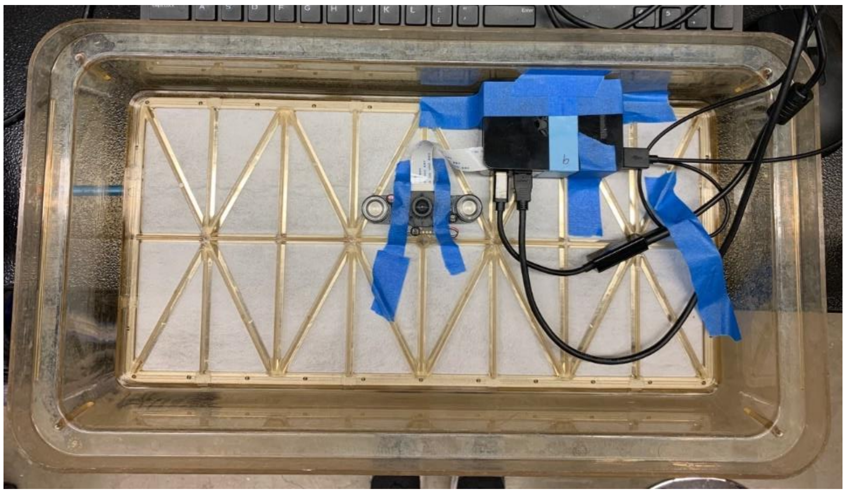
Engineering Design

i. Concept Development: Alternative Designs/Approaches

All concepts involved a CanaKit 4 Raspberry Pi computer connected to an Arducam Day-Night video camera. Key aspects of the design that needed to be developed were camera placement, camera height, compatibility with enrichment requirements, and tracking software.

Camera location:

Approach 1: Inside cage lid

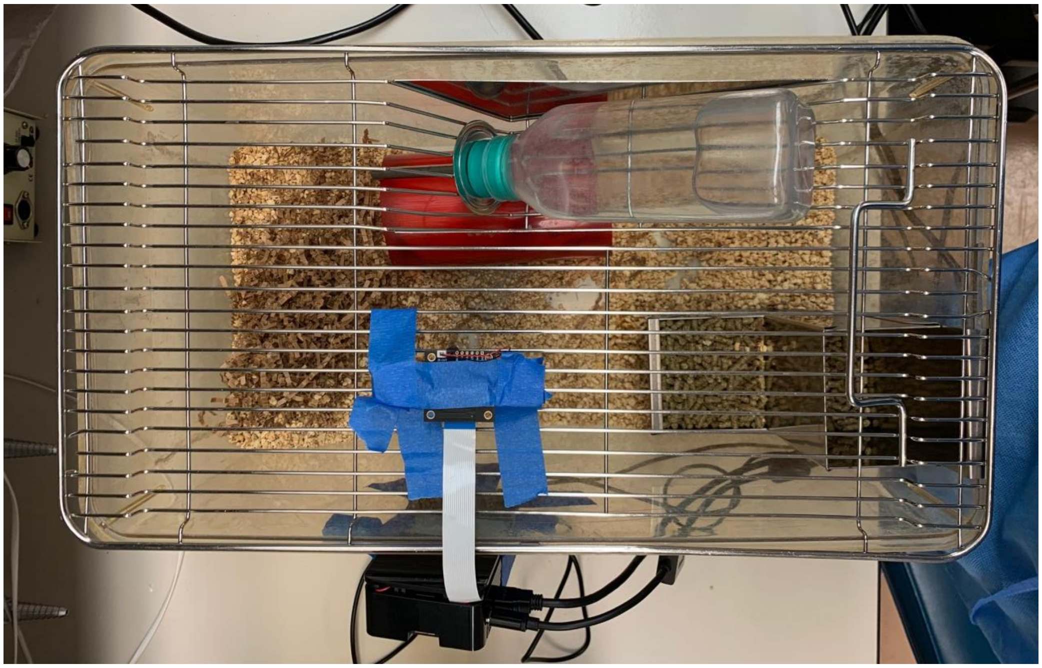


Camera view:

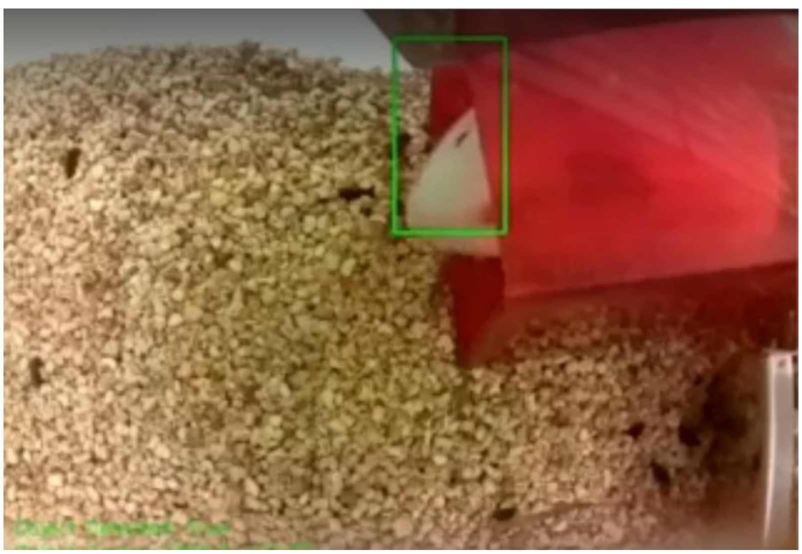
Observations: Bars interfered with video tracking

Approach 2: Camera placed on top of bars

Camera placed between 7th and 8th bars:

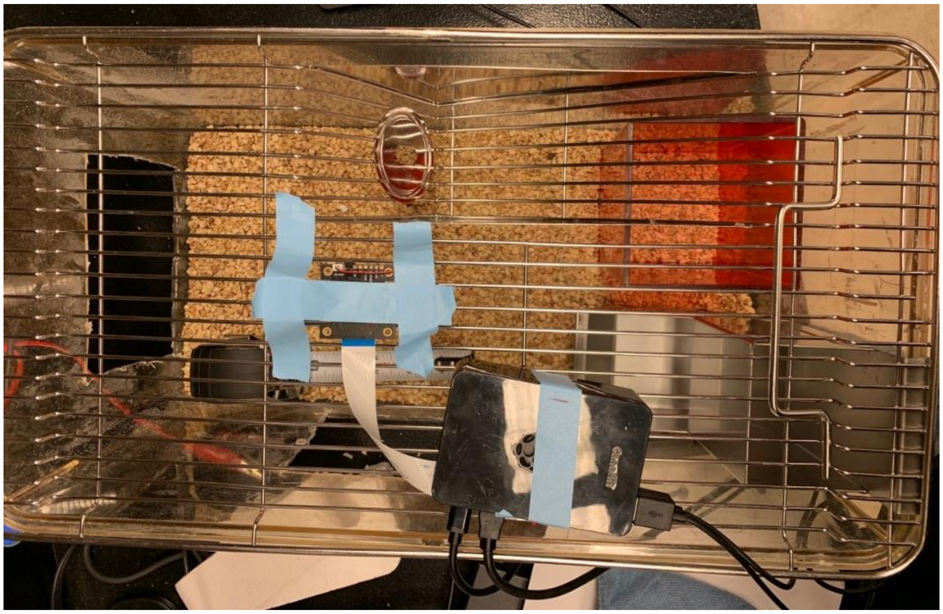


Camera view:

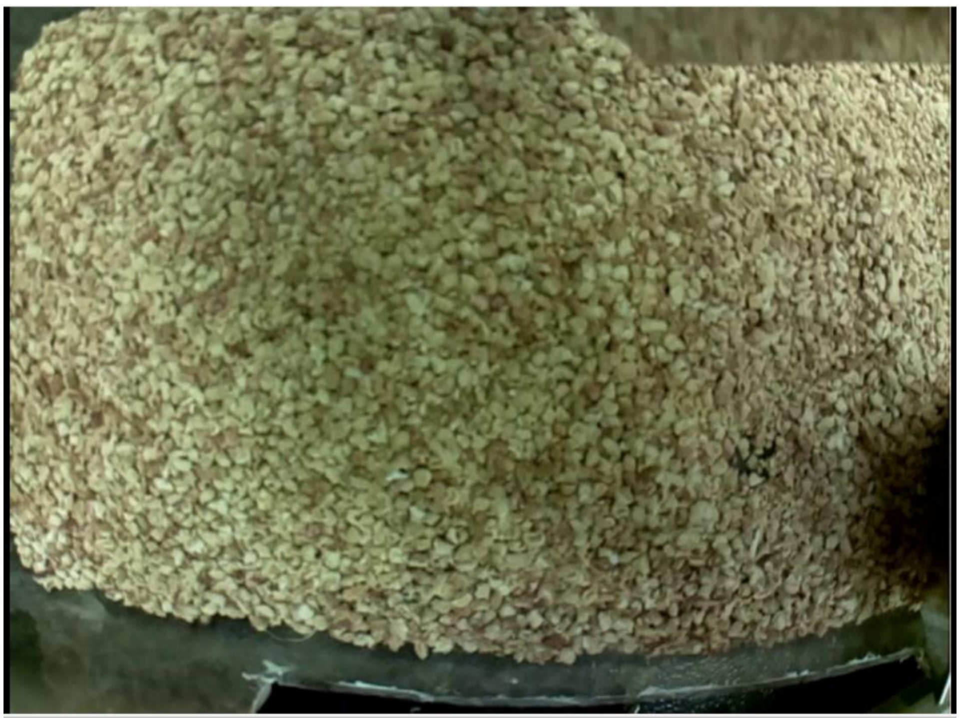


Observations: Regions at left and front of cage are not in field of view. Portion of field of view taken up by back wall rather than cage bottom

Camera placed between 11th and 12th bars:

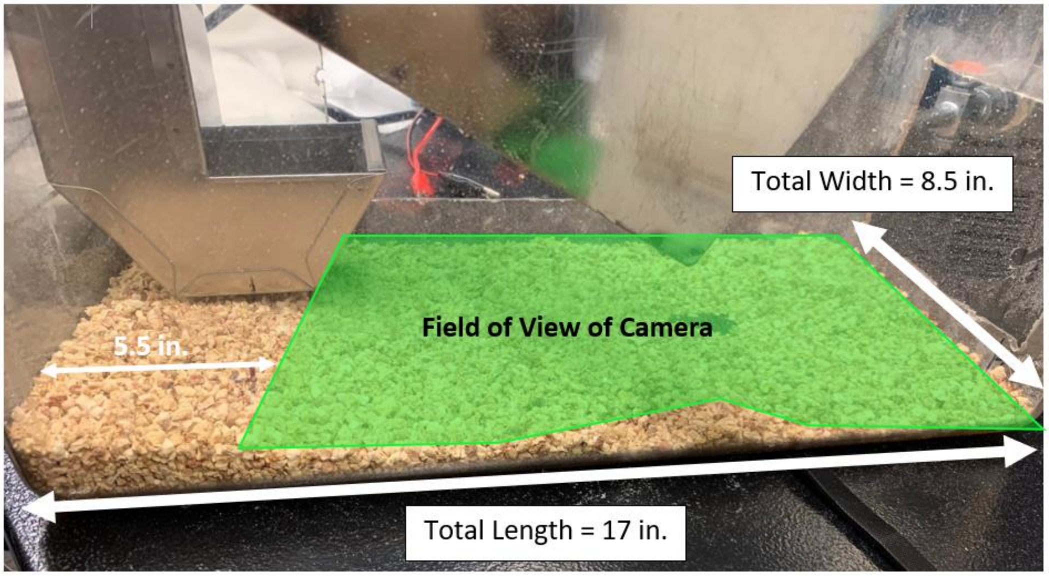


Camera view:



Observations: Maximizes area in field of view. Front, left, and back edges of cage bottom are visible. Remaining obstructions: water bottle holder, area behind feeder.

Diagram of field of view using optimized camera placement:

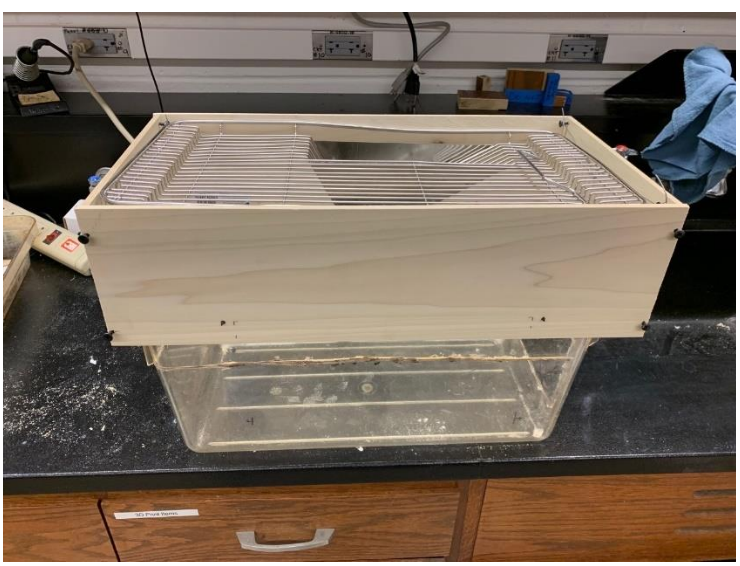


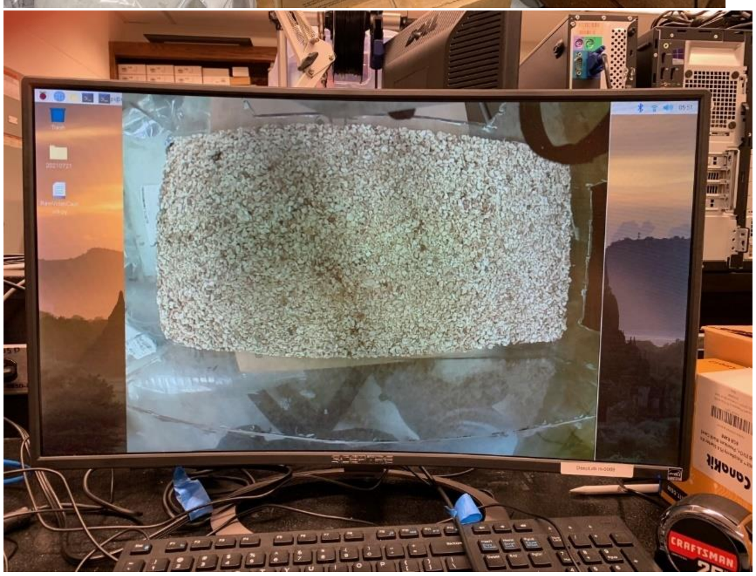
Camera Height:

Because no camera placement could enable the cage floor to be in view, and raising the camera above the metal grill would result in interference with the bars, modifications to the cage itself were explored.

Approach 1:

Wooden Frame





Wooden boards (1/4” by 6”) were cut to the length of the cage and connected with screws. Screws were also inserted on the inside of the boards 4.5” from the top of the boards. These screws provided points of contact for the frame to rest on the edge of the cage. Screws were also inserted 0.5” from the top of the board on the short side of the frame. Stiff metal wire was wrapped around these screws to create a location for the hooks of the metal cage grill to hook over.

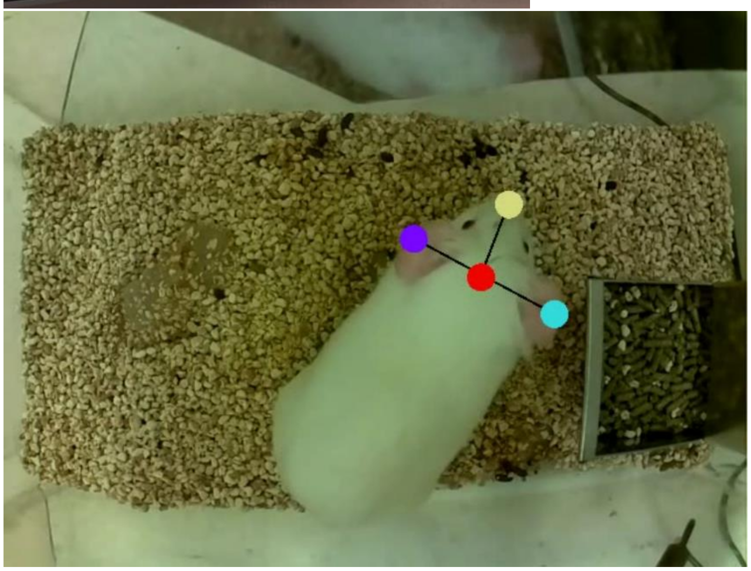
Feasibility testing observations:

- This setup enabled the entire cage floor to be in view
- Because the frame fit around the outside of the cage, the food dish could still hook over the top of the cage lip
- Assuming consistent wood cutting and screw placement, the frame should hold the camera at the same height each time

- However, the wire suspension mechanism began to sag under the weight of the lid, making the height less precise
- Wood is also currently very expensive, and takes a long time to be shipped/available for pickup
- Equipment for cutting wood is easily accessible in the lab and at the 1819 Makerspace
- Would have to find way to suspend water bottle, since placement in the water bottle holder on cage lid would make it be held too high for the animal to reach

Approach 2:

Nested Cage sections



This approach involves taking one standard guinea pig cage and using a Dremel with plastic cutting attachment to cut around the entire perimeter of the cage 2 inches from the cage bottom, resulting in this section:

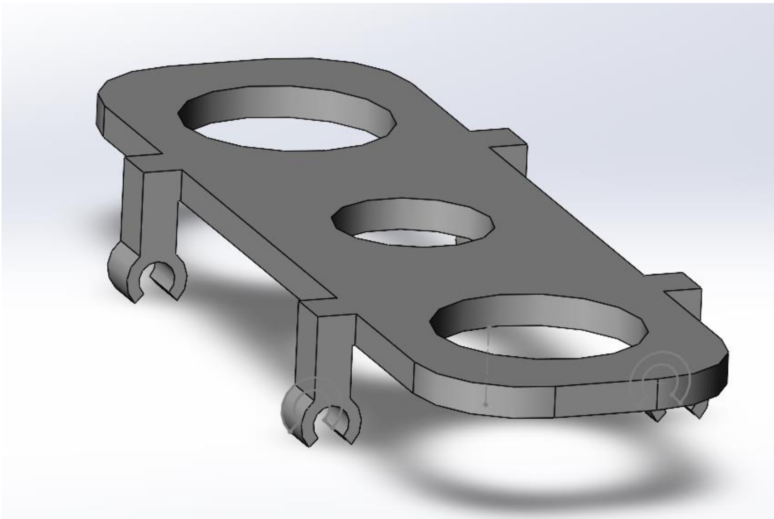
Then, screws were inserted 4.5” from the top of the cage lid (two screws on each long side of the cage). This section was then inserted into a normal, unmodified standard Guinea Pig Cage, thereby raising the height of the metal grill for the camera to sufficiently capture the entire cage. The Dremel was also used to cut out a rectangular section from the short side of the cut cage section so that the food dish could still hook onto the top of the normal cage.

Feasibility testing observations:

- Cutting the cage sections with the Dremel was not ideal, as the melted plastic had a noxious odor
- The melted plastic also sometimes re-hardened on an area that had already been cut, requiring re-cutting
- Cutting with a Dremel also resulted in sharp edges and flash that had to be sanded down with a file as it posed a hazard to the animals
- This setup enabled the camera to capture the entire cage bottom
- Camera height was consistent provided screws were inserted at same location
- Didn’t require new mechanism for grill to be attached to the cage top
- Same issue with water bottle attachment as wooden frame

Camera placement consistency and usability:

Approach 1:

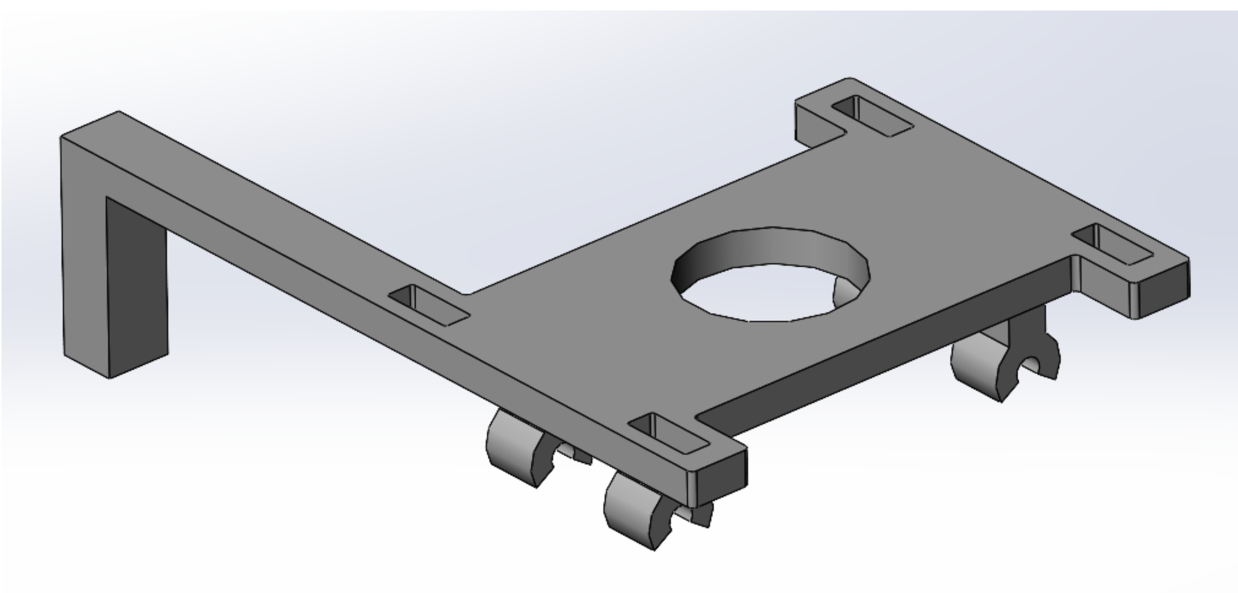


Fixture attaches to top of cage bars, holes cut out for lens and night vision lights.

Feasibility testing observations:

- holes for lights appropriate size, hole for lens could be reduced by about 1mm
- Not a secure fit, camera fits loosely and is pulled on by cord connecting it to Pi – needs to be stabilized
- Ensures stable X-position, but can still slide in Y-axis

Approach 2:



Fixture still attaches to top of cage bars. Holes for night vision lights removed; fixture now only provides slot for lens. Slots enable Velcro strips to be inserted and wrapped around camera to stabilize. Arm juts out to contact crossbar running in the Y-direction.

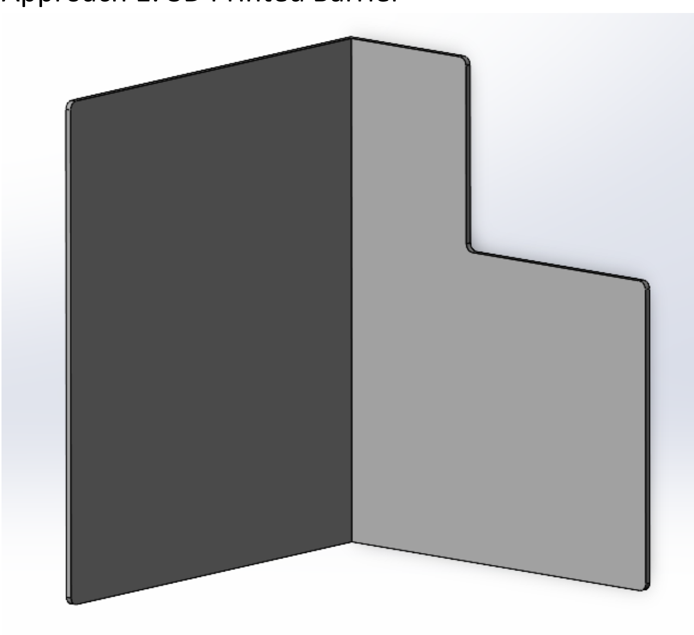
Feasibility testing observations:

- Improved lens hole size
- Velcro improves camera stability
- Arm keeps fixture in consistent Y-axis position

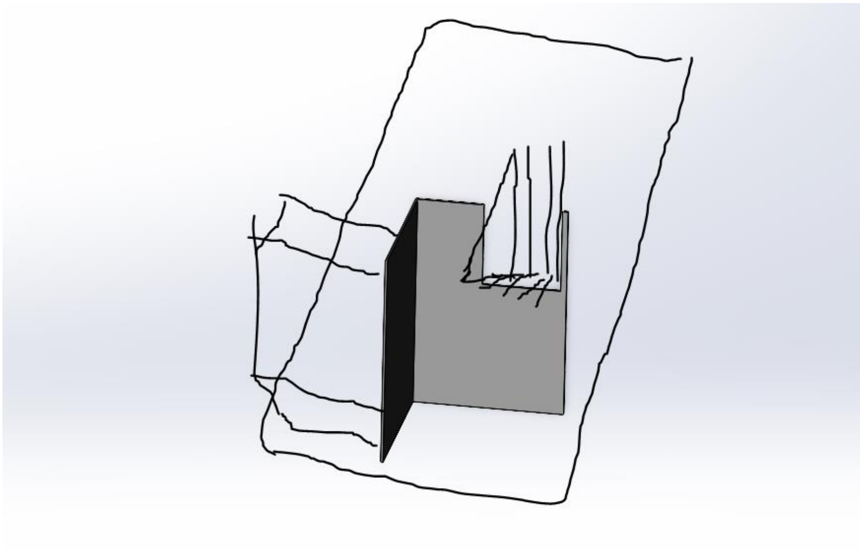
Cage obstruction:

Because the software has difficulty redetecting objects after they leave the field of view, an optimal system would keep the animal in view at all times. With the optimized camera placement, the largest region of the cage not in view is the region behind the feeder. This approximately square region could be blocked to prevent the guinea pigs from accessing it, keeping them in the frame of video. The obstacle would have to be in compliance with the IACUC requirements that the animals have 101 in^2 of accessible space.

Approach 1: 3D Printed Barrier



Position in cage:



Observations: Did not pursue further due to 3D Printer malfunction. Also, PLA not sterilizable, would not have been in compliance with IACUC requirements.

Approach 2: Tunnel

Observations: Placing a plastic tunnel that is typically placed in the cage to serve as a shelter enrichment for the animals adequately fills up the space that is outside the field of view of the camera. It is also compatible with sterilization requirements and is readily available in the lab. Raising the cage height with the wooden frame or nested cage section would make the need for cage obstruction irrelevant.

Tracking Software

Approach 1: Vaughan-Mannava Software

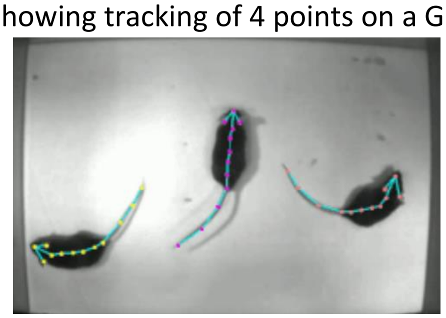
The first approach is a script developed by Dr. Benjamin Vaughan and Alekhya Mannava, both of whom are members of the lab. It functions by asking the user to draw a box around the object they wish to track, and the program records the change in position of that box as the object moves. One advantage of this software is that it does not require training of the model, which saves a significant amount of time. One major drawback is that because it identifies objects based on color, it requires the program to be run twice to track night movement, since those videos are in grayscale. Another drawback is that it can only detect gross linear movement, not circular movement or other subtle movements.

Sample Image showing tracking of a Guinea Pig's head

Approach 2: DeepLabCut

DeepLabCut is a software package developed by a research team in the Netherlands to track various aspects of lab animal activity. It requires the user to train the model with a sample dataset so it can learn what permutations in shape and position the desired object may take. This adds a significant amount of time, but results in more accurate results. DeepLabCut differs from YOLO in that it tracks an object based on "nodes" – points selected on the object by the user – rather than drawing a box around the object (Figure 5b). The nodes (Figure 5c) enable the quantification of more subtle movements and circular movement. Comparison of these factors resulted in the selection of DeepLabCut.

Sample Image showing tracking of 4 points on a Guinea Pig's head



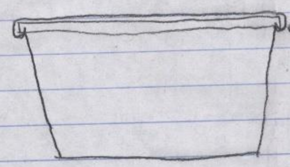
Approach 3: YOLO

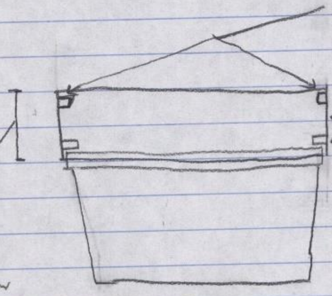
YOLO is a python program that works similarly to DeepLabCut in that it requires the user to train the model with a sample dataset so it can learn what permutations in shape and position the desired object may take. However, in YOLO, the user draws a box around the object to be tracked, so it can only tell gross linear movement. It also does not have GUI like DeepLabCut so it requires more coding expertise.

Design Process: Drawings, Diagrams, Handwritten Notes

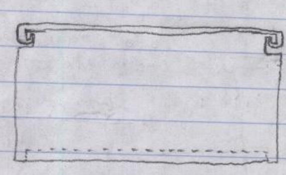
11/22

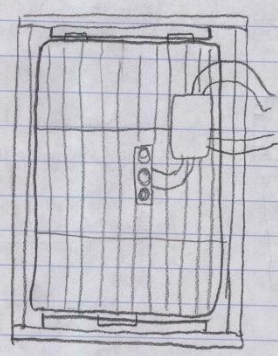
Goal: Raise height of lid so entire cage in view



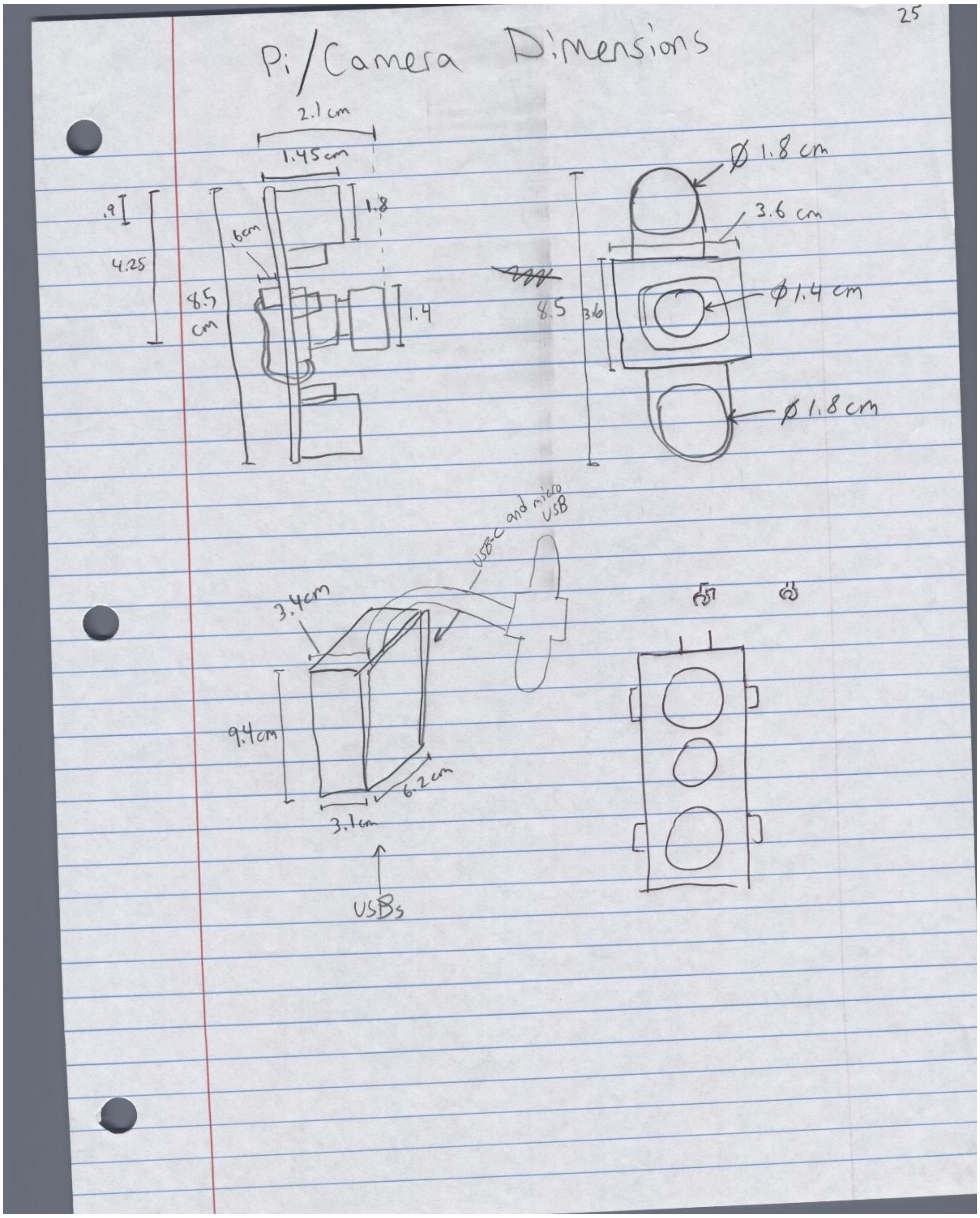


Action items:
- Determine necessary camera height
- Calculate cage dimensions and lid dimensions
- Order materials
- Check shelves in animal lab to identify size castraints

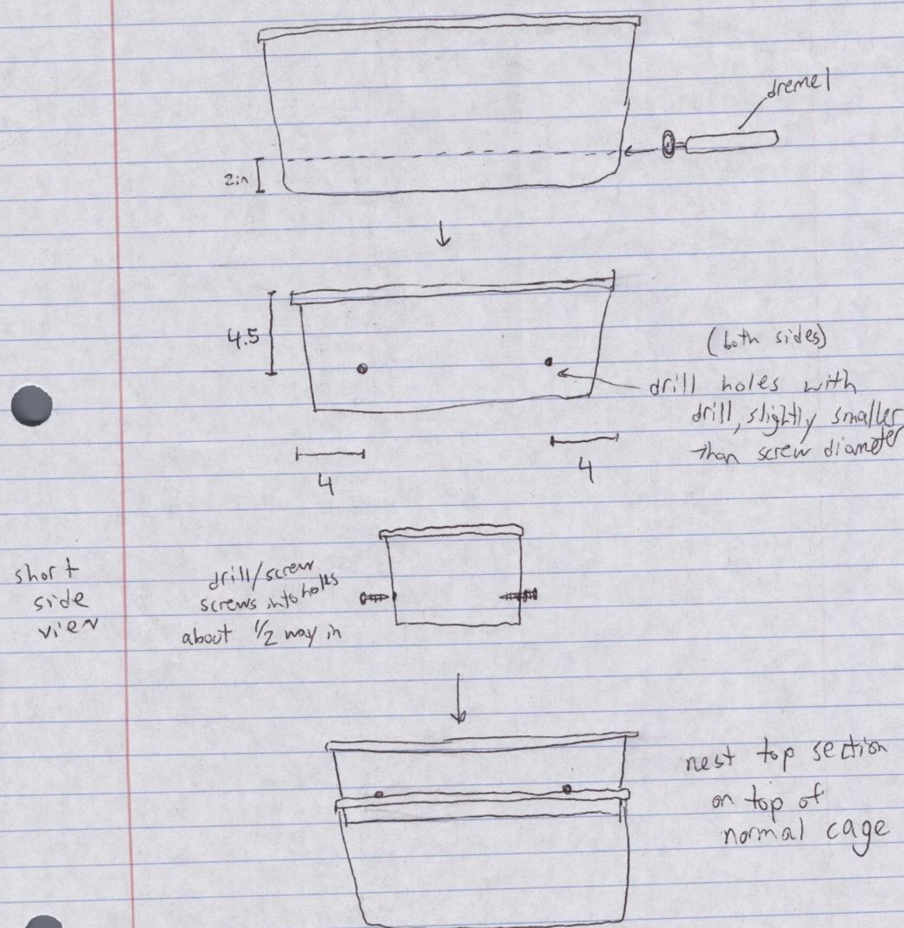




Top Down View


25
Pi/Camera Dimensions
2.1 cm
1.45 cm
1.8
.9
4.25
.6cm
8.5 cm
1.4
Ø 1.8 cm
3.6 cm
8.5
3.6
Ø1.4 cm
Ø1.8cm
USB-C and micro USB
3.4cm
9.4cm
6.2cm
3.1cm
USBs

Cage Height Raising Design



Matrix Analysis (Pugh Charts)

Tracking Software Decision Matrix				
Design Requirement	**Weight**	**Vaughan/Mannava Program**	**DeepLabCut**	**YOLO**
Tracks gross linear movement	10	+	+	+
Doesn't require training on an existing dataset	5	+	-	-
Tracks circular/subtle movements	5	-	+	-
Demonstrated success in previous literature	2	-	+	+
Fast approach	2	+	-	-
Net score		7	10	0
Continue with approach?		No	**Yes**	No

Weighting: Need = 10, Want = 5, Nice-to-have = 2
Scoring: Meets requirement = +, Incompatible with requirement = -, Does not currently meet requirement = 0

A Pugh Chart was utilized to compare three tracking software options. The first is a script developed by a professor in the lab. It functions by asking the user to draw a box around the object they wish to track (as shown in Figure 5a), and the program records the change in position of that box as the object moves. One advantage of this software is that it does not require training of the model, which saves a significant amount of time. One major drawback is that because it identifies objects based on color, it requires the program to be run twice to track night movement, since those videos are in grayscale. Another drawback is that it can only detect gross linear movement, not circular movement or other subtle movements. DeepLabCut and YOLO both require the user to train the model with a sample dataset so it can learn what permutations in shape and position the desired object may take. This adds a significant amount of time, but results in more accurate results. DeepLabCut differs from YOLO in that it tracks an object based on "nodes" – points selected on the object by the user – rather than drawing a box around the object (Figure 5b). The nodes (Figure 5c) enable the quantification of more subtle movements and circular movement. Comparison of these factors resulted in the selection of DeepLabCut.

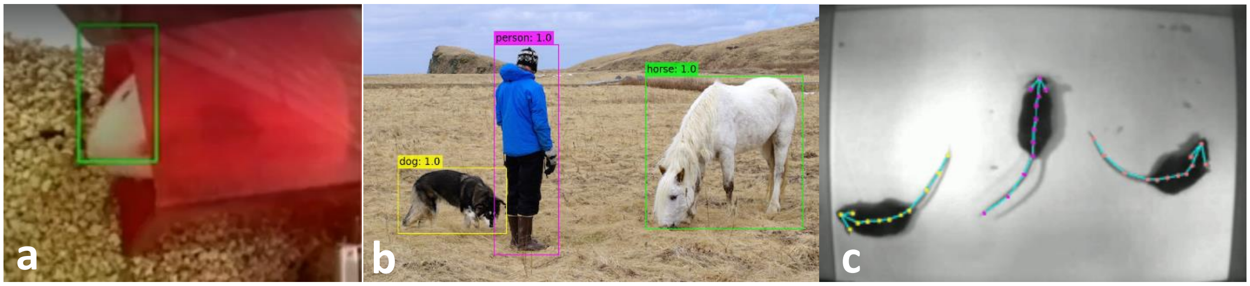


Figure 5. From left to right, depiction of object tracking in Vaughan/Mannava program, YOLO, and DeepLabCut.

Cage Setup Decision Matrix				
Design Requirement	Weight	Block off part of cage with tunnel	Raise cage lid height with part of another cage	Raise cage lid height with frame
Entire cage floor in field-of-view	10	-	+	+
Uses existing/sterilizable materials	5	+	+	-
Requires no changes to food/water setup	2	+	-	-
Net score		7	13	3
Continue with approach?		No	Yes	No
Weighting: Need = 10, Want = 5, Nice-to-have = 2 Scoring: Meets requirement = +, Incompatible with requirement = -, Does not currently meet requirement = 0				

This Pugh chart compares three approaches for ensuring that the guinea pig is in the field of view of the camera for the entire duration of the video. The first approach involved placing a red plastic enrichment tunnel on its side in the corner of the cage adjacent to the food dispenser. This would effectively cut off that region of the cage, so it would not matter if that section was not in the field of view of the camera. The second approach involved cutting around the perimeter of a cage two inches from the bottom, and then nesting the upper section inside another normal cage. A grill could then be placed on top of the upper section, and the camera could be attached, effectively raising the height of the cage to ensure the entire cage bottom is in the camera's field of view. The third option follows a similar principle to Approach 2, but uses a wooden frame placed on the top of the cage to raise the camera height. Testing of Approaches 2 and 3 showed that adequate camera view was provided, but the use of existing cages rather than wooden frames resulted in greater consistency of camera height and angle. Approach 1 was ruled out as the guinea pigs wedged themselves between the tunnel and the wall, thereby leaving the field-of-view of the camera and making this method ineffective. While a previous lab member had taped the video camera to the grill on the cage between the 7th and 8th bars, this location left a significant portion of the cage out of view. Also, while this fixed the camera in the y-axis. The taping method also allowed for variation in camera angle and posed the risk of the tape not holding the camera in place for the duration of the recording. The optimized approach involved placing the camera between the 11th and 12th bars of the grill, which allowed for all of the cage floor except the region behind the feeder to be in the field-of-view (Figure 2). In Approach 1, that region was blocked with an enrichment tunnel turned on its side to ensure part of the animal was in view at all times. In Approaches 2 and 3, this placement allows the entire cage bottom to be in view, as shown in Figure 5. The fixture shown in Figure 3 was designed to clip onto the bars of the grill and has a stopper that fixes the camera at a distance of 2 inches from the left crossbar of the grill. It also has slots for Velcro straps to be added to secure the camera.

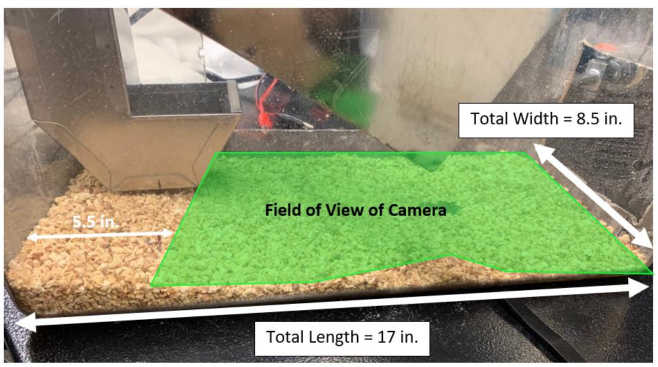


Figure 2. Region of cage in field-of-view of camera using Approach 1.

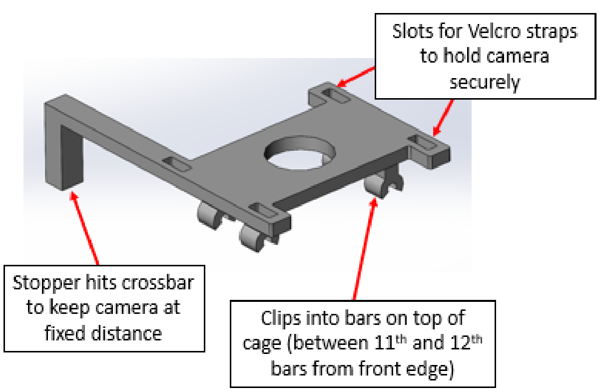


Figure 3. 3D model of camera fixture used for all three Approaches.

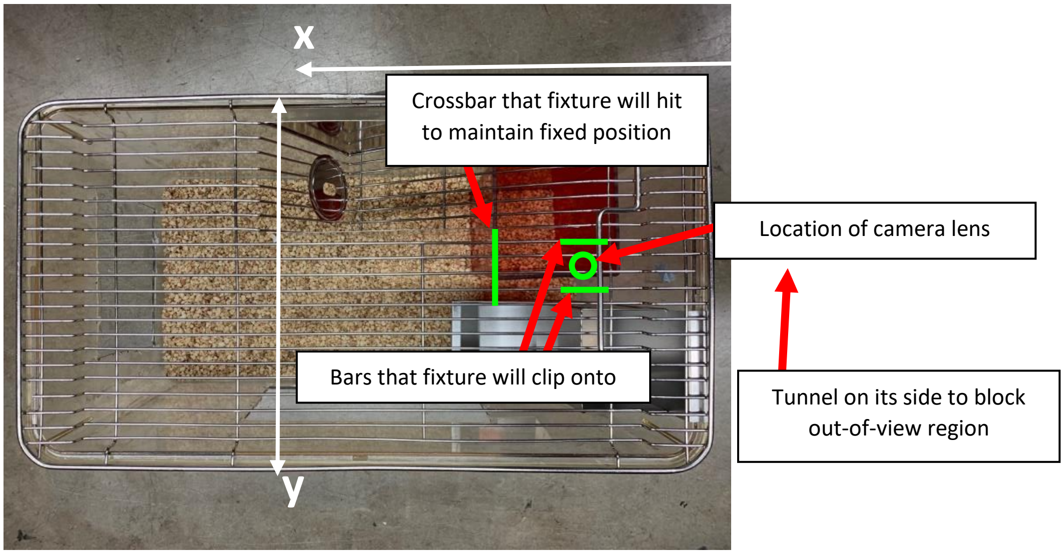


Figure 4. Aerial view of cage with Approach 1.

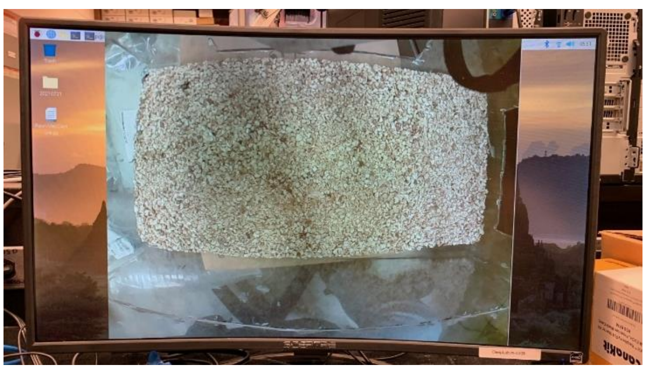
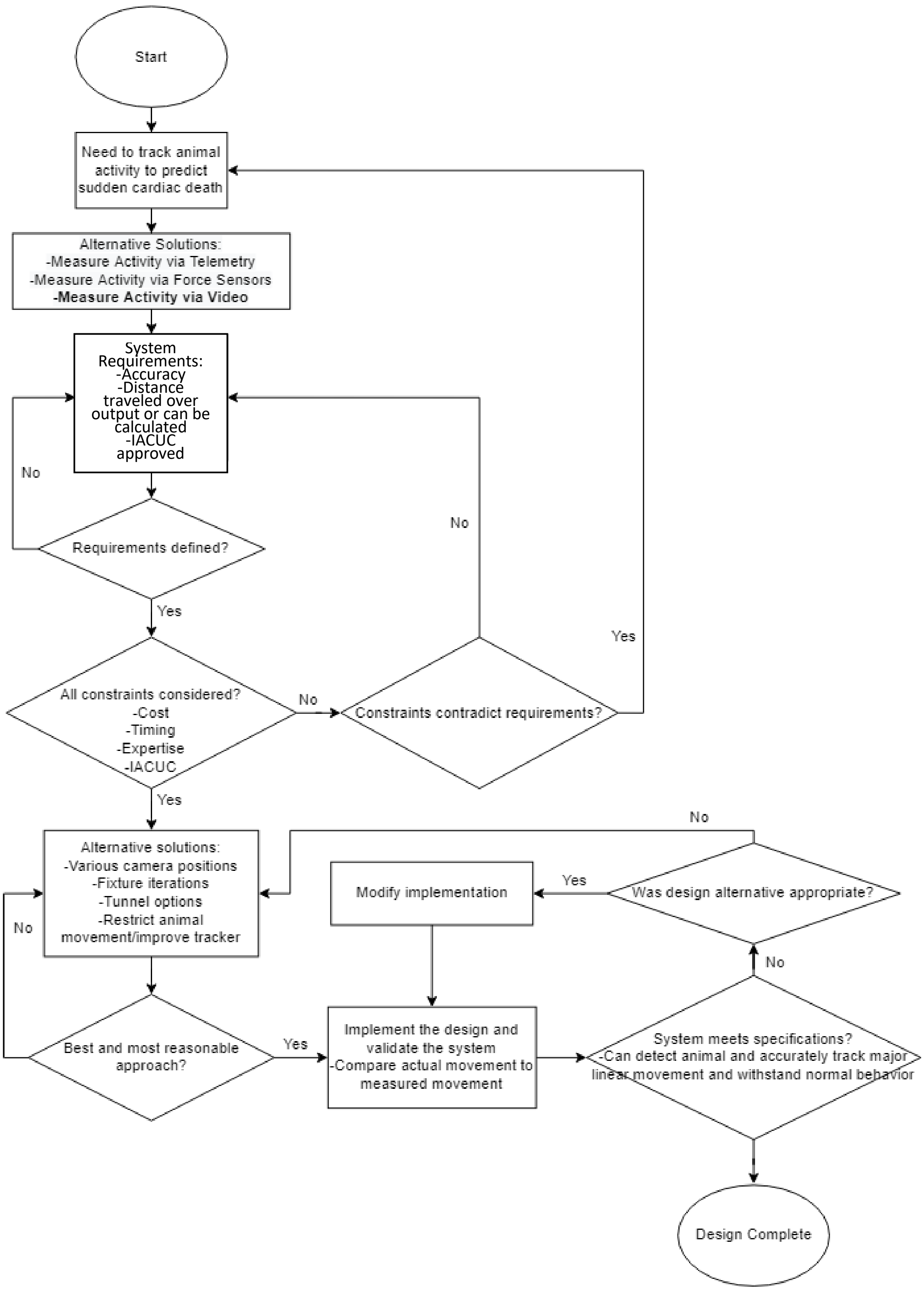


Figure 5. Field of View of Camera using cage height raiser in Approach 2 and 3.

ii. Selected Concept

The finalized design incorporates the camera location between the 11th and 12th bars on top of the cage, the second iteration of the 3D-printed camera fixture, and the use of the nested cage insert. These choices result in the highest score on the Pugh Chart, enabling all of the design needs to be met. Importantly, while not all of the wants or nice-to-haves are met with this design, almost all could be implemented using this design at a later date if deemed worthwhile. Other considerations taken into account in the concept selection were cost and availability of materials.

10. Final Design Flow Chart


Start
Need to track animal activity to predict sudden cardiac death
Alternative Solutions:
-Measure Activity via Telemetry
-Measure Activity via Force Sensors
-Measure Activity via Video
System Requirements:
-Accuracy
-Distance traveled over output or can be calculated
-IACUC approved
No
Requirements defined?
Yes
No
All constraints considered?
-Cost
-Timing
-Expertise
-IACUC
No
Constraints contradict requirements?
Yes
Yes
No
Alternative solutions:
-Various camera positions
-Fixture iterations
-Tunnel options
-Restrict animal movement/improve tracker
Modify implementation
Yes
Was design alternative appropriate?
No
No
Best and most reasonable approach?
Yes
Implement the design and validate the system
-Compare actual movement to measured movement
System meets specifications?
-Can detect animal and accurately track major linear movement and withstand normal behavior
Design Complete