# Astro-Robotic Garden Harvester (ARGH)



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## Test Readiness Review (TRR)

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#### **Section I : Project Overview**



#### Purpose



- ARGH
  - Archetypal Architecture
  - Automated Robotics Utility Tasking
  - Space Gardening



For the first time ever on Earth, we've grown tomatoes using our Astro Garden<sup>®</sup> system.

Schedule

Test Readiness

#### **Success Levels**

Levels of Success				
	Sensing	Analysis	Pathfinding	Interaction
Level 1	Visual data collection (depth, RGB, 3D location)	Identify tomatoes within environment	Find simple path to target	Locate end effector at target tomato (pointing accuracy ± 2 cm)
Level 2	Identify tomato characteristics	Determine ripeness of tomato (>80% accuracy)	Find optimal path to target	Position end effector gripper around tomato
Level 3				Complete harvest on tomato analog in ideal conditions
Level 4			Find optimal arm orientation	Full operation in realistic conditions

#### CONOPS



Overview

Schedule

#### **Baseline Design**



#### System Block Diagram



#### Sensor Mounting (CAD) Update From CDR





**Previous Design** 

Updated Design



#### **Critical Project Elements**

<u>Sensor Positioning</u>



- **Object Recognition**
- <u>Robotics/Pathfinding</u>



Schedule

Test Readiness







#### Section II : Schedule



#### Spring Plan (CDR)



#### Spring Plan (Updated)



#### Spring Plan (Continued)







#### **Section III : Test Readiness**



**Purpose :** Verify the accuracy of the Intel RealSense D435

Procedure: 1. Bullseye will be placed at different distances (1 m down to 0.3m)

- 2. The data is read from the sensor software (Intel Realsense View)
- 3. Using tape measure to record the actual distance
- 4. Data is then put to a .csv format for accuracy analysis
  - (Comparing the actual distance with the distance from the sensor)

**Risk Reduction :** Sensor Calibration, Incorrect Object Recognition

Pass Condition/ Fail Contingency : Correctly identify object positioning to 2% at 2 meters

Equipment	Intel Realsense D435, Measure Tape, Bullseye paper	
Facility	AES	
Status	In Progress	
Requirement Verification	Visual data collection (depth, RGB, 3D location) Success Level 1	
Overview Schedule Test Readiness Budget		

#### Sensor Preliminary Test Setup



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#### Sensor Preliminary Testing (Intel Realsense Software Screenshots)





#### Sensing Capability Test

To test the accuracy of our sensing capabilities, we will be utilizing the Vicon-Tracker Motion Capture Software

Purpose : Verify the accuracy and precision of the Intel RealSense D435

Procedure : - Targets will be positioned of varying depths and positions

- The sensor is calibrated to each sensor and tracker is turned on
- Tracker data is written to a .csv for accuracy analysis

Risk Reduction : Sensor Calibration, Incorrect Object Recognition

Pass Condition/ Fail Contingency : Correctly identify object positioning to 2% at 2 meters

Equipment	VICON System
Facility	ASPEN Lab
Status	Pending Completion
Requirement Verification	Remotely Collect Information, Repeatability, Extensibility; Success Level 1

#### **Robotics - Pointing Accuracy Test**



**Overview** 

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Purpose :

- Confirm Digital-to-Physical 'Mirroring'
- Verify spatial accuracy of End Effector

Procedure :

- Drive end effector to virtually defined goal state (cartesian)
- Measure 'true' position relative to BASE joint

Risk Reduction: Failed Harvest, Failed Robotic Locomotion

Pass Condition/ Fail Contingency : Positions Statistically Sig. >±2 cm\* from target= Failure

Equipment	UR10e, Driver PC, VICON (?) System/Tape Measure
Facility	AES
Status	In Progress
Requirement Verification	Physical Interaction, Repeatability, Extensibility; Success Level 1
Schedule	Test Readiness Budget

#### **Robotics - Gripper Capability Testing**



Purpose :

 Confirm gripper strength specifications to validate deformation model

Procedure :

- Fully grasp test strip
- Add mass until failure (static friction fails, objects dropped) Risk Reduction: Failed Harvest, Destruction of fruit, Plant damage Pass Condition/ Fail Contingency: Gripper must hold 5 kg (11 lbs)

Equipment	UR10e, Driver PC, Test Weight 'Band', Weights
Facility	AES Project Room
Status	Pending Completion
Requirement Verification	Physical Interaction, Repeatability, Extensibility; Success Level 2

### **ROS** Test

Purpose :

- Confirm that all software and hardware components can correctly communicate in the ROS software environment.

Risk Reduction: Overall system communication errors

Pass Condition/ Fail Contingency: Data can be packaged into a rosmsg type and published to the correct corresponding rostopic. Received data can be correctly unpacked by the corresponding rosnode.

Equipment	Linux ROS computer, UR10e, Realsense D435, ARGH Computer
Facility	AES
Status	In Progress
Requirement Verification	Data collection and communication; Success Level 1
Overview	Schedule Test Readiness Budget

#### **ROS - System Latency Check**

Purpose :

- Determine any areas of computational complexity & effect on overall system performance

Procedure :

- Incorporate code 'clocks' in critical software packages and command the system to various positions

Risk Reduction: Overall system inefficiencies, communication errors

Pass Condition/ Fail Contingency: Operations lasting >5 seconds = FAIL

Equipment	UR10e, Driver PC
Facility	AES
Status	In Progress
Requirement Verification	Automation, Repeatability; Success Level 1

### **Robotics - Tomato Deformation and Vine Interaction Testing**



**Procedure :** Using a faux tomato, continuously decrease the visibility of a tomato from the sensors FOV.

Risk Reduction : Failed Harvest, Failed Robot Locomotion.

Pass Condition/ Fail Contingency : Harvesting system is able to to determine, and pick up faux tomato's location and orientation with up to 50% covering.

Equipment	UR10e, Driver PC, Faux tomato plant and fruit, paper holder (to be constructed)
Facility	AES
Status	Pending Completion
Requirement Verification	Physical Interaction, Extensibility; Success Level 3
Overview	Schedule Test Readiness Budget

#### **Imperfect Gripper Positioning Test**

Purpose : Characterize the maximum vertical, horizontal and angel offset allowed by the end effector to safely grasp and harvest a tomato.

Procedure : Determine the maximum Horizontal, Vertical and Angle offset by positioning gripper around the center of a tomato in optimal harvesting position, and translate end effector depending on offset determination by:

- Horizontal offset: +2mm base y axis
- Vertical Offset: -2 mm base z axis
- Angle Offset: Wrist 2, +5 deg.

Repeat procedure until robot damages tomato/plant or cannot harvest

Risk Reduction : Failed Harvest, Failed Robot Locomotion.

Pass Condition/ Fail Contingency : Harvesting system meets and completes final level of success.

Equipment	Polyscope GUI Software, UR10e, real tomato and faux tomato plant
Facility	AES
Status	Pending Completion
Requirement Verification         Physical Interaction, Extensibility, Success Level 3	
Overview	Schedule Test Readiness Budget

#### **Object Recognition - Ripeness Determination Testing**

Purpose : Verify system can differentiate ripe and unripe tomatoes

Procedure : - Have team members identify ripeness of tomato plants within

diverse tomato dataset

-Compare human results to software determination

**Risk Reduction :** 

Pass Condition/ Fail Contingency : Software must have >80% accuracy while never identifying unripe tomatoes as ripe

Equipment	Ripeness determination software, tomato data set
Facility	Remote
Status	Complete
Requirement Verification	Automation, Remotely collect information; Success Level 2

### **Object Recognition - Ripeness Determination Testing Results**

- Software detects ripeness at 87% accuracy
  - Some tomatoes viewed as ripe by humans were not viewed as ripe by the computer
  - No tomatoes viewed as unripe by humans were viewed as ripe by the computer. (100% accuracy against false positives)

Conclusion: As the software never detects unripe tomatoes as ripe and has above 80% accuracy, this software test is successful.



### **Object Recognition - Tomato Acquisition**

- Model validation using Mean Average Precision
  - Measure of a mask's precision when created by the neural network when compared to ground truth annotations of a dataset
  - Currently Measured at 0.84 (0-worst 1-best)
  - mAP score will be recalculated with planned improvements in object recognition model

Equipment	ARGH Computing Machine
Facility	AES/Cloud Computing
Status	In Progress
Requirement Verification	Automation, Remotely collect information; Success Level 1

Schedule

**Overview** 

Test Readiness



**Budget** 

#### **Full Systems Test**

Purpose : Use sensor, software, and robotic arm to locate ripe tomatoes for harvesting on real tomato plant, have robotic arm harvest ripe tomatoes and place in a receptacle without human interaction.

#### **Procedure :**

- 1) **Initiate Harvesting Program**
- 2) Move sensor mount to sensing locations
- 3) Estimate the position and orientation of ripe tomatoes
- 4) Arm harvests and stores a ripe tomato in receptacle
- 5) Arm returns to home position and completes harvesting Program on remaining ripe tomatoes

Risk Reduction : Failed Harvest, Failed Robot Locomotion.

Pass Condition/ Fail Contingency : Verify harvesting system operation completes tasks as an integrated system

Equipment	Driver PC, UR10e, Realsense D435, tomato plant	
Facility	AES	
Status	Pending Completion	
<b>Requirement Verification</b>	Physical Interaction, Extensibility; Success Level 4	
Overview	Schedule Test Readiness Budget	





#### Section IV : Budget





#### **Budget - Completed Expenses**

Items	Original Budget	Final Cost	Status	Margin
PC	\$3,000	\$2049.98	Complete	\$950.02
3D Printing (Camera Mounting)	\$20	\$10	Received	\$10
Pilot Damage Deposit	\$200	\$200	Complete	\$0
D435 Sensor	\$0	\$0	Provided by Sierra Space	N/a
UR-10e Robotic Arm	\$0	\$0	Provided by Sierra Space	N/a
Robotiq 2F-85 Gripper	\$0	\$0	Provided by Sierra Space	N/a

Total Cost = \$2,259.98

Budget Remaining: \$2,740.02

**Overview** 

#### **Budget - Projected Expenses**

Items	Original Budget	Final Cost	Next Steps	Margin
USB-c Cable	\$80	\$45	<ul> <li>Status: In Progress</li> <li>C2G paperwork</li> <li>Finalize order for 2 cables</li> </ul>	\$35
Remote Desktop Software	\$500	TBD	Future decision (not project critical)	TBD
Lighting	\$250	TBD	Submit Amazon order request to dept.	TBD
Test plant materials	\$500	TBD	Evaluate best test scenarios (i.e real tomato plant vs constructed model)	\$400

Total Projected Cost = \$3,554.98

Projected Remaining Budget = \$ 1,445.02

#### **Budget - Potential use of Margin**

#### D435 Sensor - \$650

- \$299.99 each
- Possibility to integrate a second ARGH sensor
  - Added expense for manufacturing a second mount
- 100% Margin (\$300) to replace a broken sensor
- Potential remaining budget: \$795.02

#### Camera

- Continuous, stable film to analyze performance and document testing
- Tripod likely required
  - Possibly purchase for a team member device

# Backup Slides

#### Software Block Diagram



#### Sensor Mount (Most Updated)









Schedule

Test Readiness

#### Sensor Initial Testing Data

High Density Test			High Accuracy Test		
Actual Distance (± .1 cm)	Sensor Distance (± .1 cm)	% error	Actual Distance (± .1 cm) Sensor Distance (± .1 cm)	% error	
1.0	1.001	0.10%	100.0 101.	8 1.75%	
98.1	98.700	0.61%	99.9 100	1 0.20%	
90.5	90.300	0.22%	89.9 90	2 0.39%	
80.1	80.500	0.50%	78.7 80	2 1.91%	
68.5	70.000	2.19%	69.3 69.	8 0.79%	
60.1	60.100	0.00%	59.1 59.	8 1.18%	
48.5	50.000	3.09%	49.6 50	0 0.81%	
40.5	40.400	0.25%	39.6 39	9 0.76%	
29.0	29.300	1.03%	28.0 30	0 7.14%	
Default					
Actual Distance (± .1 cm)	Sensor Distance (± .1 cm)	% error			
135	133.3	1.26%			
120	120.5	0.42%			
105	102	2.86%			
90	87.9	2.33%			
75	73.4	2.13%			
60	58.8	2.00%			
45	44.6	0.89%			
30	30.2	0.67%			

#### Ripeness Test Results

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21       1       0       1       1       1       1       0       1       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0	0
22       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1       1	1
23       1       1       1       1       1       1       0       0       0       1       0       0         24       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0 <td>0</td>	0
24         0         0         0         0         0         0         1         0         0         0         1         0           25         0         0         0         0         0         1         0         0         0         1         0           26         0         0         0         0         1         0         0         1         0         0         1         0	0
25         0         0         0         0         0         1         0         0         1         0         0         1         0         1         0         0         1         0         1         0         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1         0         1	0
26 0 0 0 0 0 0 0 0 0 1 0 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0
	0
<u>27</u> 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 0 0	0
28         1         1         1         1         1         1         0         0         1         0         0	0
19         1         1         1         1         1         1         0         0         1         0         0	0
<u>30</u> 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0
<u>31</u> 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0
32         0         1         0         1         0         1         0         0         0         0         1         0	0
33 Totals 19 8 3 0 12 14 0	4
34 Fill in using 1 or 0 for true or false	
35 Math Notes Desired Category	
36         Red Prediction ALL         0.9         90% Red Accuracy         FN = 100%	
37         Red Prediction FN         1         Never misses any red         (No false negatives)	
38 Red Prediction FP 0.9 Detects more red	
39	
40 Ripe Prediction ALL 0.8666666667 87% Ripe Accuracy FP = 100%	
41 Ripe Prediction FN 0.8666666667 Ignores some ripe (No false positives)	
42 Ripe Prediction FP 1 Predicts no extra ripe	

Overview

Schedule