The ARTEMIS Project

Lunar Regolith Excavator Student Competition

ME Team #8 / ECE Team #1

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The Lunabotics Mining Competition

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
Min Excavation Material	10 kg
Max width	1.5 m
Max length	0.75 m
Max height	2 m
Max setup time	10 minutes
Operation time	15 minutes
Max take down time	5 minutes

Table 1. Competition Specifications

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

Needs Analysis Flow Diagram

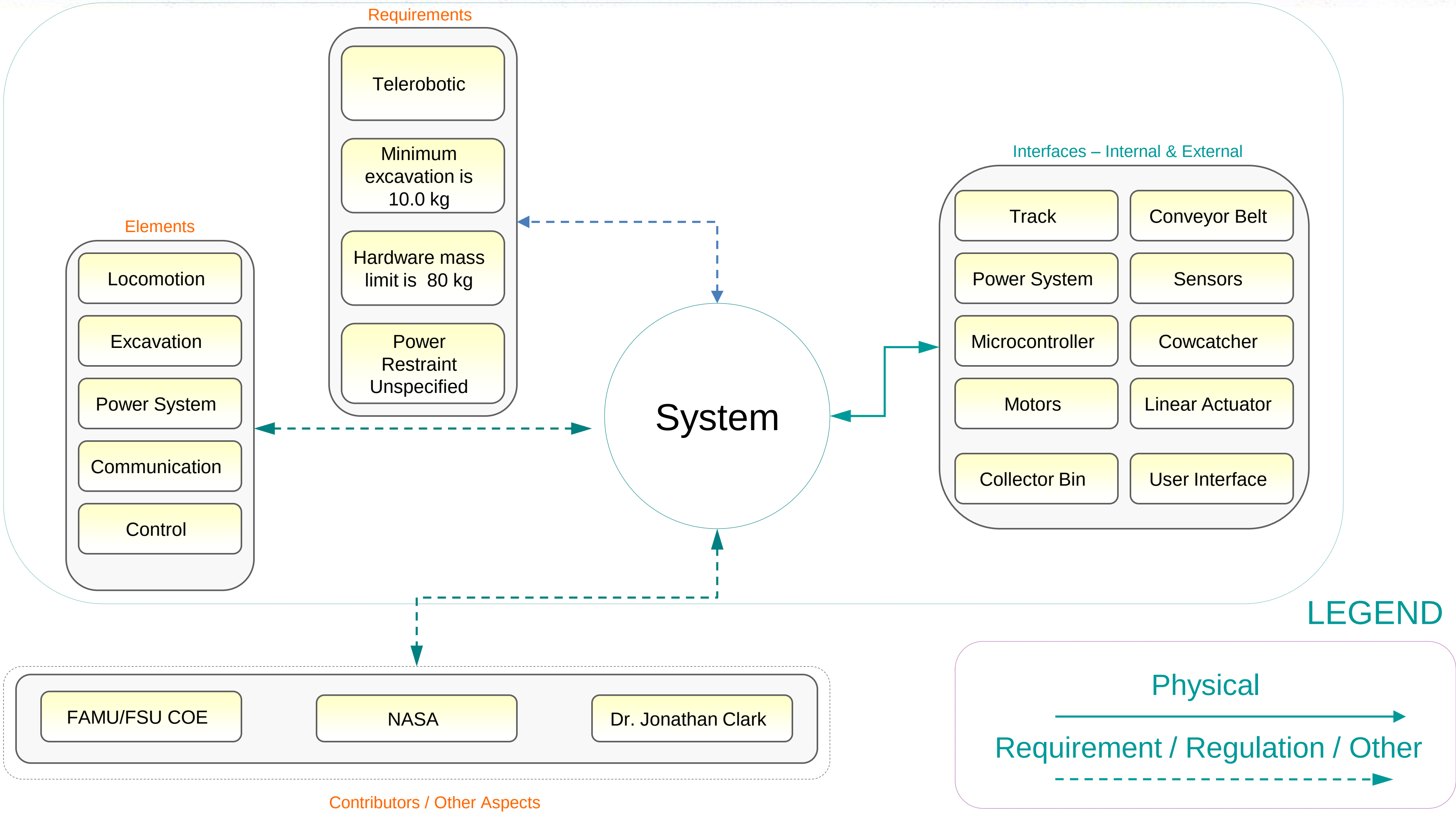


Figure 2. Needs analysis flow diagram for ARTEMIS Project

Robotic Platform Design

Figure 3. Robot design schematic

Circuit Block Diagram

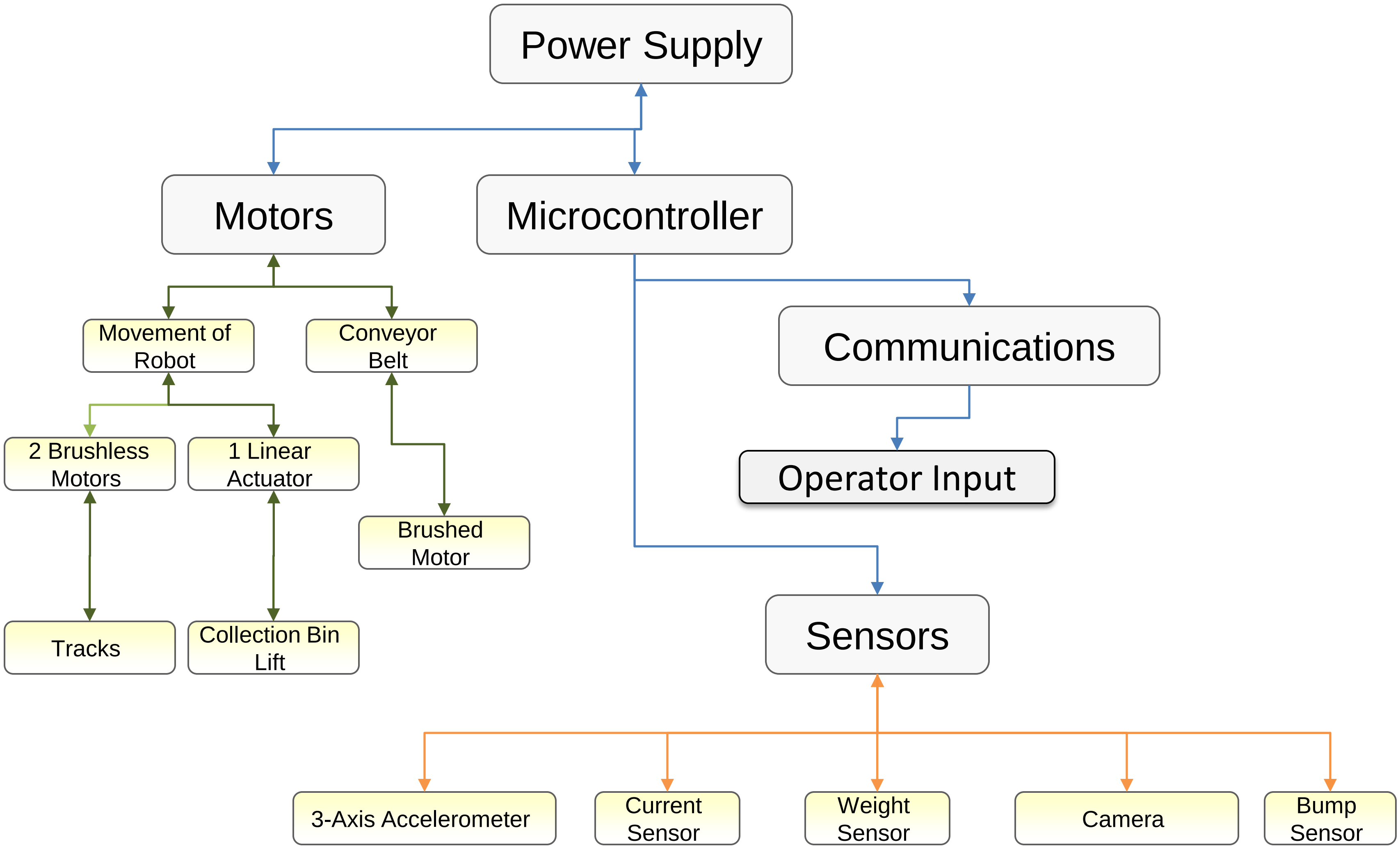


Figure 4. Circuit block diagram

System Breakdown

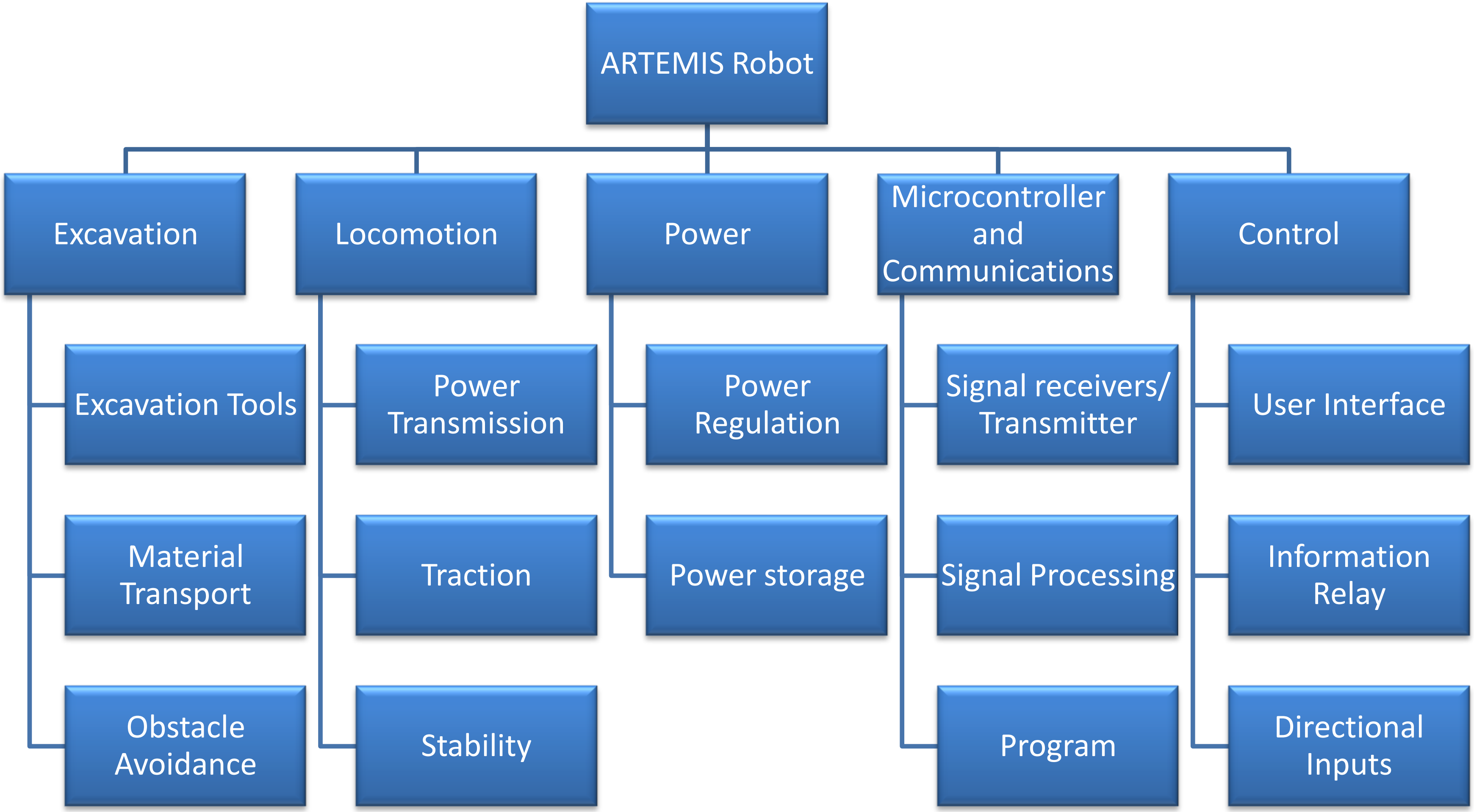


Figure 5. System breakdown structure

Concept Generation

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

Figure 6. Top 3 concepts for each subsystem

System Overview

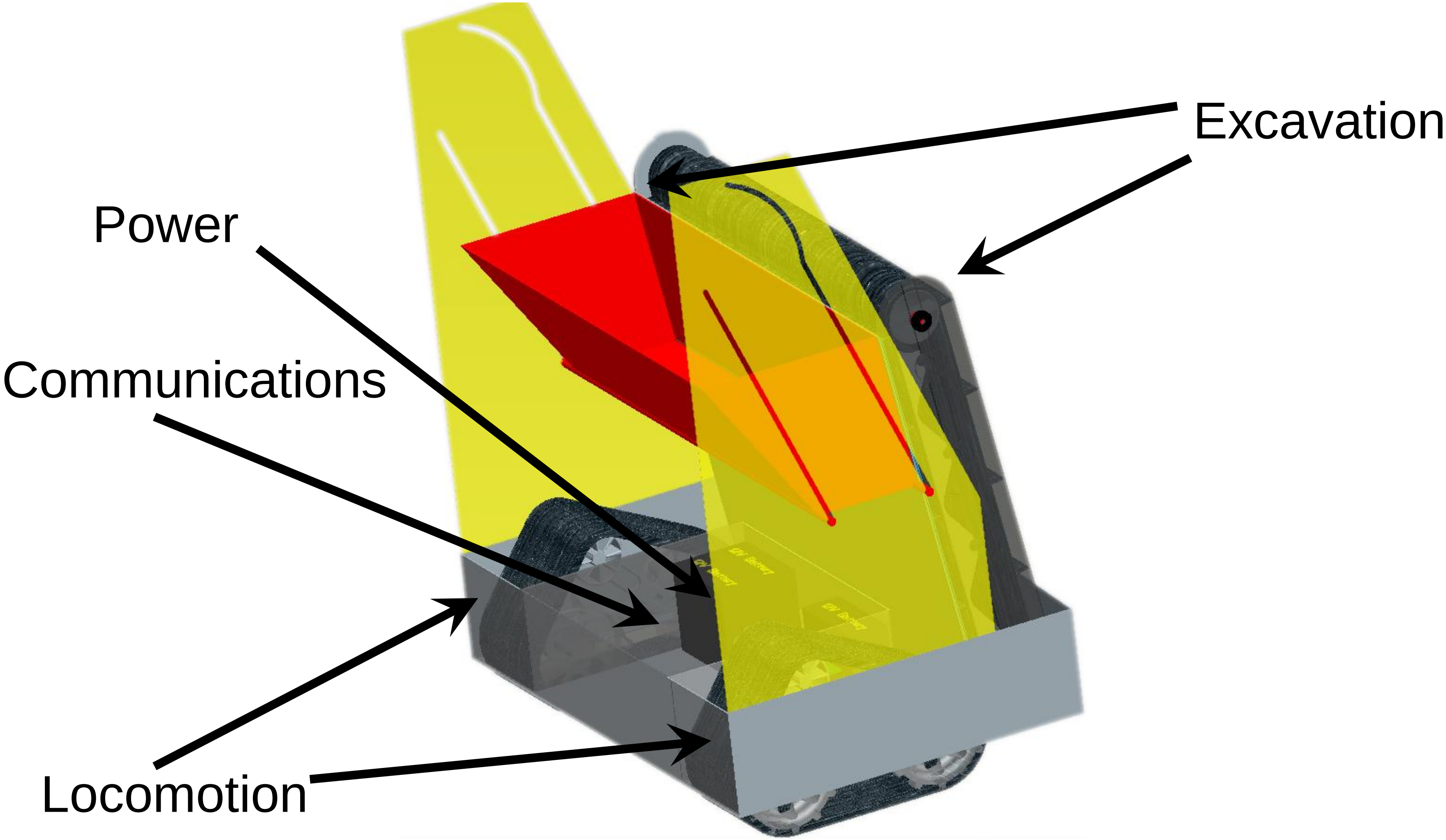


Figure 7. Overall platform design with subsystems

Excavation Subsystem Design

- Excavation Subsystem Components:
  1. Cleated Belt – cleats excavate regolith and deposit into trough
  2. Conveyor – transports regolith up trough to be deposited into bucket
  3. Bucket – holds regolith until delivery to holding bin

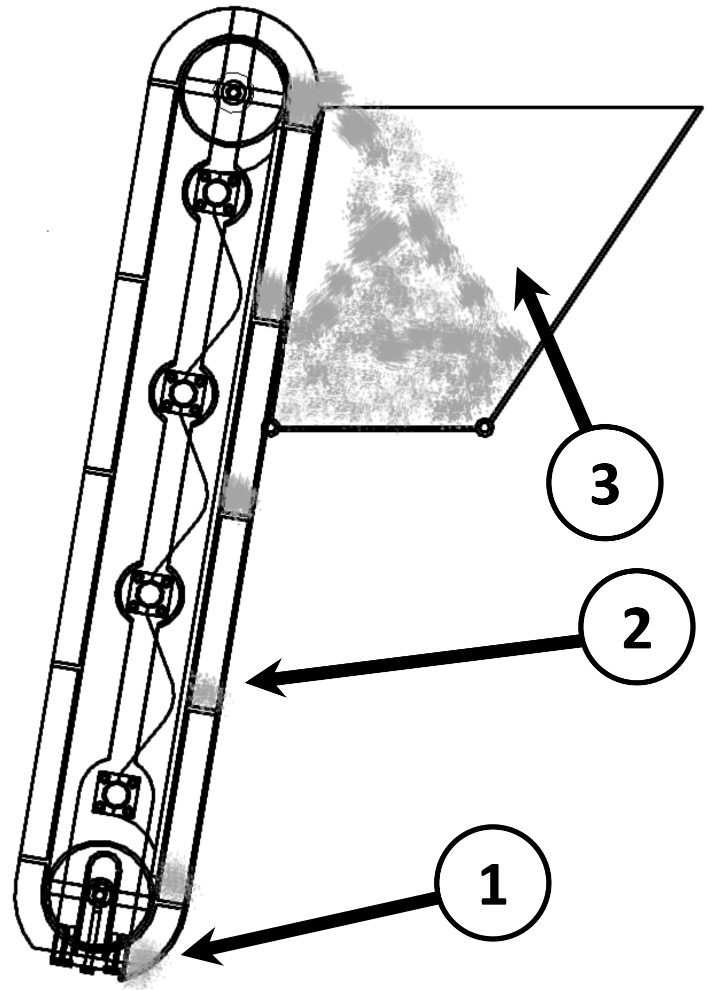


Figure 8. Excavation subsystem components and flow of regolith

CLEATED CONVEYOR

- Final Design
  - Key Design Elements
    - Two piece Al frame
    - Aluminum rollers
      - One driven, one idle
      - 10.16 cm in dia
    - Paddle belt
      - PVC 120 material
      - 90 cm belt width
      - Ten total cleats
      - 21.6 cm cleat spacing
      - 2.54 cm cleat height
    - Belt tension mechanism
      - One per side
    - Low friction sliders
      - 4 total
      - Delrin material
    - Belly pan
      - Aluminum
    - Hardware
      - Sixteen Al Allen head screws
      - Five sealed, radial ball bearings
      - Eight Al tension plate bolts
      - Two SS adjuster bolts
    - Spur Gear
      - Al 6065

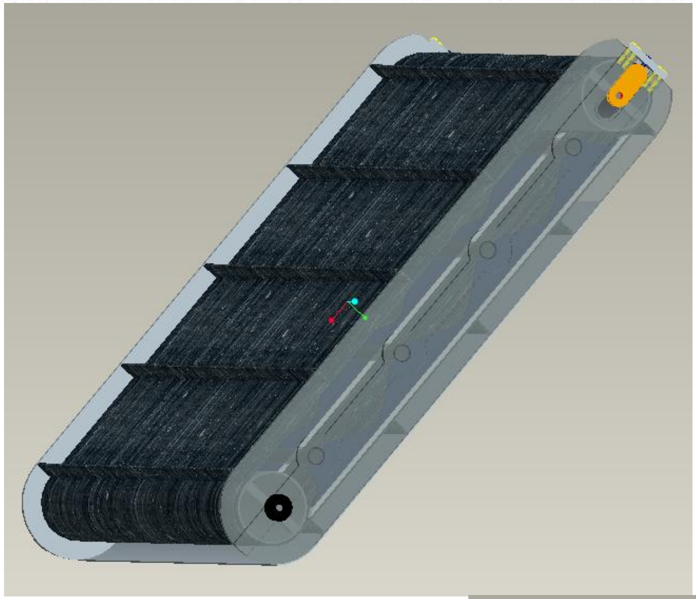


Figure 9. Isometric Design View

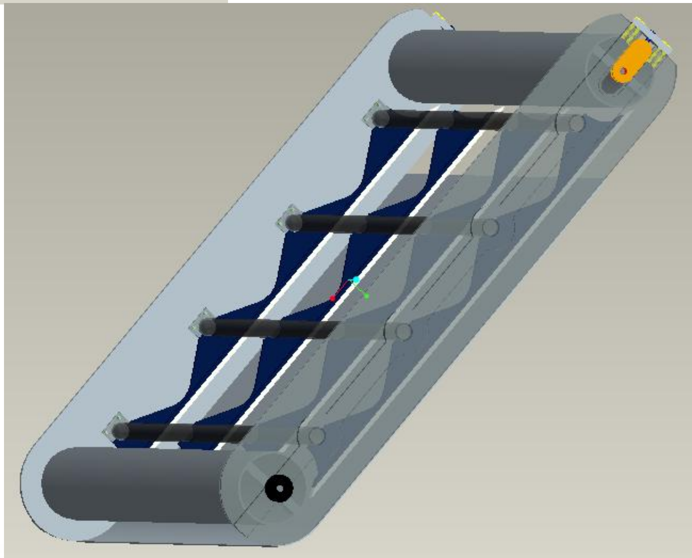
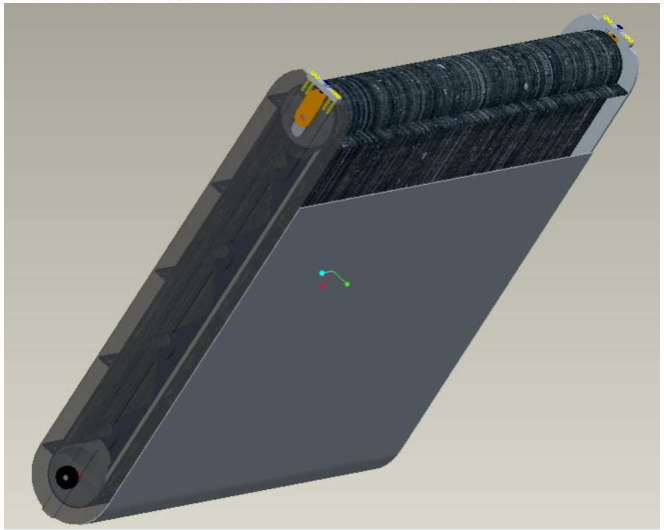


Figure 10. Isometric Design View w/o Belt

CLEATED CONVEYOR

- Design Analysis
  - Assumptions and Constants
    - Inclination angle of 55 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 2471.17 cm^3
    - Belt coefficient of friction of 0.3
    - Bearing coefficient of friction of 0.0015
  - Results
    - Angular velocity of 9.84 rad/s
    - Angular acceleration of 6.56 rad/s^2
    - Max load of 23.6 kg
    - Required input torque of 10.3 N*m



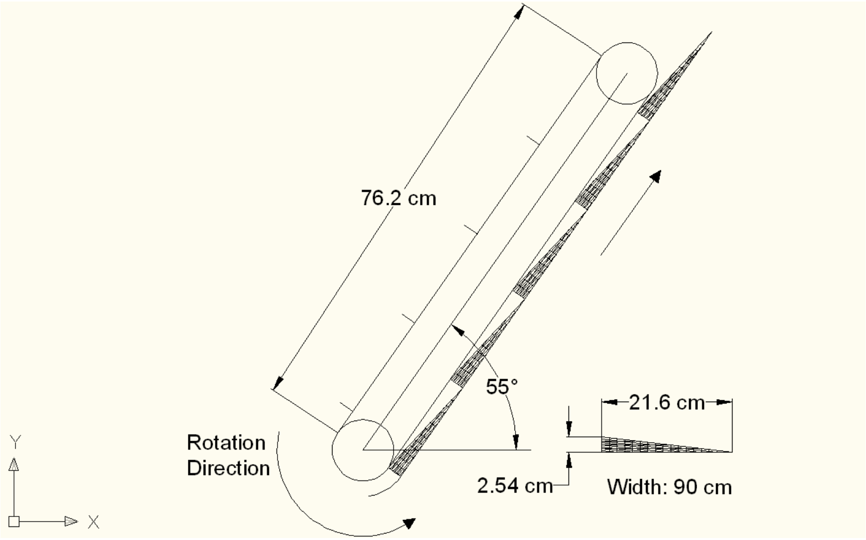


Figure 11. Conveyor Design Drawing

CLEATED 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

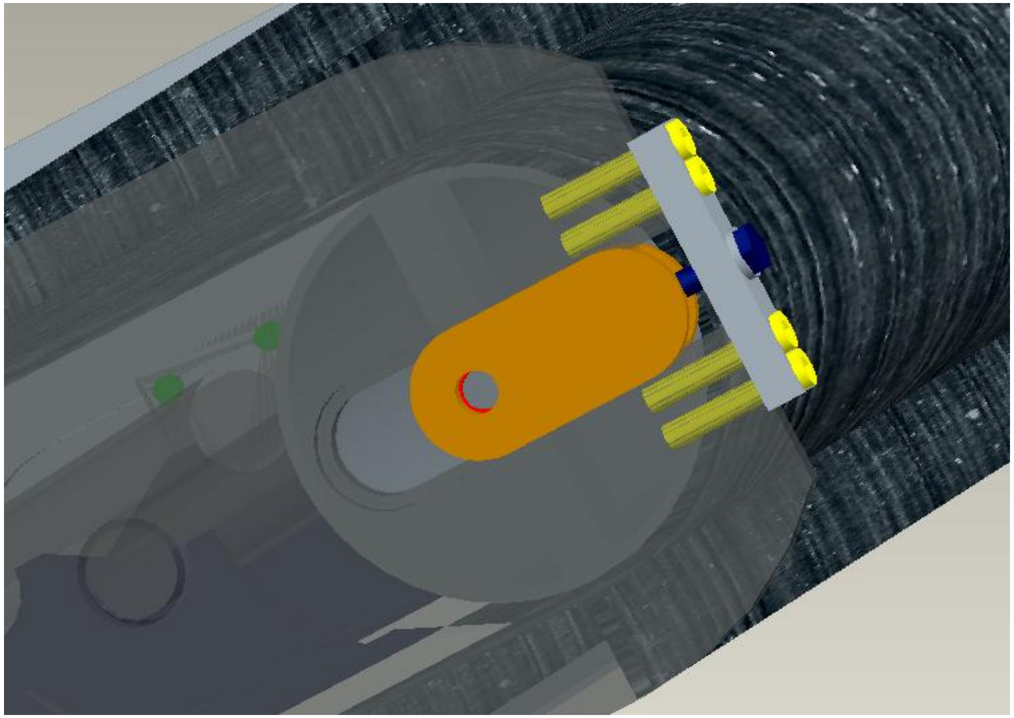


Figure 12. Belt Tensioning Mechanism

Bucket Design

- Density of Regolith – 1.5 g/cm^3
- Desired capacity – 100 kg
- Required Volume – 0.066 m^3
- Our Bucket
  - Volume 0.0675 m^3
  - Height 0.3 m
  - Length 0.4 m
  - Width 0.9 m
  - Material Al 6061
  - Weight 8 kgs

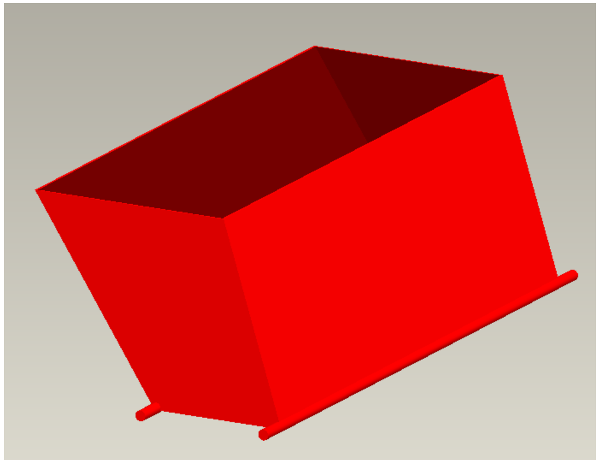


Figure 13. Isometric view of bucket design

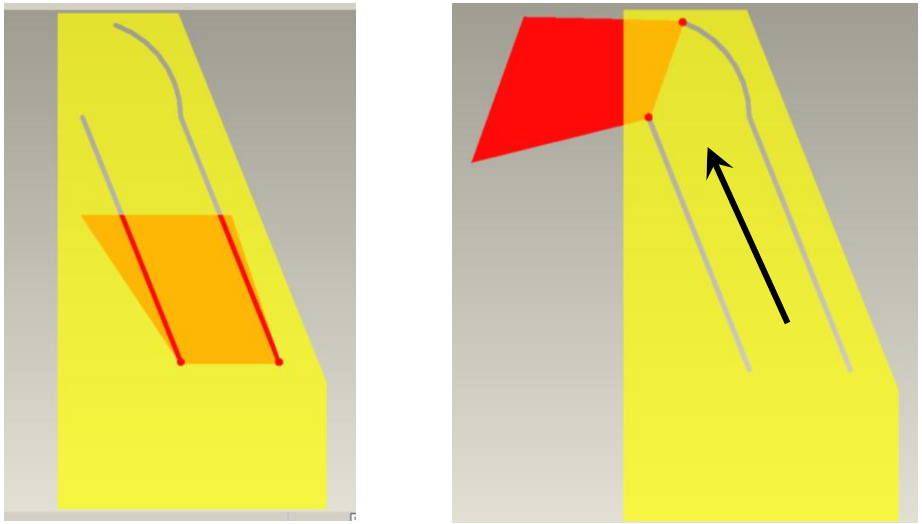


Figure 14. Example of bucket dumping from side view

Locomotion Subsystem Design

- Torsion Spring tensioner, K=150 Nm/deg
- Rear sprockets driven by independent 24 V motors housed in main body
- Total mass of each track ~10 kg with tread
- Reduction of mass through using lattice work frame

Figure 15. Isometric view of track frame

Locomotion Subsystem Design

- Chain Assembly
  - 15 cm tread surface at center made of heavy duty, reinforced rubber
  - Individually adjustable connector links using nut and bolt to tighten
  - Pin Joint allows large circular deformations
  - Tread links drawn tight by tensioning arm on frame

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

Power Subsystem Design

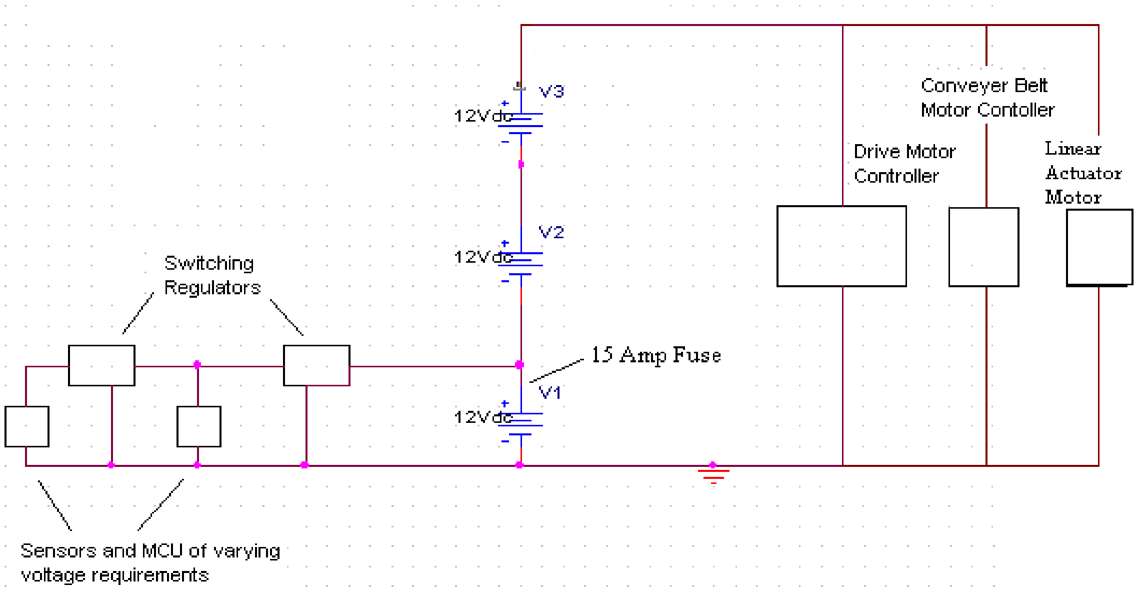


Figure 17. Power subsystem schematic

Artemis Power System Specifications		
Part	**Type**	**Weight**
Switching Regulator (2)	DE-SWADJ	N/A
Lead-Acid Batteries (3)	Powersonic 12V 18AH	5.94 kg
Accessories	Wires/Fuses/Switches/Capacitors	N/A
	Total:	17.82 kg

Table 3. ARTEMIS Power System Specifications

Power Subsystem Simulation

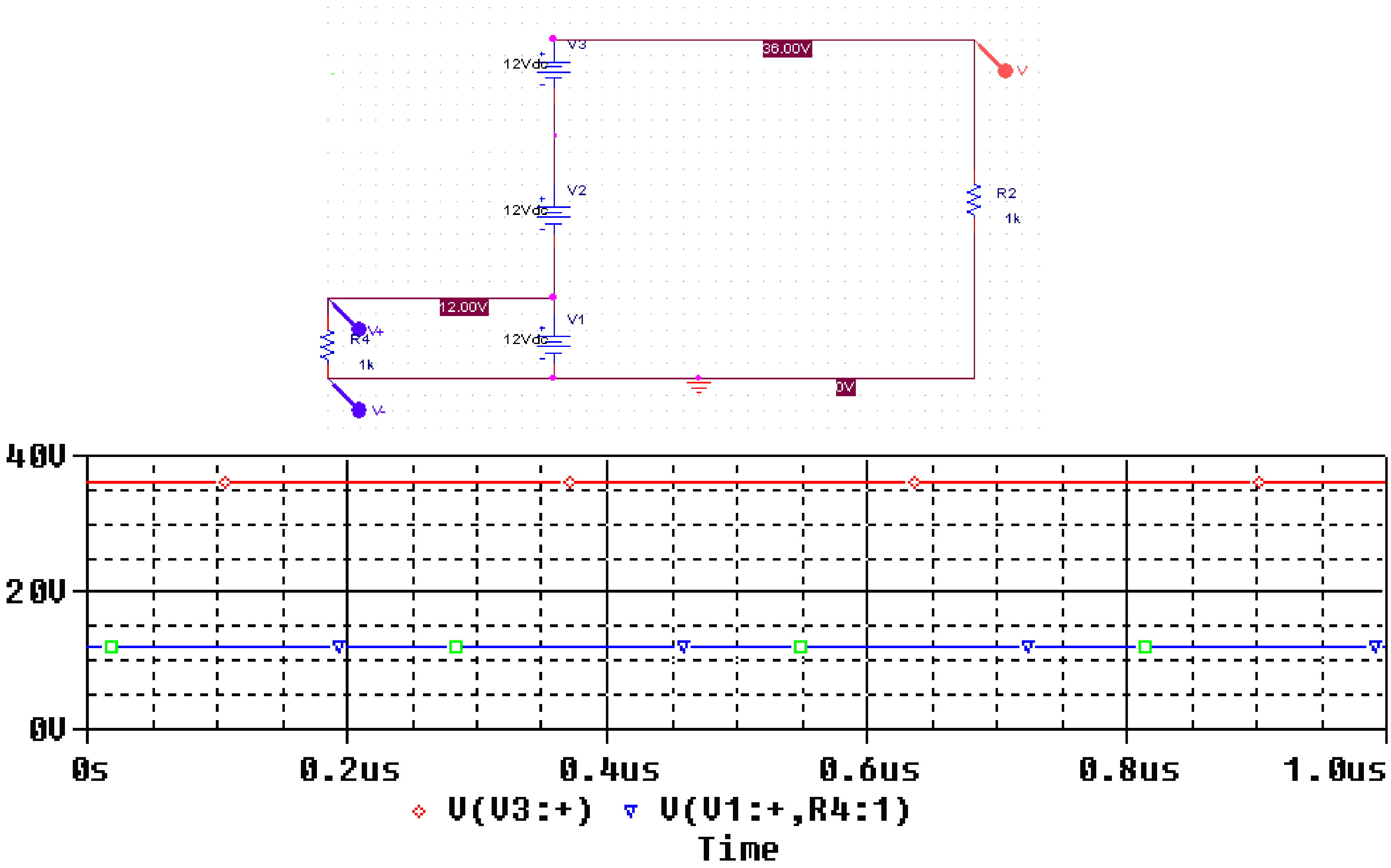
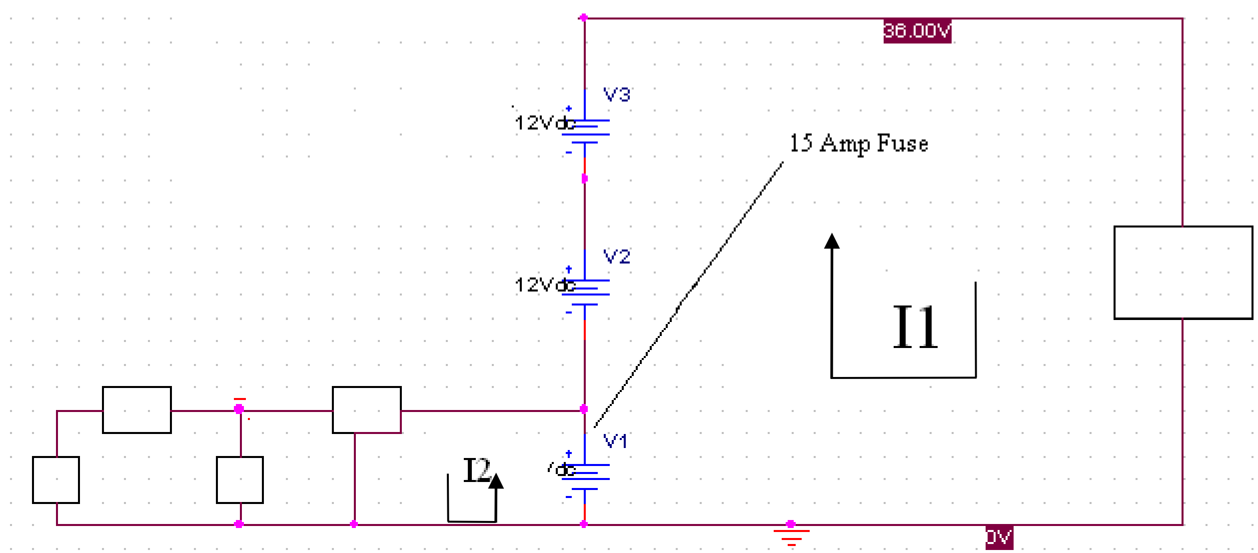


Figure 18. Schematic of power system simulation (top) and results (bottom)

Maximum Current Analysis

The combined current of I1 and I2 must never exceed 15A.



Current Restrictions: $I1+I2 < 15A$

Figure 19. Diagram of circuit with fuse

Power Subsystem Overview

PHASE 1: Regolith Collection
PHASE 2: Regolith Deposit into Collector

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

Maximum Device Specifications in accordance to phase and 15A draw limit:

Device	Maximum Allowable Current Draw	Maximum Power Draw
Drive Motor 1	5A	180W
Drive Motor 2	5A	180W
Conveyor Motor	2A	72W
Linear Actuator	12A	432W
MCU/Sensors	2A	12W

Telerobotic Interface

- Network provided now has no delay
  - Control robot directly – not autonomous

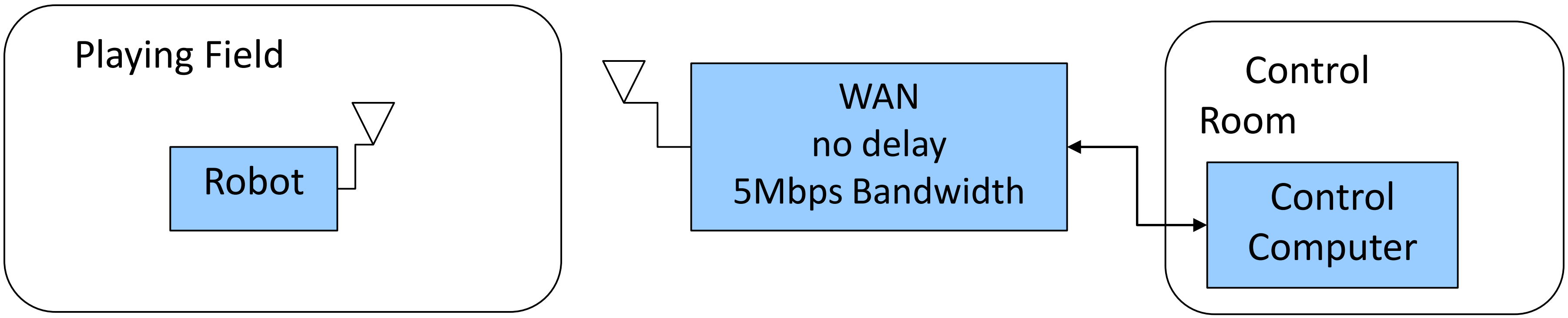


Figure 20. Diagram of communications during competition

- Link Robot to WAN Wirelessly
  - WiFi access point to WAN provided
  - Using serial to WiFi module on robot
- Virtual serial port redirection software on control computer
  - Works like wired serial connection from both ends
- Transmit data as ASCII character

Microcontroller Side

Programming tasks required for microcontroller

- Read in data from sensors
- Send gathered data through comm link
- Receive commands through comm link
- Drive motors for that command
- Control loop to keep motors at correct speed

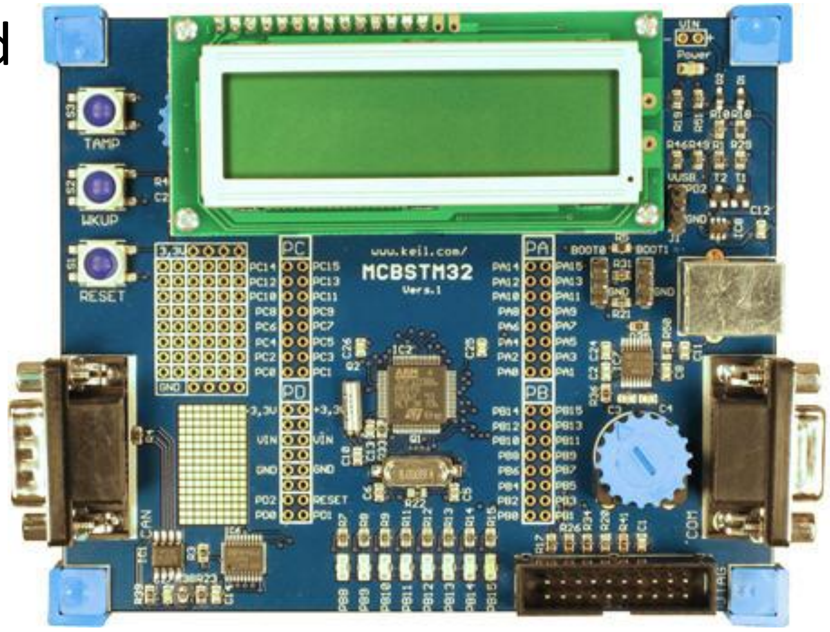
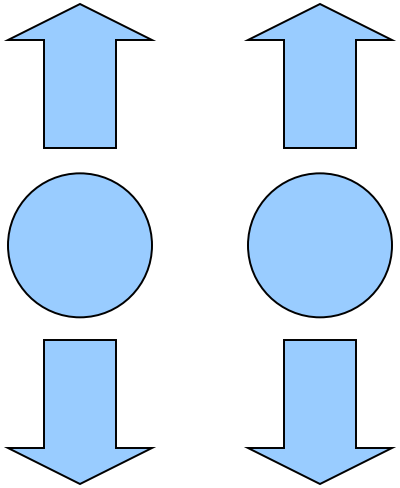


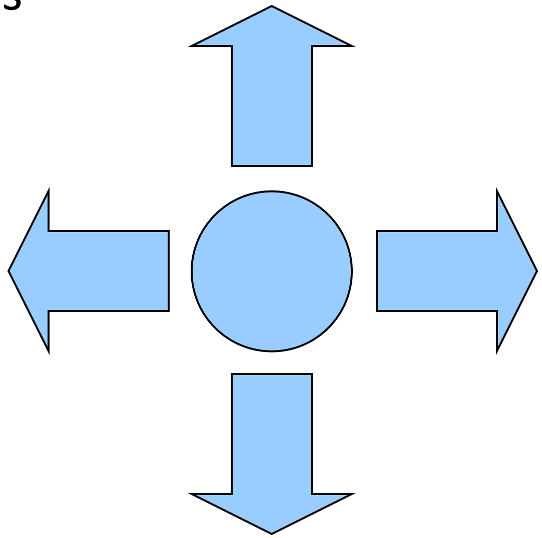
Figure 21. ARM Microcontroller

Control Computer Side

- Programming tasks required for control computer
  - Read in and interpret input from a joystick – PS2 controller
  - Send commands over comm link
  - Receive and display data from comm link
- Two options for control of drive motors



Direct
Each joystick directly
controls a drive motor



Indirect
Drive motors to go in
direction of joystick

Controller

The standard PS2 controller has 15 buttons; all of them, except for start and select, which are analog. They include:

- Four buttons arranged as a directional pad on the top left
- Analog, Start and Select buttons in the top middle
- Four action buttons on the top right
- Two action buttons on the front left
- Two action buttons on the front right
- One analog joystick on the top left
- One analog joystick on the top right

Figure 22. Example of controller inputs

Figure 23. Internal circuitry of controller

Sensors

- **Accelerometer**
  - Accelerometers provide position and direction sensing independent of the robots environment
  - Accelerometers measure acceleration in X, Y, and Z axis
- **Tactile Bump Sensor Circuits**
  - Once sensors run into an object a signal is sent to the microprocessor.

Figure 24. Three axis accelerometer

Figure 25. Bump Sensor

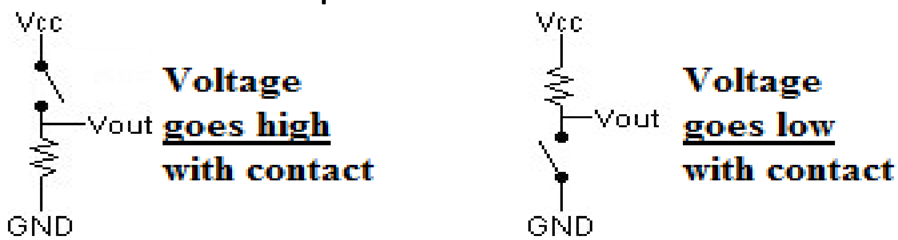


Figure 26. Bump Sensor Circuit

Sensors

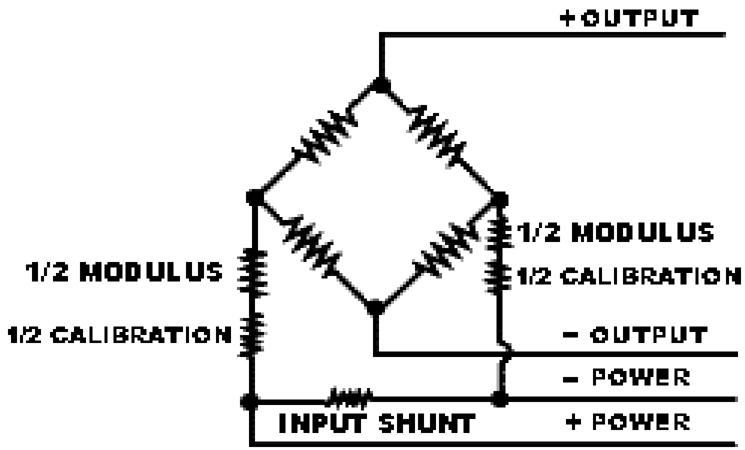


Figure 27. Weight Sensor Circuit uses a wheatstone bridge to measure electrical resistance

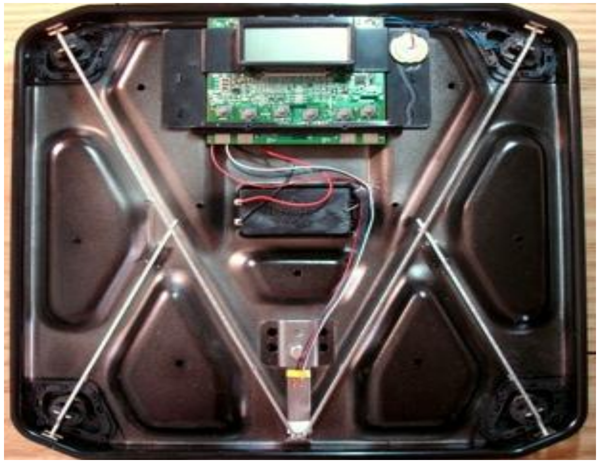


Figure 28. Weight sensor in situ

Figure 29. Web camera for sensing environment

Figure 30. Current sensor

Cost Analysis of System

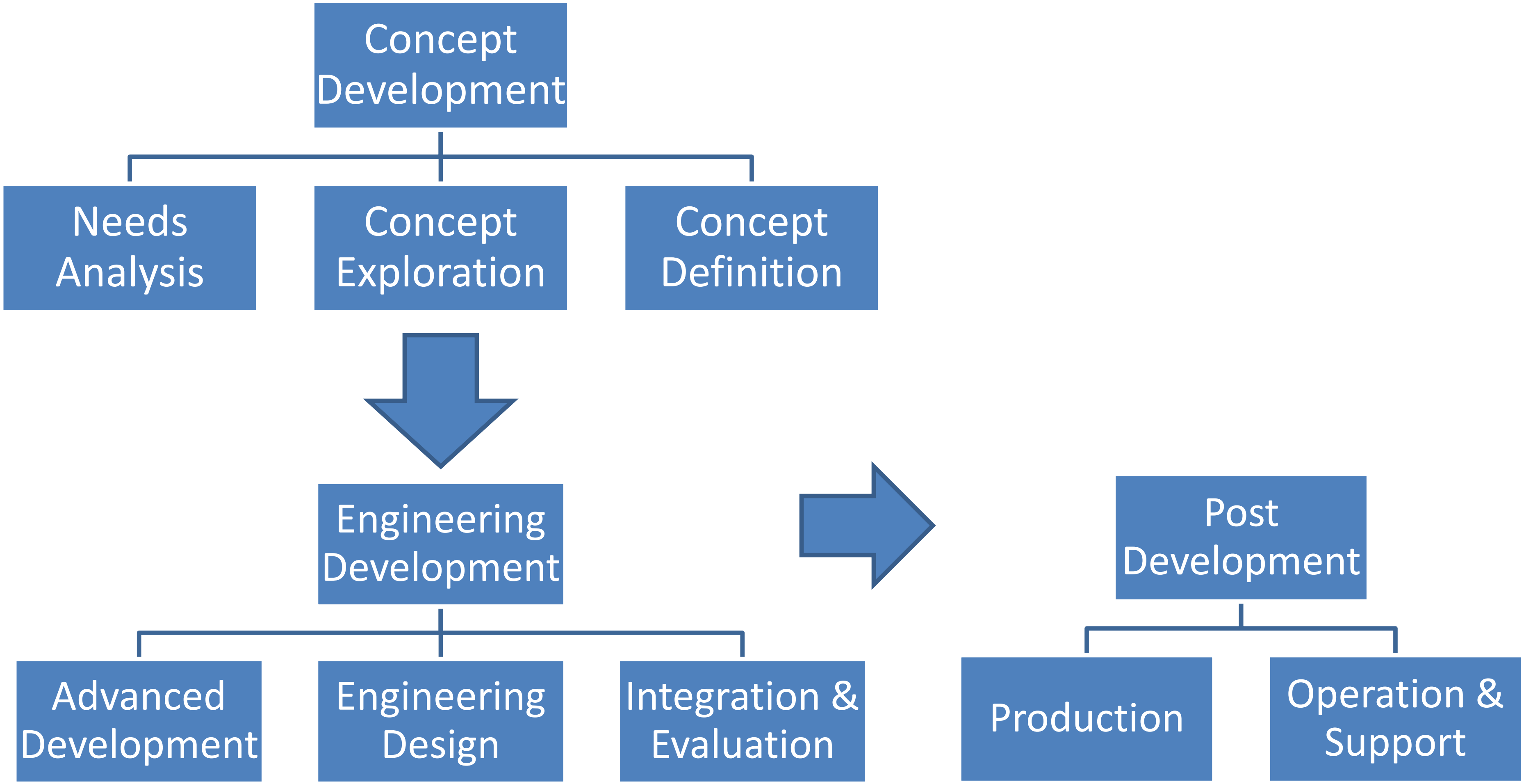
The Artemis Project Budget Breakdown

Part Description	QTY	Price	Total
Excavation			**$1,237.78**
Radial Ball bearings	1	$8.95	$8.95
Tensioner Belt	1	$5.45	$5.45
Washer	2	$0.35	$0.70
Frame Mounting hardware	3	$5.78	$17.34
Tensioner Mounting Bolts	1	$5.78	$5.78
Sheet AL6061	2	$46.28	$92.56
AL 1.5" Tube	1	$34.76	$34.76
AL 3" Tube	1	$28.94	$28.94
AL 1" Tube	1	$17.83	$17.83
0.5" Square Al Sheet	1	$26.28	$26.28
Paddle belt	1	$63.24	$63.24
Radial gear	1	$17.58	$17.58
Teflon sheet	1	$47.56	$47.56
Aluminum Sheet	1	$61.81	$61.81
Linear Actuator	1	$809.00	$809.00
Locomotion			**$3,702.47**
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
Roller, 40mmx50mm	2	$31.90	$63.80
Brass Flat plate, 3/32"x3/4"x72"	2	$21.56	$43.12
Maxon Motor Controller	2	$497.09	$994.18
Maxon DC Motor	2	$661.72	$1,323.44

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
Control			**$43.00**
3-Axis Accelerometer	1	$50	$50.00
Bumper Sensor	2	$1.50	$3.00
Weight Sensor	1	$40.00	$40.00
Total Cost of System			**$6,123.10**
Miscellaneous Costs (Shipping, etc)	1		$300
Regolith Simulant for evaulation	1		$500

Current cost of system: $6,123.10

Lifecycle


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

Conclusions

- Cleated Conveyor belt used for excavation
- Tracks on either side used for locomotion
- Lead-acid batteries for power
- ARM Microcontroller for processing
- Tele-robotic interface using sensors

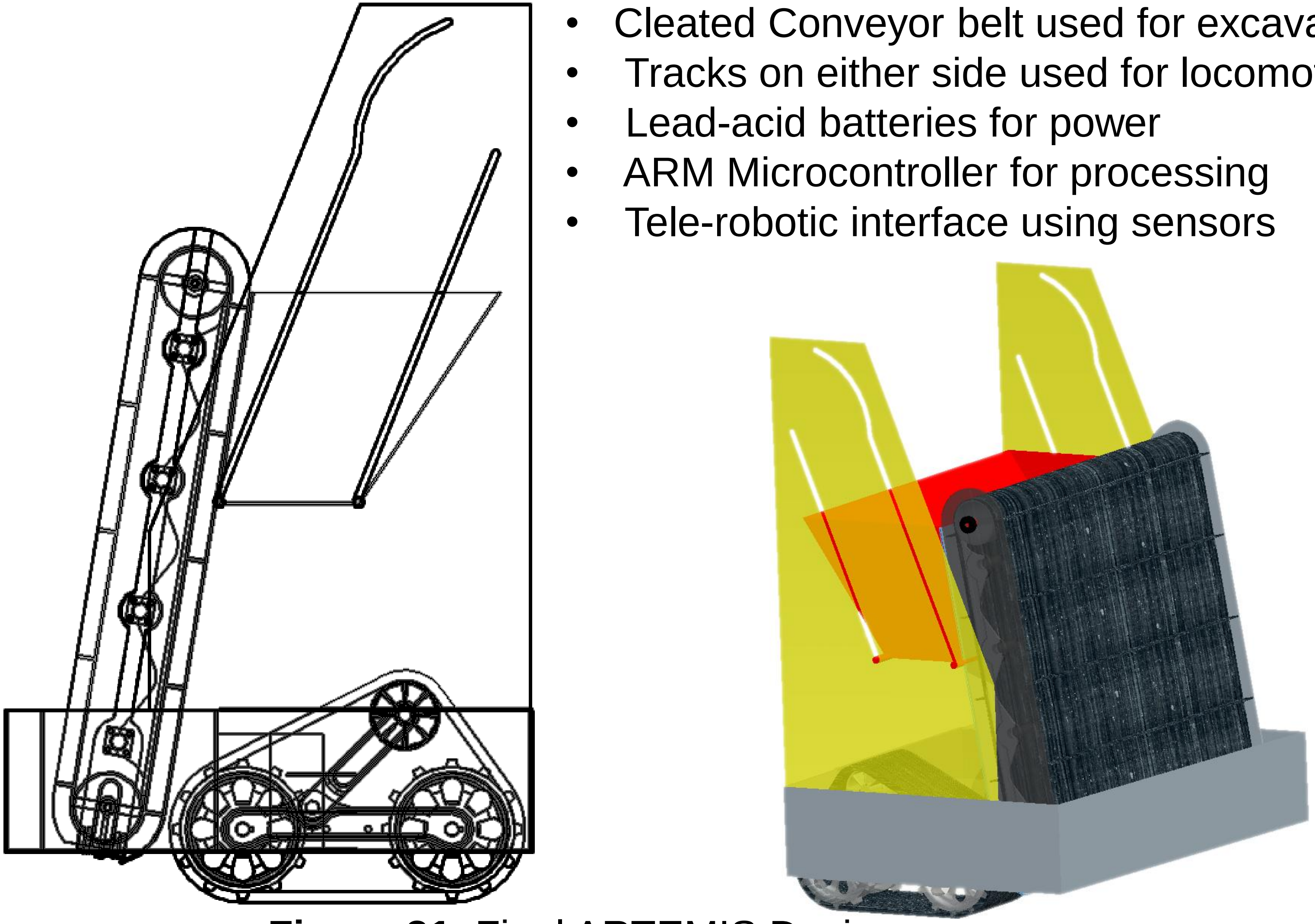


Figure 31. Final ARTEMIS Design

Questions and Comments

The ARTEMIS Project