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NASA LUNABOTICS ROBOTIC MINING COMPETITION 10TH ANNIVERSARY (2010 – 2019): TAXONOMY AND TECHNOLOGY REVIEW

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Introduction

The annual NASA Robotic Mining Completion (RMC): Lunabotics competition is a full-on engineering exercise where students receive practical experience in the full engineering lifecycle process from concept development, design, robot fabrication, hands on competition to system closeout.

- **Robot Controlled Remotely or Autonomously**
- **Visual and Auditory Isolation from Operator**
- **Excavates Black Point 1 (BP-1) Lunar Basalt Regolith Simulant**
- **Weight Limit - 60 kg**
- **Dimension Limits - 1.0 m length x 0.5 m width x 0.5 m height**
- **Designed, Built and Tested by University Student Teams**
- **Uses NASA systems engineering methods**
- **Over 55 US universities attend each year at Kennedy Space Center**

https://www.nasa.gov/offices/education/centers/kennedy/technology/nasarmc.html

[redacted]

Past Winners:

Year	Joe Kosmo Prize	Robotic On-Site Mining	Systems Engineering Report
2010	Montana State University	Montana State University	Auburn University
2011	University of North Dakota	Laurentian University	John Brown University
2012	The University of Alabama in collaboration with Shelton State Community College	Iowa State University in collaboration with Wartburg College	Montana State University - Bozeman
2013	Iowa State University	Iowa State University	The University of Alabama
2014	The University of Alabama	Iowa State University	Milwaukee School of Engineering
2015	The University of Alabama	The University of Alabama	University of Illinois Urbana-Champaign
2016	The University of Alabama	The University of Alabama	University of Illinois Urbana-Champaign
2017	The University of Alabama	The University of Alabama	Case Western Reserve University
2018	The University of Alabama	The University of Alabama	The University of Alabama
2019	The University of Alabama	NA*	The University of Alabama

Autonomy:

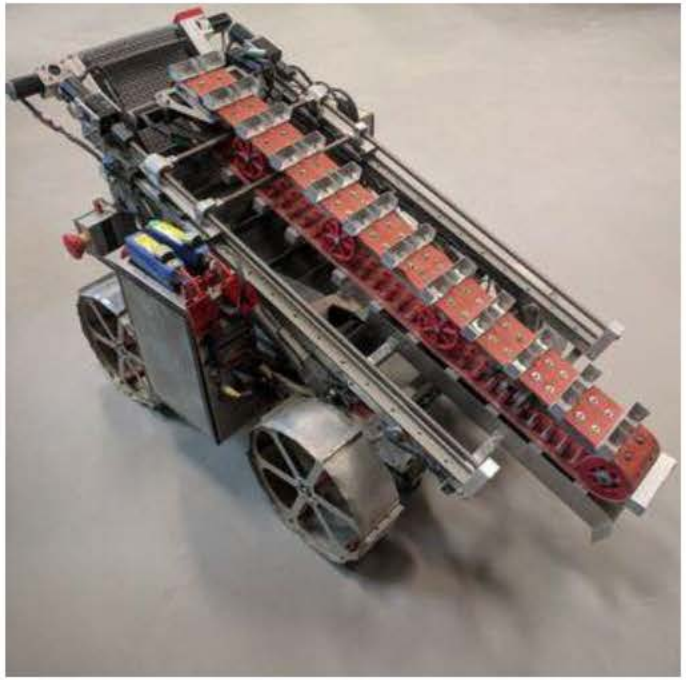
Year	Caterpillar Autonomy Award
2013	None
2014	None
2015	1st – University of Alabama
2016	1st – University of Alabama 2nd - South Dakota School of Mines
2017	1st – University of Alabama 2nd - University of Illinois at Chicago 3rd - University of North Carolina at Charlotte

Year	Caterpillar Autonomy Award
2017	1st – University of Alabama 2nd - University of Illinois at Chicago 3rd - University of North Carolina at Charlotte
2018	1st – University of Alabama 2nd - North Dakota State University 3rd - North Carolina at Charlotte
2019	1st – University of Alabama 2nd – North Dakota State University 3rd – Colorado State University 4th – Case Western Reserve University

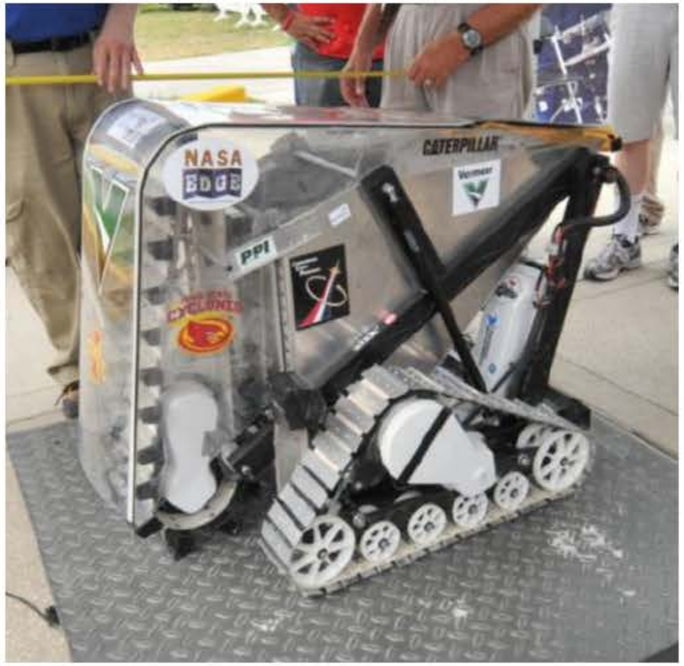
Most popular excavation and regolith transportation mechanisms

# sys	**regolith excavation mechanism**	# sys	**regolith transportation mechanism**
101	bucket ladder	103	bucketladder
37	front end loader	40	in scoop
29	bucket belt	22	conveyor belt
27	bucketwheel	21	bucketbelt
17	bucket drum	15	auger
15	snow blower (auger or brush)	11	Over shoulder dump into hopper
12	auger	8	chute for guiding regolith
8	backhoe	7	bucketdrum
8	bulldozer	7	drum
8	scraper	6	bucketwheel
7	large single scoop	6	impeller
4	dual auger	4	bucket rim
4	dual bucket wheel	4	bucketwheel discharge through bottom
4	rotating brush	4	in bucket
3	excavating wheels	4	rotate scoop to slide simulant in hopper
2	claw/gripper scoop	3	throw from impeller
2	dual bucketladder	2	bucketwheel with side discharge
2	dual counter rotating bucketdrums	2	paddle conveyor
2	large bulldozer scoop	2	raising scraper with chute
2	paddle conveyor	2	thrown from brush up ramp

Most popular excavation and regolith transportation mechanisms:



University of Alabama



Iowa State University

Vanderbilt University

Most popular excavation and regolith transportation mechanisms:

Illinois Institute of Technology

University of Utah

Front End Loaders

Most popular regolith storage and regolith dumping mechanisms

# sys	regolith storage mechanism	# sys	regolith dumping mechanism
213	hopper	111	rotating tilting hopper
41	in scoop	36	conveyor belt as bottom and inclined side c
10	drum	30	scoop tilting
6	bucketdrum	7	auger
6	on conveyor belt	6	counter rotate buckedrum
4	auger	6	raising/tilting hopper/ scissor lift
3	scraper	5	conveyor belt
2	in bucket	5	fixed rotating hopper
1	bucketdrums	4	raising hopper with back chute
1	bucketladder	4	rotate and lift scoop to slide off back into co
1	bulldozer	4	scissor lift and tilting hopper
1	drums	4	tilted raised drum
1	in auger pipe	3	bucketladder
1	in clamshell	3	raising counterrotating drum
1	inside tube body	3	raising hopper with bottom conveyor belt
1	large conveyor belt with crazy carpet	3	tilting raising scoop
1	saddle hopper (two sides)	3	tilting scoop
1	scraper scoop	2	angled vibrating hopper
1	side hopper	2	chute
1	slide	2	horizontal conveyor belt

Most popular regolith storage and regolith dumping mechanisms

In Hopper
In Scoop
In Drum

Rotating tilting Hopper
Conveyor in bottom and inclined conveyor
Scoop Tilting

Most popular robot movement mechanisms

	robot
# sys	**movement mechanism**
173	4 fixed wheels
73	tracks
21	6 fixed wheels
10	4 steerable wheels with custom profile
6	two auger drums to propel
5	stationary with swivel
4	4 fixed track wheels
3	4 digging wheels
2	3 wheels (2 driven, one steering)
2	4 six-legged wheels
2	4 wheels with suspension
2	each of two robots hase 4 fixed wheels with grousers
2	four individual steerable tracks
2	three robots working together, two transport, one excavator, each with 4 fixed wheels
1	3 fixed wheels (front wheel swivels freely)
1	3 large wheels (2 with grousers, third with scoops)
1	4 medium and 2 large front wheels
1	4 wheels (two steerable coupled) with grousers
1	4 wheels with grousers, two of which have buckets to fill with regolith to increase counterweight
1	4 wheels, of which 2 steerable rear wheels

Most popular robot movement mechanisms

4 fixed wheels
tracks
6 fixed wheels

Localization Algorithm / Architecture Approaches (2019 results)

Localization Algorithm / Architecture Approaches	**# of machines employing Algorithm / Architecture Approaches types**	**Sensors**	
	Position & Orientation	Position & Orientation	Relative Change in Position & Orientation
Position & Orientation – Only (6)			
Fiducials (5)	AprilTags (4)	Mono Camera	NA
	Pixel sizing objects at known distance apart (1)	Mono Camera	NA
Ranging Radio Beacons (1)	Simple Triangulation (1)	DecaWave TOF radios	NA
	Position & Orientation	Fusion Method	
Position & Orientation – w/ fusion of relative change in position/orientation (5)			
Fiducials (4)	April Tags (3)	Stereo Camera	IMU 6 DOF, Encoders
		Stereo Camera	Encoders
		Stereo Camera	Stereo Camera – Visual odometry
	Specialized fiducials for LIDAR (1)	LIDAR	IMU 6 DOF, Encoders
Ranging Radio Beacons (1)	Simple Triangulation (1)	DecaWave TOF radios,	IMU (3axis gyros), Encoders

Perception Algorithm / Architecture Approaches (2019 results)

Perception Algorithm / Architecture Approaches	**# of machines employing Algorithm / Architecture Approaches types**	**Sensors**
Object extraction based on Ground State Estimation	6	Stereo Camera (4) LIDAR (2)
Object extraction based on Normal Vectors to terrain	1	Stereo Camera
Object extraction based on Artificial Intelligence – Convolutional Neural Network	2	Mono Camera (1) Stereo Camera (1)
Fly Blind	2	NA

Algorithm / Architecture Approaches (2019 results)

Mission Planning Algorithm / Architecture Approaches	# of machines employing Algorithm / Architecture Approaches types
Navigation Planning	
A* based on occupancy grid	5
D* based on occupancy grid	1
Rapidly explored Random Trees (RRT) w/ Modified Dynamic Window	1
Predefined plan	4
Excavation Planning	
Velocity Control	1
Torque Control	2
Position Control	2
Velocity & Torque Control	3
Position & Torque Control	1

Conclusions:

- This paper has presented the results of ten Lunabotics Robotic Mining Competitions (RMC) held between May 2010 and May 2019.
- Each year over 50 university teams have attended, resulting in over 500 excavation robot designs and subsequent prototypes.
- Over 6,000 university students have been part of the on-site competition at KSC.
- Even more students and the public were engaged via internet broadcasting and social networking media.
- The various designs have been cataloged and categorized here to provide information to future Lunabotics RMC mining robot designers and competitors.
- In addition, the paper discussed changes in learning paradigms occurring in the current generation of students, and how this competition leverages those changes to challenge students to develop skills in graduate level concepts and apply them.
- Examples of how this translates to hiring opportunities for commercial sponsors has also been discussed.
- Overall, the RMC continues to be a success after ten years of annual competitions.

Inspiring the Next Generation!

University of Alabama: Outreach 2020
https://www.alabamaastrobotics.com/2020-outreach.html