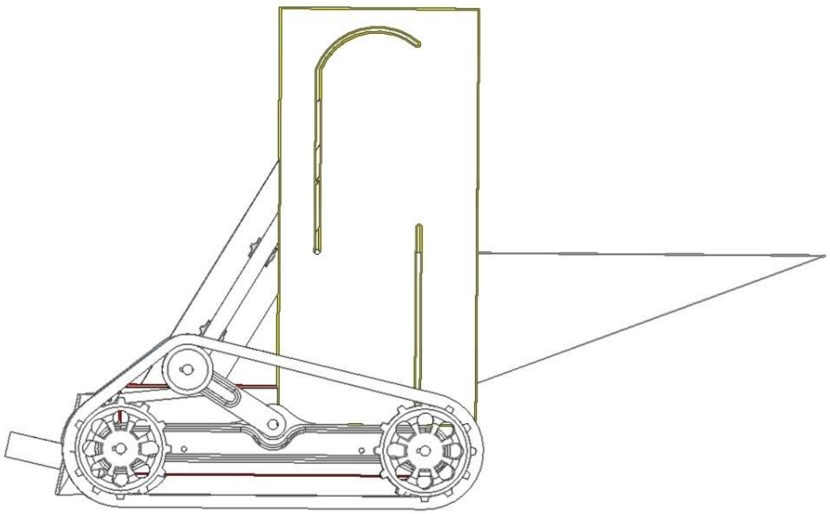
Cost Analysis of System

The Artemis Project Budget Breakdown			
Part Description	**QTY**	**Price**	**Total**
Excavation			$1,409.97
Aluminum Plate, 1/8"x12"x24"	4	$22.84	$91.36
Aluminum Rod, 3/16"x72"	1	$2.61	$2.61
Linear Actuator, Plow	1	$512.00	$512.00
Linear Actuator, Bucket	1	$804.00	$804.00
Radial ball bearings, 4 pack	3	$8.95	$26.85
Tensioner Belt	1	$5.45	$5.45
Washer	2	$0.35	$0.70
Frame Mounting Hardware	1	$5.78	$5.78
Tensioner Mounting bolts, 5 pack	1	$5.78	$5.78
Aluminum 1.5" tube	1	$34.76	$34.76
Aluminum 3" tube	1	$28.94	$28.94
Aluminum 1" tube	1	$17.83	$17.83
Paddlebelt	1	$63.24	$63.24
Radial Gear	1	$17.58	$17.58
Locomotion			$1,384.85
Aluminum Block, 8"x8"12"	1	$435.40	$435.40
Aluminum Rectangular Tube, 2"x4"x72"	3	$54.43	$163.29
Aluminum Rod, 1"x60"	1	$20.92	$20.92
Aluminum Rod, 1/2"x72"	4	$6.22	$24.88
Bearings, 1"	8	$12.23	$97.84
Rubber Sheet, 1-1/2"x24"x6'	2	$71.10	$142.20
Maxon Brushless DC Motor	2	$196.70	$393.40
Roller, 40mmx50mm	2	$31.90	$63.80
Brass Flat plate, 3/32"x3/4"x72"	2	$21.56	$43.12
Power			$229.85
Switching Regulator	2	$12.00	$24.00
Lead Acid Batteries	3	$51.95	$155.85
Accessories (Wires, Fuses, etc)	1	$50.00	$50.00
Microcontroller and Communications			$110.00
ARM Microcontroller*	1	$0.00	$0.00
Accessories (Wires, Breadboard, etc.)	1	$75.00	$75.00
Bluetooth Adapters	1	$35.00	$35.00
Navigation			$242.80
IR Sharp Sensor	1	$9.95	$9.95
IR Beacon Detector	1	$14.95	$14.95
IR LEDs (850 nm 100pcs)	100	$0.07	$7.00
IR LEDs (940 nm 100 pcs)	100	$0.06	$6.00
IMU	1	$149.95	$149.95
Gyroscope	1	$11.95	$11.95
Bumper Sensor	2	$1.50	$3.00
Weight Sensor	1	$40.00	$40.00
Total Cost of System			$3,884.38
Miscellaneous Costs (Shipping, etc)	1		$300

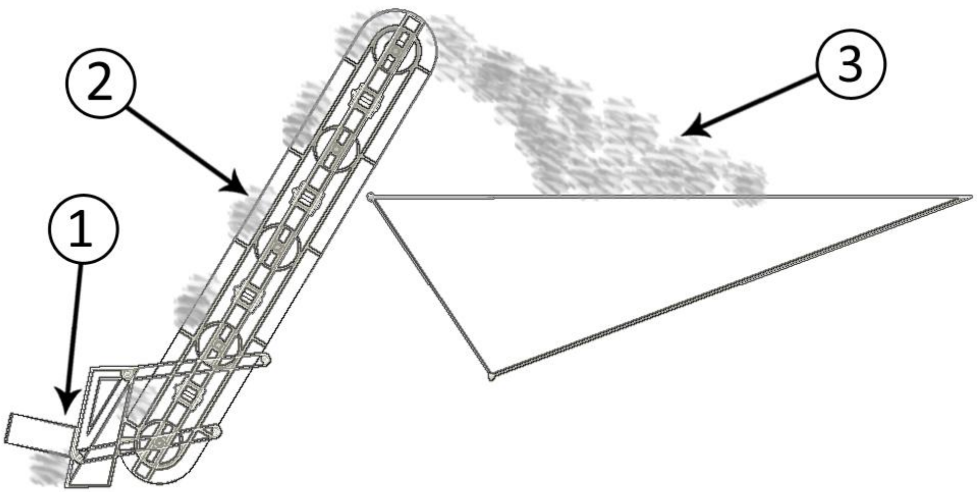
Lifecycle


Concept Development
Needs Analysis
Concept Exploration
Concept Definition
Engineering Development
Advanced Development
Engineering Design
Integration & Evaluation
Post Development
Production
Operation & Support

Conclusions



- Plow excavation unit with conveyor belt for regolith transport
- Tracks on either side used for locomotion
- Lead-acid batteries for power integrated in regulator circuits for components
- ARM Microcontroller for control
- Various sensors for navigation and obstacle avoidance



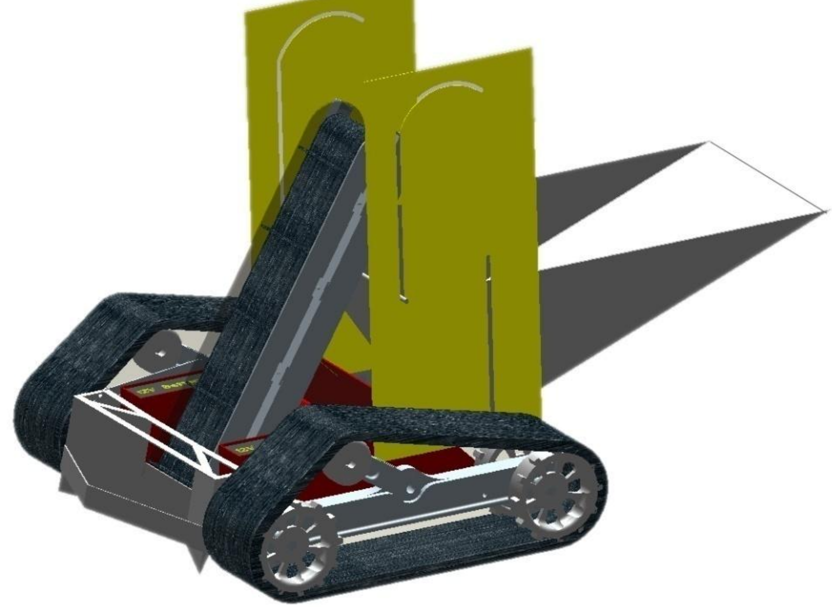


Figure 33. Final ARTEMIS Design

Questions and Comments

The ARTEMIS Project