

Team 523: Mixed Reality Wearable for 3D Body Tracking

FAMU-FSU College of Engineering



Team Introductions



Timothy Rubottom *Project Manager & System Integration*



Joshua Segall Design Engineer



Caleb Pitts Fabrication Engineer



Matthew Bigerton Test Engineer



Josiah Bazyler Mechatronics Engineer





Sponsor and Advisor

Philanthropic Contributor Yubin Xi, Ph.D. Human Factors Engineer



<u>Academic Advisor</u> Shayne McConomy, Ph.D. *SD Professor*







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Project Overview

- Anthropometry is the measurement of the size and proportions of the human body
- Anthropometric scans typically output a 3D figure that can be used for body measurements and for Engineering design



Figure 1: 3D cad image of different hand views



Project Overview (cont.)

- Currently, scan participants are given verbal instructions on where and how to position and orient themselves for an anthropometric scan
- This process is tedious and time consuming for the scan technician



Figure 2: Example of 3D scanning





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Objective

The objective of this project is to provide a user interface for a participant in a 3D body scan environment in order to shorten the duration of the overall process by reducing the amount of instructions given by the scan technician to position/orient the participant.



Figure 3: Example of a visualization

Design Process





Customer Needs

Table 1: Customer needs table

#	CUSTOMER STATEMENTS	INTEPRETED NEED
1	It would be beneficial if the device could indicate to the user when the "ideal scan location" is filled	If possible, the device will be able to notify the user to hold the current orientation of the participant's head/hand
2	The device must not interfere with the scanner	The device must cease operating upon successful fulfillment of the ideal pose
3	Project something into space for the participant to aim their head/hand	The device must indicate to the participant the ideal location and orientation for accurate scans
4	The device must be a stand-alone system	The device must complete its intended function without the assistance of other devices
5	The device must be able to be powered remotely	The device requires a method for power control
6	The device must not create any safety hazards	The device must minimally impact the participant

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Functional Decomp.

- Functional Decomposition acted as a funnel for the ideation process
- From top to bottom, the boxes become more and more specific



Joshua Segall

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Targets & Metrics

- Functional decomposition led to a large set of targets & metrics (T&M) that was determined to be necessary for a successful design
- These are the most important T&M from the original list
 - They satisfy industry/governmental standards

Table 2:	Customer	needs	table
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Mixed Reality Wearable For Body Tracking						
Main Functions	Sub-Functions	<u>Metrics</u>	<u>Targets</u>			
	Self-Contained	Dimensions (in)	≤ 30 x 30 x 30			
Device		Weight (lbs)	≤ 25			
	Free of Interfernece	Distance From Scanner (m)	~ 1			
Safety	Safe For Participant	Brightness Level (Lumens)	≤ 200			
Visual Indication	Signals Participant to Hold Position	Time in designated location and Orientation (Seconds)	< 30			



Concept Generation: Overall Design

- 1. AR and Leap Motion
- 2. Mirage/Schlieren Imaging
- 3. BMW Holo-Touch
- 4. 3D Image Live Feed Camera
- 5. Adafruit with 3D Camera
- 6. Illumination Mirascope
- 7. Semi-Autonomous Robot with 3D camera
- 8. Mixed Reality Wearable for 3D body tracking





Concept Selection: Overall Design

- AHP shows the results of our re-calculated concept selection
- Final selection found that the Mixed Reality
 Wearable was in fact the best selection

Table 3: Analytical Hierarchy Process

SELECTION:	Mixed Reality Wearable	Adafruit w/ 3D Camera	Semi-Automatis Robot w/ 3D Camera		
Design Volume	0.64	0.36	0.10		
Weight	0.45	0.10	0.45	Table 4: Final S	Selection
Distance from Scanner	0.45	0.23	0.22	FINAL CONCEPT V	VEIGHTED
Tolerance of Depth Measurement	0.57	0.15	0.29	Mixed Reality Wearable	0.56
Brightness Level/Intesity Level	0.60	0.20	0.20	Adafruit w/ 3D Camera	0.21
Operationg Temperature:	0.70	0.10	0.10	Semi-Autonomous Robot w/ 3D Camera	0.23
Resolution	0.60	0.20	0.20		
Operating Time	0.43	0.36	0.30		
SUM	4.44	1.70	1.86		



Concept Generation: Wearable

Table 5: Various Wearable concepts





Concept Selection: Wearable Design

Table 6: Wearable Concept Selection

	Scale (1,3,6)												
Needs:	Weight:	ldea 1	11	ldea 2	12	Idea 3	13	ldea 4	14	ldea 5	15	ldea 6	16
Multiple Tags	6	6	36	6	36	3	18	6	36	3	18	6	36
Easy Removal	12	6	72	1	12	3	36	6	72	1	12	6	72
Consistant Placement	10	6	60	3	30	3	30	6	60	6	60	3	30
Aesthetics	2	3	6	3	6	9	18	1	2	3	6	6	12
Versatile Placement	4	6	24	1	4	3	12	6	24	3	12	3	12
Easy to put on/tighten	8	6	48	3	24	3	24	6	48	6	48	3	24
	Totals	24	16	11	2	13	8	24	2	15	6	18	6
	Rank	1	l	6	3	5		2		4		3	



Figure 5: 3D printed hand with wearable attached

Winner:
Elastic Band with AprilTags Clipping on, with Dove Tail release



Figure 6: 3D printed wearable





Design Production





Design Components

- 1) ZED Mini
 - 3D Camera
- 2) Wearable
 - Apriltag(s) attach to it
- 3) NVIDIA Jetson TX2 Computer
 - Tracks Apriltag with Robot Operating System (ROS)
- 4) Steady State Monitor
 - Information is displayed through Rviz/Gazebo (virtual worlds)



Figure 7: Overall design setup



Progress: ROS

 Can track/display the position & the orientation of the ZED Mini within Rviz



Figure 8: Video of the ZED Mini's pose being tracked in Rviz



Progress: ROS (Cont.)

- Need to finalize 2 input parameters in order to use the "AprilTags2" node within ROS
 - Nodes are executables that communicate with other nodes within ROS



Figure 9: Inputs and outputs of the "apriltags2_ros" node



Wearable Iterations



Figure 10: Apple Watch concept



Figure 11: Temporary tattoo concept



Figure 12: Magnetic bracelet concept

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Future Testing

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Future Testing



Figure 13: AprilTag pose tracking



Figure 14: Drop and impact testing



Figure 15: Increasing efficiency



Main Takeaways

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Most Important Points

- 1. Can currently track/display the pose of the ZED Mini in Rviz
- 2. Have a functional/versatile wearable design
- 3. Need to finalize the 2 input parameters for the ROS node
- 4. Need to order a mobile monitor adjustable mount (~\$56)
- 5. Need to attribute a 3D image to an AprilTag within Rviz or Gazebo
- Need to place a stationary 3D image in an ideal pose within Rviz or Gazebo



Lessons Learned

- 1. Everything that can go wrong...
- 2. Continue to think about splitting up workloads evenly so that nobody has to be working on the project until 4:00am
 - Quality of work goes down at this time of hour
- 3. Transforming multiple moving 3D frames into a camera frame is incredibly challenging
- 4. Wearable design needs to have a balance between satisfying the problem as well as sparking interest in the participant/customer



References

- Garrido-Jurado, S., Muñoz-Salinas, R., Madrid-Cuevas, F., & Marín-Jiménez, M. (2014). <u>"Automatic generation and detection of highly reliable fiducial markers under occlusion,"</u> *Pattern Recognition,47*(6), 2280-2292. doi:10.1016/j.patcog.2014.01.005
- 2. Malyuta, D. (2017). "<u>Navigation, Control and Mission Logic for Quadrotor Full-cycle</u> <u>Autonomy</u>," Master thesis, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA.
- 3. Romero-Ramirez, F. J., Muñoz-Salinas, R., & Medina-Carnicer, R. (2018). <u>"Speeded up</u> <u>detection of squared fiducial markers,"</u> *Image and Vision Computing*, 76, 38-47. doi:10.1016/j.imavis.2018.05.004
- 4. Wang, J. & Olson, E. (2016). "<u>AprilTag 2: Efficient and robust fiducial detection</u>," in *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS).*



Questions?

Josiah Bazyler



Backup Slides



Functional Decomp Backup



Targets and Metrics Backup



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Targets and Metrics

Table #:Full Targets and Metrics Table

Ideal Location Indicator For Anthropometric Scanners					
Main Function	Sub-Functions	<u>Metrics</u>	<u>Targets</u>		
	Solf Contained	Dimensions (in)	≤ 30 x 30 x 30		
	Sen-Contained	*Weight (lb.)	≤ 25		
Device	Free of Scanner Interference	*Distance from Scanner (m)	~ 1		
	Accurately displays location and orientation	*Tolerance of depth Measurement (cm)	≤ 4		
	Safe for participant	*Brightness level (Lumen)	< 200		
Safety		Intensity level (Lux)	< 200		
	Safe for operator	Operating temperature (°F)	< 150		
	Clearly seen by participant	Perceived Brightness level (Lux)	100 - 200		
Visual Indication	oleany seen by participant	Resolution (Pixel)	≥ 480		
	Signals participant to hold position	*Time in designated Location & Orientation (Second)	< 30		
Power	Power supply	Power consumption (Watts)	< 11		
FUWEI	гомет заррту	Operating voltage (Volts)	≤ 55		





Targets and Metrics: Device

- The device must be self contained
- Does not interfere with the scanner
- Accurately displays where the participant should be and how they should be orientated

Table #: Targets and Metrics Table Row 2

Ideal Location Indicator For Anthropometric Scanners					
Main Function	Sub-Functions	<u>Metrics</u>	<u>Targets</u>		
Device	Solf Contained	Dimensions (in)	≤ 30 x 30 x 30		
	Sen-Contained	*Weight (lb.)	≤ 25		
	Free of Scanner Interference	*Distance from Scanner (m)	~ 1		
	Accurately displays location and orientation	*Tolerance of depth Measurement (cm)	≤ 4		



Targets and Metrics: Safety

The device should be safe for the participant and the operator Table #: Targets and Metrics Table Row 2

Ideal Location Indicator For Anthropometric Scanners						
Main Function	Sub-Functions	<u>Metrics</u>	<u>Targets</u>			
	Safe for	*Brightness level (Lumen)	< 200			
Safety	participant	Intensity level (Lux)	< 200			
	Safe for operator		< 150			



Device will signal them to

hold the current position

The "sweet spot" must be

clearly seen by the

participant

Table #: Targets and Metrics Table Row 3

Ideal Location Indicator For Anthropometric Scanners					
	Main Function	Sub-Functions	<u>Metrics</u>	<u>Targets</u>	
		Clearly seen by	Perceived Brightness level (Lux)	100 - 200	
	Visual Indication	participant	Resolution (Pixel)	≥ 480	
		Signals participant to hold position	*Time in designated Location & Orientation (Second)	< 30	



Targets and Metrics: Visual Indication

Targets and Metrics: Power

- Power is important for
 - ➤ Safety
 - ➤ Efficiency

Table #: Targets and Metrics Table Row 4

"Sweet Spot" Indicator For Anthropometric Scanners					
Main Function	Sub-Functions	<u>Metrics</u>	<u>Targets</u>		
Power	Doworowoolu	Power consumption (Watts)	< 11		
	Power supply	Operating voltage (Volts)	≤ 55		



Concept Selection Backup



Concept Selection: Pair Wise Comparison

Concept Selection Process:

Pair Wise Comparison

Customer Requirements	Weight	Importance
1) Self Contained	1	6
2) Doesn't interfere with scanner	4	1
5) Clearly seen by participant	4	2
3) Accurately displays "Sweet Spot" Location	2	3
6) Signals to hold position and orientation	2	4
4) Accurately displays desired orientation	2	5

Table #: Pair Wise Comparison Results for Customer Requirements



Concept Selection: House of Quality

Concept Selec	ction Process:		Tal	ble # : House d	of Quality						
House of	f Quality	Engineering Characteristics									
	Improvement Direction	↓	↓	-	Î	-	↓	↑	Ļ		
	Units	in³	lbf	m	cm	Lumen/Lux	۴F	Pixel	Sec		
Customer Requirements	WF	Design Volume	Weight	Distance from Scanner	Tolerance of Depth	Brightness Level/Intesity	Operating Temperature	Resolution	Operating Time		
Self Contained	1	9	3	3			3				
Does Not Interfere with the Scanner	4	9		9	3	9	1				
Accurately Displays the "Sweet Spot" Location	3			9	9	9	1	9	3		
Accurately Displays the Desired Orientation	2			9	9	9	1	9	3		
"Sweet Spot" clearly Seen by the Participant	4			9	3	9	1	9	9		
Signals to the Participant to Hold/Update Position and Orientation	2			3		9	1	9	9		
Raw Score	564	45	3	126	69	135	18	99	69		
Percentage	(%)	7.98	0.53	22.34	12.23	23.94	3.19	17.55	12.23		
Rank		5	7	2	4	1	6	3	4		



Concept Selection: Pugh Matrix Round 1

Concept Selection Process:

Pugh Matrix

Table #: First Pugh Chart for final 8 concepts

Selection Criteria		AR & Leap Motion	Mirage/ Schlieren	BMW Holo-Touch	3D Image Live Feed Camera	Cast of Hand/Head	Adafruit w/ 3D Camera	Illuminating Mirascope	Semi-Automatic Robot w/ 3D Camera
1) Self Contained		+	-	+	-	+	S	+	+
2) Does Not Interfere with the Scanner		+	-	S	+	S	S	+	+
3) Accurately Displays the "Sweet Spot" Location	DATUM: Hypervsn Wall	+	-	+	+	+	+	S	+
4) Accurately Displays the Desired Orientation		+	-	+	+	+	+	+	+
5) "Sweet Spot" clearly Seen by the Participant		S	-	-	+	+	+	-	-
6) Signals to the Participant to Hold/Update Position and Orientation		+	-	+	+	-	+	+	S
7) Price		+	+	+	+	+	+	+	+
# of Pluses (+)		6	1	5	6	5	5	5	5
# of Minuses (-)		0	6	1	1	1	0	1	1

"S" – Similar

r "+" – Concept plus

"-" - Concept negative



Concept Selection: AHP #1

Concept Selection Process:

AHP

				Normalized [C]		Table #: Ar	nalytical H	ierarchy Pro	ocess					
Evaluation Criteria	Design Volume	Weight	Distance from Scanner	Tolerance of Depth Measurement	Brightness Level/Intesity Level	Operating Temperature	Resolution	Operating Time	Weight Factor	ws	Consistency			
Design Volume	0.060	0.100	0.041	0.115	0.029	0.150	0.056	0.115	0.083	0.726	8.717	Lambda	8.956	
Weight	0.020	0.033	0.029	0.038	0.016	0.050	0.056	0.038	0.035	0.300	8.543			
Distance from Scanner	0.300	0.233	0.205	0.346	0.146	0.150	0.167	0.115	0.208	1.919	9.231	CI	0.137	Reference
Tolerance of Depth Measurement	0.060	0.100	0.068	0.115	0.438	0.050	0.167	0.115	0.139	1.370	9.837	CR	0.098	CR < 0.10
Brightness Level/Intesity Level	0.300	0.300	0.205	0.038	0.146	0.250	0.167	0.346	0.219	1.954	8.918			
Operating Temperature	0.020	0.033	0.041	0.115	0.029	0.050	0.056	0.038	0.048	0.425	8.870			
Resolution	0.180	0.100	0.205	0.115	0.146	0.150	0.167	0.115	0.147	1.333	9.046			
Operating Time	0.060	0.100	0.205	0.115	0.049	0.150	0.167	0.115	0.120	1.020	8.490			
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000					



Concept Selection: AHP #1 Continued

Concept Selection Process:

AHP

- The final concept was determined using multiple pair wise comparisons for each engineering characteristic
- The output is the weighted number ranking of the final 3 selections

Table #: Analytical Hierarchy Process

	pi		
SELECTION:	Semi-Automatic Robot w/ 3D Camera	Adafruit w/ 3D Camera	3D Image Live Feed Camera
Design Volume	0.11	0.26	0.63
Weight	0.09	0.45	0.45
Distance from Scanner	0.23	0.32	0.45
Tolerance of Depth Measurement	0.57	0.29	0.14
Brightness Level/Intesity Level	0.60	0.20	0.20
Operationg Temperature:	0.60	0.20	0.20
Resolution	0.60	0.20	0.20
Operating Time	0.14	0.43	0.43
SUM	2.94	2.35	2.71

Table #: Final Selection

FINAL CONCEPT WEIGHT							
Semi-Automatic Robot w/ 3D Camera	0.40						
Adafruit w/ 3D Camera	0.28						
3D Image Live Feed Camera	0.32						



Concept Selection: Pugh Matrix Round 2

Concept Selection Process:

Pugh Matrix

Selection Criteria		BMW Holo-Touch	Mixed Reality Wearable	Cast of Hand/Head	Adafruit w/ 3D Camera	Illuminating Mirascope	Semi-Automatic Robot w/ 3D Camera
1) Self Contained		-	+	S	+	+	+
2) Does Not Interfere with the Scanner		-	+	+	-	-	S
3) Accurately Displays the "Sweet Spot" Location	New Datum	-	+	-	S	-	S
4) Accurately Displays the Desired Orientation	AR & Leap Motion	S	+	-	S	S	S
5) "Sweet Spot" clearly Seen by the Participant		-	+	S	S	-	-
6) Signals to the Participant to Hold/Update Position and Orientation		S	S	-	S	S	S
7) Price		+	+	+	+	+	+
8) Multi Purposed		+	+	+	+	+	+
# of Pluses (+)		2	7	3	3	3	3
# of Minuses (-)		4	1	3	1	3	1

Table #: Pugh Matrix including the Mixed Reality Wearable



Bill of Materials: Preliminary Part 1

Table #: Part 1 of the Preliminary BoM

	TEAM 523 - Ideal Location Indicator BILL OF MATERIALS											
Part #	Part Name	Description	Quan tity	Vendor	Price	Price (after 7.5% tax)	BoM Maturity					
1	Base Plate	Plytanium 15/32" CAT PS1-09 Pine Sanded Plywood, 4' x 8'	1	Lowe's	\$27.85	\$29.94	50%					
2	Linear Actuator	Okin Refined Power Recliner Motor Actuator Model JLDQ-11	1	Sears	\$121.71	\$130.84	50%					
4	AL 8020 T-slotted Bar	Single Rail, Silver, 30 mm High x 30 mm Wide, Hollow	4	McMaster-Carr	\$159.76	\$171.74	50%					
5	M4 Screw	Alloy Steel Low-Profile Socket Head Screw	32	McMaster-Carr	\$10.83	\$11.64	50%					
6	M4 Washer	18-8 Stainless Steel Washer for M4 Screw Size, 4.3 mm ID, 9 mm OD	32	McMaster-Carr	\$1.86	\$2.00	50%					
7	M4 Nut	Steel Hex Nut, Medium-Strength, Class 8, M4 x 0.7 mm Thread	32	McMaster-Carr	\$1.32	\$1.42	50%					
8	M3 Screw	Alloy Steel Low-Profile Socket Head Screw	12	McMaster-Carr	\$7.00	\$7.53	50%					
9	Inside Corner Bracket	10pcs Of 3030 Corner Fitting Angle 30x30 Decorative Brackets Aluminum Profile Accessories L Connector	1	Aliexpress	\$7.79	\$8.37	50%					
10	Idler Pulley	GT2 5mm Bore Aluminum Toothless Timing Belt Idler Pulley	4	DHgate	\$11.00	\$11.83	50%					
11	Timing Belt Pulley	Aluminum GT2 Timing Pulley - 6mm Belt - 20 Tooth - 8mm Bore	4	Adafruit	\$ 31.80	\$34.19	50%					
12	Timing Belt Tensioner	Tensioner Locking Spring for GT2 Timing Belt (pack of 50)	1	Adafruit	\$2.75	\$2.96	50%					
13	Timing Belt	Timing Belt GT2 Profile - 2mm pitch - 6mm wide 1164mm long	1	Adafruit	\$9.95	\$10.70	50%					
14	Motor Mount Kit	Mounting bracket chassis mount for timing belt motors	2	Digi-Key Electronics	\$ 15.98	\$17.18	50%					

Table #: View of Full Preliminary BoM

		TEAM 523 - "SWEET SPOT" INDICATOR	RBILL	OF MATERIALS	3	Drive /after	Dell
Part#	Part Name	Description	tity	Vendor	Price	7.5% tax)	Maturity
1	Base Plate	Plytanium 15/32" CAT PS1-09 Pine Sanded Plywood, 4' x 8'	1	Lowe's	\$27.85	\$29.94	50%
2	Linear Actuator	Okin Refined Power Recliner Motor Actuator Model JLDQ-11	1	Sears	\$121.71	\$130.84	509
4	AL 8020 T-slotted Bar	Single Rail, Silver, 30 mm High x 30 mm Wide, Hollow	4	McMaster-Car r	\$159.76	\$171.74	505
5	M4 Screw	Alloy Steel Low-Profile Socket Head Screw	32	McMaster-Car r	\$10.83	\$11.64	50%
6	M4 Washer	18-8 Stainless Steel Washer for M4 Screw Size, 4.3 mm ID, 9 mm OD	32	McMaster-Car r	\$1.86	\$2.00	50%
7	M4 Nut	Steel Hex Nut, Medium-Strength, Class 8, M4 x 0.7 mm Thread	32	McMaster-Car r	\$1.32	\$1.42	50%
8	M3 Screw	Alloy Steel Low-Profile Socket Head Screw	12	McMaster-Car r	\$7.00	\$7.53	509
9	Inside Corner Bracket	10pcs Of 3030 Corner Fitting Angle 30x30 Decorative Brackets Aluminum Profile Accessories L Connector	1	Aliexpress	\$7.79	\$8.37	50%
10	Idler Pulley	GT2 5mm Bore Aluminum Toothless Timing Belt Idler Pulley	4	DHgate	\$11.00	\$11.83	501
11	Timing Belt Pulley	Aluminum GT2 Timing Pulley - 6mm Belt - 20 Tooth - 8mm Bore	4	Adathuit	\$31.80	\$34.19	507
12	Timing Belt Tensioner	Tensioner Locking Spring for GT2 Timing Belt (pack of 50)	1	Adaftuit	\$2.75	\$2.96	509
13	Timing Belt	Timing Belt GT2 Profile - 2mm pitch - 6mm wide 1164mm long	1	Adathuit	\$9.95	\$10.70	505
- 14	Motor Mount Kit	Mounting bracket chassis mount for timing belt motors	2	Digi-Key Electronics	\$15.98	\$17.18	
15	Wheel Motors	Cytron Power Window Motors w 5* Wheels (Pair)	2	Robotshop	\$125.00	\$134.38	505
16	Timing Belt Motor	Brushed DC Motor Gearmotor	4	Digl-key Electronics	\$79.96	\$85.96	509
17	3D Printer Filament	1.75 mm and 1 kg per Spool	1	Hatchbox	\$23.99	\$25.79	505
18	3D Camera	ZED Camera High-Resolution and High Frame-rate 3D Video Capture	1	Stereolabs	\$449.00	\$482.68	501
19	LCD Display	7" 1024 x 600 IPS Display	1	DFRobot	\$34.00	\$36.55	505
20	Microcontroller						
		Raspberry PI 3 Model B	1	Raspberry Pi	\$27.49	\$29.55	509
21	LED Lights	Raspberry PI 3 Model B Smm LEDs assortied colors (Yellow, Green & Red)	1	Raspberry Pi MS Direct	\$27.49 \$12.99	\$29.55 \$13.96	505
21	LED Lights Motor Driver for Robot Wheel	Raspbeny PI 3 Model B 5mm LEDs assoried colors (Yellow, Green & Red) Sabertooth Dual 2x32A 6V-24V Regenerative Motor Driver	1	Raspberry Pi MS Direct Robot Shop	\$27.49 \$12.99 \$119.99	\$29.55 \$13.96 \$128.99	505
21 22 23	LED Lights Motor Driver for Robot Wheel Motor Driver for V-Wheels	Raspberry PI 3 Model B 5mm LEDs assortied colors (Yellow, Gineen & Red) Sabertooth Dual 2x22A 6V-24V Regenerative Motor Driver L298 Dual H-Bridge DC Motor Controller	1 1 1 2	Raspberry Pi MS Direct Robot Shop Robot Shop	\$27.49 \$12.99 \$119.99 \$15.76	\$29.55 \$13.96 \$128.99 \$16.94	509 509 509 509
21 22 23 24	LED Lights Motor Driver for Robot Wheel Motor Driver for V-Wheels Jumper Wires	Responny IP 3 Model B Som ECDs associate colors (Vetox, Green & Red) Sabertoch Unal 2023 A V-24V Regenerative Motor Dativer L285 Dual H-Bridge DC Motor Controller SMMAYT 20nd J 20m 40 Pin Mate to Female Cupont Wire, 40 Pin Mate to Female Cupont Wire, 40 Pin Mate to Male, 40 Pin Female To Female Breadback at Jumper unit Robion Cables At	1 1 2 1	Raspberry Pi MS Direct Robot Shop Robot Shop Newegg	\$27.49 \$12.99 \$119.99 \$15.76 \$7.49	\$29.55 \$13.96 \$128.99 \$16.94 \$8.05	509 509 509 509 509
21 22 23 24 25	LED Lights Motor Driver for Robot Wheel Motor Driver for V-Wheels Jumper Wires Battery Pack for Microgonitoller	Responny P. 3 Model B Erm LEDs assoched colony (Nelbow, Gleen & Bied) Sabertooth Dual 2x32A 6V-24V Regetersateve Motor Driver L286 Dual H- Biege DC Motor Controller SIMANAY T2Inch / 30cm 40 Pen Male to Pennale Duary View, 60 Pin Male to AD Pin Permale to Fernale Brendboard Jumper view Robion Catalies kit 5200mAh battevy pack w/ micro USB	1 1 2 1	Raspberry Pi MS Direct Robot Shop Robot Shop Newegg Grainger	\$27.49 \$12.99 \$119.99 \$15.76 \$7.49 \$33.20	\$29.55 \$13.96 \$128.99 \$16.94 \$8.05 \$35.69	509 509 509 509 509
21 22 23 24 25 26	LED Lights Motor Driver for Robot Wheel Motor Driver for V-Wheels Jumper Wires Battery Pack for Microcomoler Battery Pack for Wheels	Respering P.3 Model 8 Emm LCDs associate colony (Network Green & Red) Satertion Dual 2022, 9(-):24 Bagenerative Mater Diver Ballwart Tamon J Som 40 Pen Mater Pennale Duard View, 40 Pin Mater Aumper wire Robon Cables M 5000mÅh battery pack wir micro USB 12/VC Battery Packer Wir micro USB 12/VC Battery Packer	1 1 2 1 1 1	Raspberry Pi MS Direct Robot Shop Newegg Grainger SuperBrightL EDs	\$27,49 \$12,99 \$119,99 \$15,76 \$7,49 \$33,20 \$33,20	\$29.55 \$13.96 \$128.99 \$16.94 \$8.05 \$35.69 \$35.69 \$3.75	509 509 509 509 509 509 509
21 22 23 24 25 26 27	LED Lights Mote Driver for Robet Wheel Motor Driver for V-Wheels Jumper Wires Battery Pack for Microcontroller Battery Pack for Wheels Aluminum Plate	Resperny, P.3 Model B Semi LDD assoches color Stahrton Dua 2023 AV-247 Regenerate Mator Diver (128) Dual H-Brage DC Motor Controller SMMWY Taten / Jone d Pin Mater Van H-Brage DC Motor Controller SMMWY Taten / Jone d Pin Mater Jone d Pin Fernate D-Ronald Enradout Jone Hernate Branch States 18 127/ DC Battery Power Suggin - Cell D Mounting Br I (JD acrees 1199) inches Mounting Br I (JD acrees 1199) inches Mounting Br I (JD acrees 1199) inches Mounting Br I (JD acrees 1199) inches	1 1 2 1 1 1 1 1	Raspberry Pi MS Direct Robot Shop Robot Shop Newegg Grainger SuperBrightL EDs Online Metals	\$27.49 \$12.99 \$119.99 \$15.76 \$7.49 \$33.20 \$33.49 \$16.67	\$29.55 \$13.96 \$128.99 \$16.94 \$8.05 \$35.69 \$3.75 \$17.92	50% 50% 50% 50% 50% 50% 50%
21 22 23 24 25 26 27 28	LED Lights Motor Driver for Robot Whell Motor Driver for V-Wheels Jumper Wires Battery Pack for Microcontroller Battery Pack for Wheels Abarinum Pitate Electrical Tape	Respering P1:3 Model Velocity First LCD associated Cold Velocity Sub-front Cold 2020 ArX-2027 Regrestrative Matter Diver (256 Dual H-Brange DC: Moto Controller SubMark Titorio 170 cm 4 Pin Master Mass. On Primate Doriel Pinatol Controller Mass. Do Pin Formate Drandborner Mass. 2000mb Mattery pack wir mou USB 12/ VC Dather Ponet' Supph - S-CHD Bit Areas Social Supph Velocity Finatoria	1 1 2 1 1 1 1 1 1	Raspberry Pi MS Direct Robot Shop Robot Shop Newegg Grainger SuperBrightL EDS Online Metals Lowes	\$27.49 \$12.99 \$119.99 \$15.76 \$7.49 \$33.20 \$3.49 \$16.67 \$3.98	\$29,55 \$13,96 \$128,99 \$16,94 \$8,05 \$35,69 \$335,69 \$33,75 \$17,92 \$4,28	505 50% 50% 50% 50% 50% 50% 50% 50%



Bill of Materials: Preliminary Part 2

Table #: Part 2 of the Preliminary BoM

15	Wheel Motors	Cytron Power Window Motors w/ 5" Wheels (Pair)	2	Robotshop	\$125.00	\$134.38	50%	
18	Timing Belt Motor	Brushed DC Motor Gearmotor	4	Digi-key Electronics	\$79.96	\$85.96	50%	
17	3D Printer Filament	1.75 mm and 1 kg per Spool	1	Hatchbox	\$23.99	\$25.79	50%	
18	3D Camera	ZED Camera High-Resolution and High Frame-rate 3D Video Capture	1	Stereolabs	\$449.00	\$482.68	50%	
19	LCD Display	7" 1024 x 600 IPS Display	1	DFRobot	\$34.00	\$36.55	50%	
20	Microcontroller	Raspberry Pi 3 Model B	1	Raspberry Pi	\$27.49	\$29.55	50%	
21	LED Lights	5mm LEDs assortied colors (Yellow, Green & Red)	1	MS Direct	\$12.99	\$13.96	50%	
22	Motor Driver for Robot Wheel	Sabertooth Dual 2x32A 6V-24V Regenerative Motor Driver	1	Robot Shop	\$119.99	\$128.99	50%	
23	Motor Driver for V-Wheels	L298 Dual H-Bridge DC Motor Controller	2	Robot Shop	\$15.76	\$16.94	50%	
24	Jumper Wires	SIM&NAT 12inch / 30cm 40 Pin Male to Female Dupont Wire, 40 Pin Male to Male, 40 Pin Female to Female Breadboard Jumper wire Ribbon Cables kit	1	Newegg	\$7.49	\$8.05	50%	
25	Battery Pack for Microcontroller	5200mAh battery pack w/ micro USB	1	Grainger	\$33.20	\$35.69	50%	
28	Battery Pack for Wheels	12V DC Battery Power Supply- 8 Cell D Battery Holder	1	SuperBrightLEDs	\$3.49	\$3.75	50%	
27	Aluminum Plate	Mounting for LCD screen; 1/8th inch thickness	1	Online Metals	\$16.67	\$17.92	50%	
28	Electrical Tape	Scotch Super 33+ 66-ft Electrical Tape	1	Lowes	\$3.98	\$4.28	50%	
29	V-Wheel Kit	V-Wheel Kit B	1	ServoCity	\$29.99	\$32.24	50%	
	Total:							

Table #: View of Full Preliminary BoM

		TEAM 023 - SWEET SPUT" INDICATOR	Conte	UP APO EPICALS		Data a faithean	Della
Part#	Part Name	Description	tity	Vendor	Price	Price (after 7.5% tax)	Maturity
1	Base Plate	Plytanium 15/32" CAT PS1-09 Pine Sanded Plywood, 4' x 8'	1	Lowe's	\$27.85	\$29.94	50
2	Linear Actuator	Okin Refined Power Recliner Motor Actuator Model JLDQ-11	1	Sears	\$121.71	\$130.84	50
4	AL 8020 T-slotted Bar	Single Rail, Silver, 30 mm High x 30 mm Wide, Hollow	4	McMaster-Car r	\$159.76	\$171.74	50
5	M4 Screw	Alloy Steel Low-Profile Socket Head Screw	32	McMaster-Car r	\$10.83	\$11.64	50
6	M4 Washer	18-8 Stainless Steel Washer for M4 Screw Size, 4.3 mm ID, 9 mm OD	32	McMaster-Car r	\$1.86	\$2.00	50
7	M4 Nut	Steel Hex Nut, Medium-Strength, Class 8, M4 x 0.7 mm Thread	32	McMaster-Car r	\$1.32	\$1.42	50
8	M3 Screw	Alloy Steel Low-Profile Socket Head Screw	12	McMaster-Car r	\$7.00	\$7.53	50
9	Inside Corner Bracket	10pcs Of 3030 Corner Fitting Angle 30x30 Decorative Brackets Aluminum Profile Accessories L Connector	1	Aliexpress	\$7.79	\$8.37	50
10	Idler Pulley	GT2 5mm Bore Aluminum Toothless Timing Belt Idler Pulley	4	DHgate	\$11.00	\$11.83	5
11	Timing Belt Pulley	Aluminum GT2 Timing Pulley - 6mm Belt - 20 Tooth - 8mm Bore	4	Adathuit	\$31.80	\$34.19	9
12	Timing Belt Tensioner	Tensioner Locking Spring for GT2 Timing Belt (pack of 50)	1	Adafruit	\$2.75	\$2.96	5
13	Timing Belt	Timing Belt GT2 Profile - 2mm pitch - 6mm wide 1164mm long	1	Adathuit	\$9.95	\$10.70	50
					_		
		Cutron Power Window Motors w/ 5"		Electronics			-
15			<u> </u>	Robotshoo			
	Wheel Motors	Wheels (Pair)	4	Diel her	\$125.00	\$134.38	9
16	Timing Belt Motor	Wheels (Pair) Brushed DC Motor Gearmotor	4	Digl-key Electronics	\$125.00	\$134.38 \$85.96	5
16 17	Timing Bett Motors 3D Printer Filament	Wheels (Pair) Brushed DC Motor Gearmotor 1.75 mm and 1 kg per Spool	4	Digi-key Electronics Hatchbox	\$125.00 \$79.96 \$23.99	\$134.38 \$85.96 \$25.79	5 5 5
16 17 18	Timing Belt Motors Timing Belt Motor 3D Printer Filament 3D Camera	Wheels (Pair) Brushed DC Motor Gearmotor 1.75 mm and 1 kg per Spool ZED Camera High-Resolution and High Frame-rate 3D Video Capture	2 4 1	Digi-key Electronics Hatchbox Stereolabs	\$125.00 \$79.96 \$23.99 \$449.00	\$134.38 \$85.96 \$25.79 \$482.68	9 5 5 9
16 17 18 19	Wheel Motors Timing Belt Motor 3D Printer Filament 3D Camera LCD Display	Wheels (Pair) Brushed DC Motor Gearmotor 1.75 mm and 1 kg per Spool ZED Camera High-Resolution and High Frame-rate 3D Video Capture 7* 1024 x 600 IPS Display	2 4 1 1	Digi-key Electronics Hatchbox Stereolabs DFRobot	\$125.00 \$79.96 \$23.99 \$449.00 \$34.00	\$134.38 \$85.96 \$25.79 \$402.68 \$36.55	5 5 5 5
16 17 18 19 20	Wheel Motors Timing Bett Motor 3D Printer Filament 3D Camera LCD Display Microcontroller	Wheels (Pair) Brushed DC Motor Gearmotor 1.75 mm and 1 kg per Spool 2ED camere high-Resolution and High Frame-rate SO Video Capture 7* 1024 x 600 IPS Display Resphere, P1 3 Model B	4 1 1 1 1	Digi-key Electronics Hatchbox Stereolabs DFRobot Raspberry PI	\$125.00 \$79.96 \$23.99 \$449.00 \$34.00 \$27.49	\$134.38 \$85.96 \$462.68 \$36.55 \$29.55	5 5 5 5 5 5
16 17 18 19 20 21	Wheel Motors Timing Belt Motor 3D Printer Fitament 3D Camera LCD Display Microcontroller LED Lights	Wheels (Par) Brushed DC Motor Gearmotor Trismand 1 kg per Spool ZED Carriera High-Resolution and High Frame-rate 30 Video Capture 7* 1024 x 600 IPS Display Raspberry PI 3 Model B Semi LEOs assorated colors (Vellow, Calcen & Red)	2 4 1 1 1 1	Digi-key Electronics Hatchbox Stereolabs DFRobot Raspberry PI MS Direct	\$125.00 \$79.96 \$23.99 \$449.00 \$34.00 \$27.49 \$12.99	\$134.38 \$85.96 \$25.79 \$402.68 \$36.55 \$29.55 \$13.96	9 5 5 5 5 5
16 17 18 19 20 21 21 22	Wheel Motors Timing Bett Motor 3D Plinter Filament 3D Camera LCD Display Microcontroller LED Lights Motor Driver for Robot Wheel	Wheek (Par) Brushed DC Molor Gearmotor 1.75 mm and 1 kg per Spot ZED Camera High-Resolution and High Frame-cate SO Video Capture 7*1024 x 600 IPS O Video Capture 78 apport P.3 Model B Satertooth Dual 2x23A 6V-34V Regenerative Motor Driver	2 4 1 1 1 1 1 1	Digi-key Electronics Hatchbox Stereolabs DFRobot Raspberry PI MS Direct Robot Shop	\$125.00 \$79.96 \$23.99 \$449.00 \$34.00 \$27.49 \$12.99 \$119.99	\$134.38 \$85.96 \$25.79 \$402.68 \$36.55 \$29.55 \$13.96 \$13.96	5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
16 17 18 19 20 21 21 22 23	Wheel Motors Timing Belt Motor 3D Pinter Filament 3D Camera LCD Display Microcontroller LED Lights Motor Driver for Robot Wheel Motor Driver for Wheels	Wheels (Par) Brushed DC Motor Gearmotor 175 mm and 1sg per Spool 2ED Camera High-Resolution and High Prame and 8 20 kines (Camera Parties and 8 20 kines) Been and Camera (Camera) Been and Camera (Camera) General Resol Selection Duci 2023 (Pri-20) Regenerative Motor Driver Regional Camera (Camera) Regional Camera (Camera) Been (Camera) Selection Duci 2023 (Pri-20) Regenerative Motor Driver Regional Camera (Camera)	2 4 1 1 1 1 1 1 1 2	Digi-key Electronics Hatchbox Stereolabs DFRobot Raspberry PI MS Direct Robot Shop Robot Shop	\$125.00 \$79.96 \$23.99 \$449.00 \$34.00 \$27.49 \$12.99 \$119.99 \$115.76	\$134.38 \$85.96 \$25.79 \$462.60 \$36.55 \$29.55 \$13.96 \$128.99 \$16.94	5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
16 17 18 19 20 21 21 22 23 24	Viheel Adders Timing Belt Motor 3D Pinter Filament 3D Camesa LCD Display Microcontoller LED Lights Motor Driver for N-Viheels Jumper Vilres	Vilveste (Pay) Brushel CC Mutor Gearmotor 17. form and 1. 19 per Spot 20. Carrent rely-Resolution and rely- Pri 1024 x 400 PS Display Respective (PB Signal Respective) (PB Signal Resolution) (PB Resolution) (PB Signal Resolution) (PB Resolution) (PB Signal Resolution) (PB Resolution) (PB Resolution) (P	2 4 1 1 1 1 1 1 2 1	Digi-key Electroncs Hatchbox Stereolabs DFRobot Raspberry PI MS Direct Robot Shop Robot Shop Newegg	\$125.00 \$79.96 \$23.99 \$449.00 \$34.00 \$27.49 \$12.99 \$119.99 \$15.76 \$7.49	\$134.38 \$85.96 \$25.79 \$462.68 \$396.55 \$29.55 \$13.96 \$128.99 \$16.94 \$8.05	5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
16 17 18 19 20 21 21 22 23 24 24 25	Wheel Addors Timing Bell Motor 3D Pinter Fisament 3D Camera LCD Display Microcontroller LED Lights Motor Dinver for Robot Wheel Motor Dinver for Witheels Jumper Wires Bathey Pack for Microcontroller	When (Par) Brahed Co Lukel Gemoto 13 mm and 18 ppr 6 light Co Carrens 19th Association and 19th Prime 4at 20 Water Caption 71 1524 x 400 PD Light Response 19th Light Carol (Park Bern Licha andreit Caro) Hellow Sterricht Card 2024 01-24 Sterricht Card 2024 01-24 Sterricht Card 2024 01-24 Height Carol (Park Lington) Sterricht Card 2024 01-24 Height Carol (Park Lington) Amerikan Carol (Park Lington) Amerikan Resource Carolina Amerikan Resource Carolina	2 4 1 1 1 1 1 1 1 2 1 1 1	Digi-lesy Electronics Hatchbox Stereolabs DFRobot Raspherry PI MS Direct Robot Shop Robot Shop Newegg Grainger	\$120.00 \$79.95 \$23.99 \$449.00 \$34.00 \$27.49 \$12.99 \$119.99 \$119.99 \$15.76 \$7.49	\$134.38 \$85.96 \$25.79 \$402.68 \$356.55 \$29.55 \$13.96 \$128.99 \$16.94 \$8.05 \$35.69	5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
16 17 18 19 20 21 21 22 23 24 24 25 26	Vithed Mattris Timing Bet Motor 3D Printer Planett 3D Camera UCD Display Motor Objet for Notice Wheth Motor Driver for V-Withess Jumper Wites Battry Pack for Motor Controller Battry Pack for V-Withess	Weeke (Par) Binahed DC Makel Gematrix 175 mm and 118 per Spool 2012 Cancera sigh Section 2014 from Failer das 53 Vales Capitale Failer das 53 Vales Capitale Sasphorn 9 Statistics (San San San Sasphorn 9 Statistics) and Parkas Capitale San San San San Biogenerative Marci Cale Binaked Topon Vales of Parkas 2012 Data H 450gg Col Cabo Carotrate Binaked Topon Vales (Failer San 2012 Data H 450gg Col Cabo Carotrate Binaked Topon Vales (Failer San 2012 Data H 450gg Col Cabo Carotrate Binaked Topon Vales (Failer San 2012 Data H 450gg Col Cabo Carotrate Binaked Topon Vales (Failer San 2012 Data H 450gg Col Cabo Carotrate Binaked Topon Vales (Failer San 2012 Data H 450gg Col Cabo Carotrate San San San San 2012 Data H 450gg Col Cabo Carotrate San San San San San 2012 Data Binaked Cabo (Failer San 2012 Data Binaked Cabo (F	2 4 1 1 1 1 1 1 1 2 1 1 1 1 1	Digi-lery Digi-lery Electronics Halcribox Stereolabs Di-FRobot Raspberry Pi MS Direct Robot Shop Robot Shop Newegg Grainger SuperflightL EDS	\$120.00 \$79.96 \$23.99 \$449.00 \$34.00 \$27.49 \$12.99 \$119.99 \$15.76 \$7.49 \$33.20 \$33.20 \$3.49	\$134.38 \$805.96 \$255.79 \$462.00 \$13.66 \$13.96 \$13.96 \$128.99 \$16.94 \$8.05 \$35.69 \$33.569 \$33.75	5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
16 17 18 19 20 21 21 22 23 24 24 25 26 27	Vibed Motors Training Bett Motor 30 Drinter Flament 30 Camera 30 Camera 30 Conserver Motor Convert Rebot Motor Convert Rebot Motor Convert Rebot Motor Daver for Vibries Motor Daver for Vibries Motor Convert for Vibries Battery Pack for Motor Control Rebut Motor Cont	Weeke (Pay) Brunket Co Kukk Gemotrix 175 mm and 118 jor Spot 200 cmmer styk househout and information Protection and the state of the state Protection of the state of the state Protection of the state of the state State of the state of the state of the state State of the state of the state of the state State of the state of the state of the state Protection of the state of the state of the state State of the state of the state of the state State of the state of the state of the state State of the state of the state of the state State of the state of the state of the state of the state State of the state of the state of the state of the state State of the state of the state of the state of the state State of the state of the	2 4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Digi-key Electronics Hatchbox Soverokabs DFRobot Robot Shop Robot Shop Robot Shop Robot Shop Grainger SuperfrightL EDS Online Metals	\$120.00 \$79.96 \$23.99 \$449.00 \$34.00 \$27.49 \$112.99 \$15.76 \$7.49 \$15.76 \$7.49 \$33.20 \$33.49 \$16.67	\$134.38 \$85.56 \$25.79 \$402.60 \$129.55 \$29.55 \$13.06 \$128.99 \$16.94 \$30.55 \$33.55 \$33.75 \$33.75 \$33.75	5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
16 17 18 19 20 21 21 22 23 24 24 25 26 27 28	Vited Kilderi Timerg Bell kloor 3D Printer Flammet 3D Camera LCD Display Microcontroller LCD Lights Motor Driver for Vitel Motor Driver for Vithees Microcontroller Battery Pack for Microcontroller Battery Pack for Display Topes Tope	Weeke (Par) Weeke (Par) Bruhed DC Lotter Gemotor 1.75 mm and 118 per Spoor 1.25 mm and 118 per Spo	2 4 1 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1 1	Digi-try Electronics Hatchook Shereotabs DFRobot Raspberry PI MS Direct Robot Shop Robot Shop Newegg Grainger SuperBright, EDS Online Metals	\$120.00 \$79.95 \$23.99 \$449.00 \$34.00 \$27.49 \$12.99 \$119.99 \$119.99 \$115.76 \$7.49 \$33.20 \$33.40 \$33.49 \$33.49	\$134.38 \$85.56 \$25.79 \$402.60 \$13.06 \$128.09 \$16.84 \$8.05 \$33.69 \$33.75 \$37.70 \$17.70	5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5



Bill of Materials: Final Design BoM

Table #: Final Design BoM

	TEAN	1 523 - Mixed Reality Wearable for 3D Boo	ly Trad	king BILL OF MATE	RIALS		
Part #	Part Name	Description	Quan tity	Vendor	Price	Price (after 7.5% tax)	BoM Maturity
1	3D Camera	Zed mini	1	Stereolabs	\$449.00	\$469.00	100%
2	Computer Processor	NVIDIA Jetson TX2 Developer Kit (with Educational Discount)	1	NVIDIA	\$299.00	\$310.96	100%
4	3D Printer Filament	Hatchbox PLA 3D Printer Filament: 1kg spool, 1.75mm, black	1	Amazon	\$19.99	\$21.49	100%
5	USB Flash Drive	SanDisk Extreme Pro 128 GB	1	TheImagingWorld (Amazon)	\$47.60	\$48.67	100%
6	USB Port Hub	Anker 10 Port 60W Data Hub with 7 USB 3.0 Ports	1	AnkerDirect (Amazon)	\$42.99	\$44.06	100%
7	Keyboard Wrist Rest	CushionCare Keyboard Wrist Rest Pad	1	CushionCare (Amazon)	\$13.87	\$14.94	100%
8	HDMI to VGA adapter	VicTsing HDMI to VGA Adapter Converter: black	1	VicTsingDirect (Amazon)	\$7.59	\$12.45	100%
9							
10							
					Total:	\$921.58	

Table #: View of Full Preliminary BoM



Detailed Math Backup

Department of Mechanical Engineering



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