Robot Arm: Soft Hanging Fruit Tests

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Purpose

This test is to evaluate the performance of a robot arm-based harvesting system on soft hanging fruit. This test uses a set of artificial proxy fruit – plastic strawberries and evaluates the ability of the robot system to effectively pick them in a range of increasingly challenging scenarios.

The target capability of the system to evaluate is the precision of identifying ripe from un-ripe strawberries and the speed of successfully picking strawberries.

Test Facility

The test site is indoors in a greenhouse or polytunnel setting (i.e. a semi-controlled environment, which could include artificial light and assumes no wind).

There are multiple test frames, each with an assortment of hanging proxy fruit (e.g. strawberries). Figure 1 shows an example frame set-up.

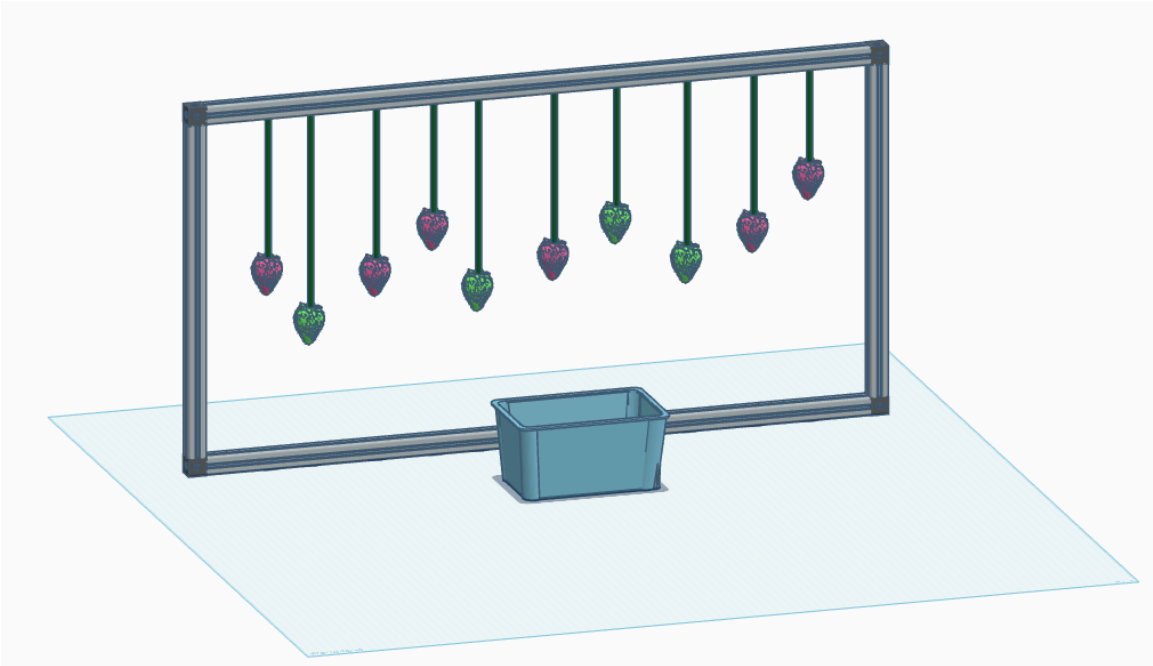

Figure 1. Example test set-up.

The proxy fruit are plastic strawberries, with two types of coloring – red for ripe strawberries and green for raw (un-ripe) strawberries. Figure 2 shows an assortment of the proxy fruit used in these tests.

Figure 2. Green (raw – un-ripe) and red plastic strawberries used as proxy fruit.

The test frame for the scenario has varying dimensions, shown in Figure 3, which include the width and the height of the frame. The fruit are affixed to the frame by rigid "stem-like" wire and are not rigid. The fruit are attached to the stem via a magnetic conntact, which can detach under the forces for picking a strawberry. he target is magnetically attached to the stem, and detaches under grasping actions. Dimeas et al. (2013) have measured that a direct pulling detachment force of ~14N, or a bend of pull detachment force of ~3N is adequate to detach a ripe strawberry.

The depth of the fruit arrangement is mostly planar – there may be some variation in the more complex scenarios below. There is a range of the expected fruit height as defined by the minimum and maximum height dimensions.

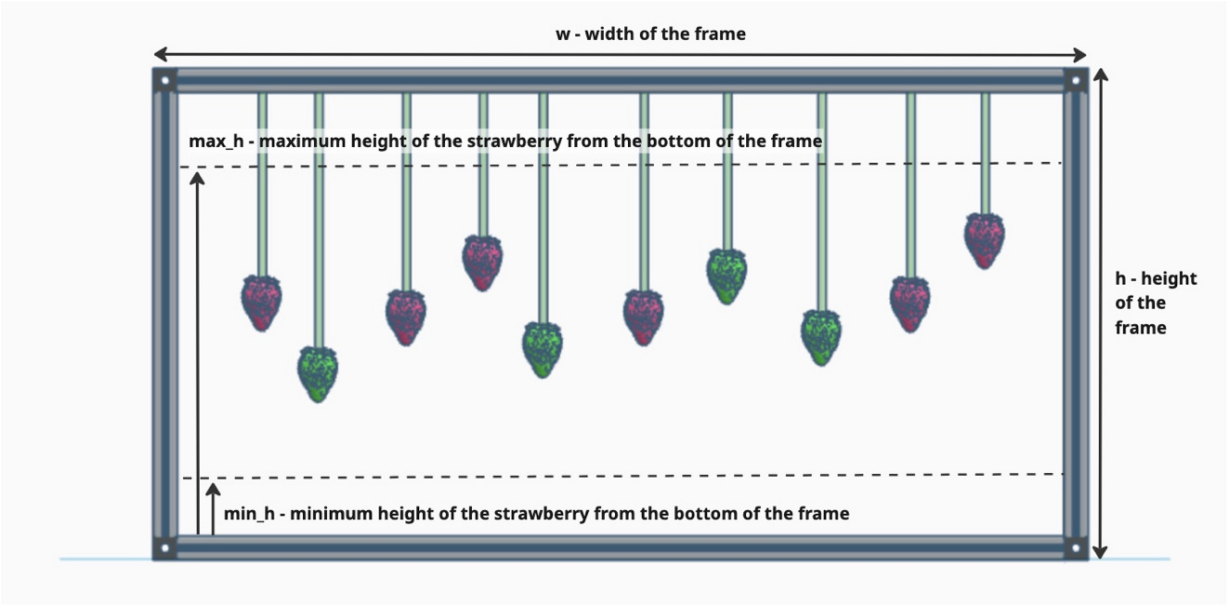

Figure 3. Test frame dimensions.

A punnet – the fruit receptacle – is located (affixed) on the ground in front of a test frame, and its placement relative to the test frame is shown in Figure 4. The punnet has a fixed set of dimensions (it is a common strawberry punnet) shown in Figure 5.

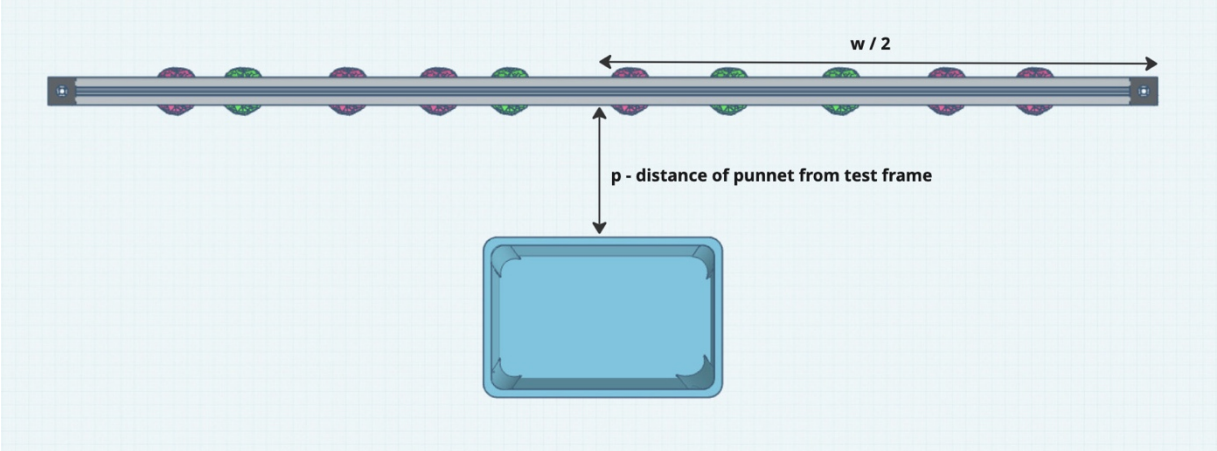

Figure 4. Punnet placement relative to the test frame.

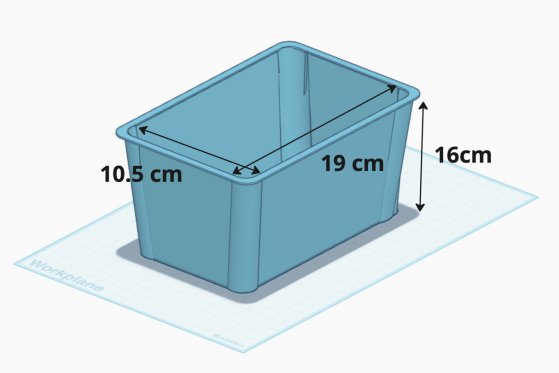

Figure 5. Punnet dimensions.

Test Scenarios

For this test we evaluate five type of soft fruit arrangements, which are adapted from Xiong et al. (2020). Each scenario type is described below in Excerpt 1, and examples are shown in Figure 6. Each scenario is more challenging than the previous one.

> (1) Type A: One isolated ripe strawberry with no other strawberries around it. This is the simplest situation but also common in this strawberry variety.
> (2) Type B: Two ripe strawberries growing very close to each other but with no other strawberries around. Their distribution may be left–right, front–rear, or top–bottom and so on.
> (3) Type C: One ripe strawberry partially surrounded by unripe strawberries. There are spaces through which the gripper can access the ripe berry. This situation is also common in this variety.
> (4) Type D: Two ripe strawberries partially surrounded by unripe strawberries. This situation is similar to type B and type C but more complicated.
> (5) Type E: One ripe strawberry that is fully surrounded by unripe strawberries. This is the most challenging growing situation but was not commonly seen in our experiments with the variety "Lusa."

Excerpt 1. Strawberry arrangement types, except from Xiong et al. (2020) page 218.

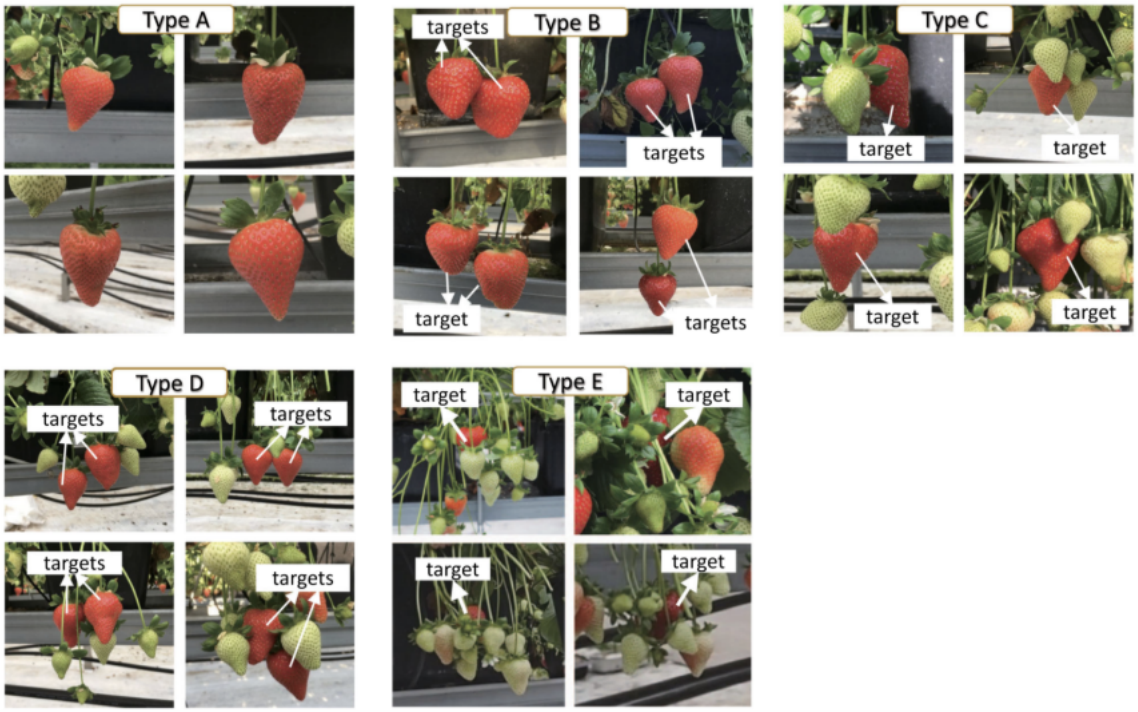

Figure 6. Strawberry arrangement types. Figure 17 from Xiong et al. (2020), page 218.

Test Procedure

The test procedure is a sequence of harvesting tasks with progressively more complicated soft fruit arrangements based on the arrangement types in Figure 6. The heights of the strawberries will be randomized between the minimum and maximum height dimensions specified in the test set-up. There will be at most 10 ripe strawberries in each arrangements to pick. Other than Task Type A0, there will be an unspecified number of raw strawberries.

Each task will be re-run with **5 consecutive trials**. The robot system may be reset, but no off-line training is permitted between trials.

Passing the acceptance criteria of one tasks is necessary to continue on to the next task. The set-up for the tasks are described below.

Task Type A0 – Ripe Strawberry Arrangement

This task involves an arrangement of only ripe strawberries with no raw strawberries. An example arrangement of ripe strawberries is shown in Figure 7. The strawberries will be placed at least 1 strawberry width apart (i.e. no pairs).

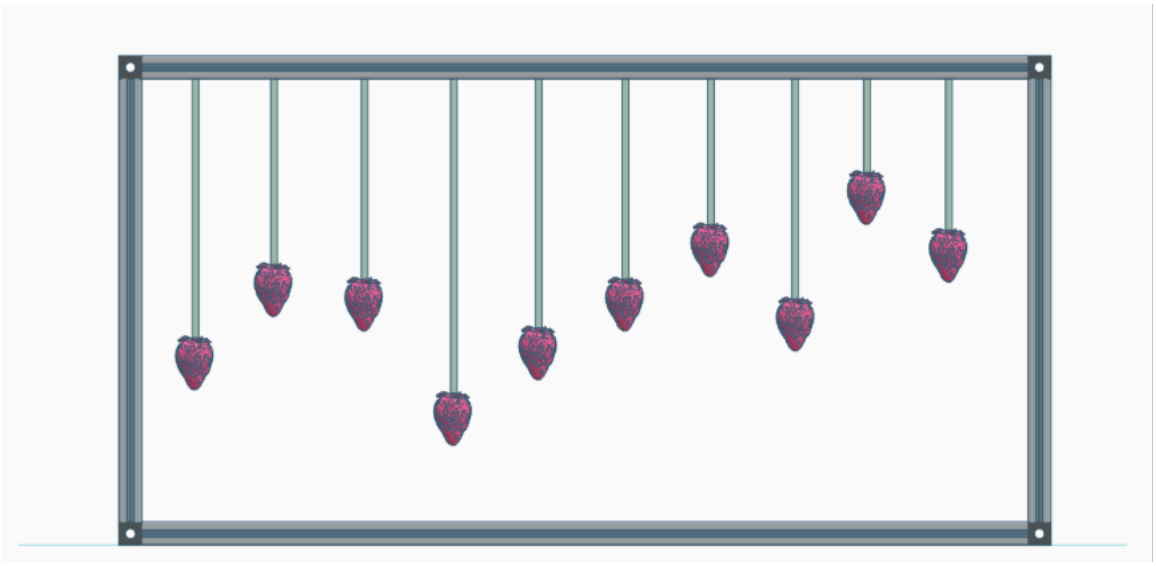

Figure 7. Task Type A0 Strawberry Arrangement

Task Type A1 –Mixed Ripe-Raw Strawberry Arrangement

This task involves an arrangement of a randomized mix of ripe strawberries with no raw strawberries. An example arrangement of mixed strawberries is shown in Figure 8. The strawberries will be placed at least 1 strawberry width apart (i.e. no pairs).

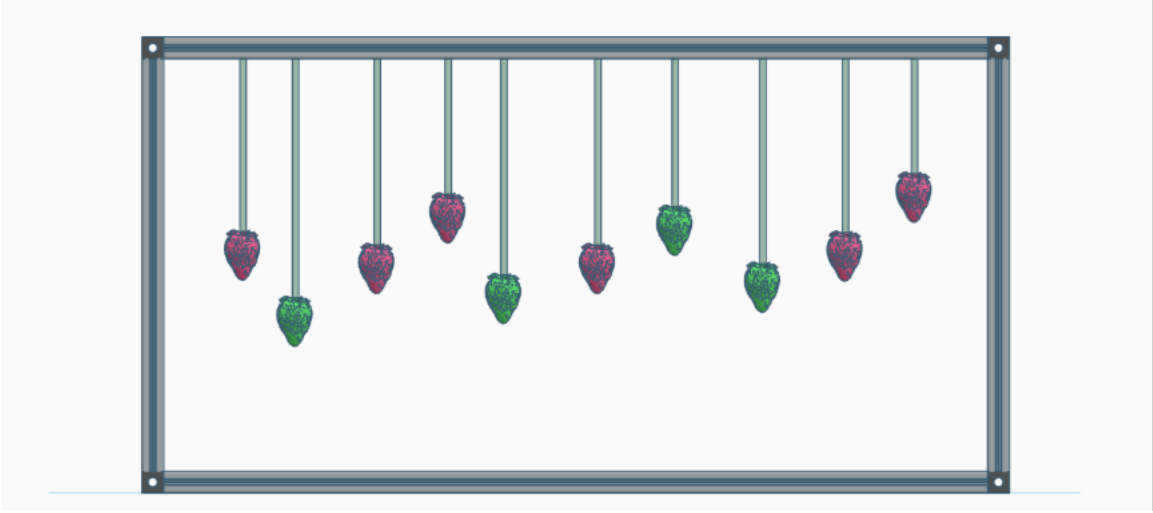

Figure 8. Task Type A1 Strawberry Arrangement

Task B – Ripe Strawberry Pair Arrangement

This task involves the pairs of ripe strawberries (i.e. closer than one 1 strawberry width apart). An example arrangement of strawberry pairs is shown in Figure 9.

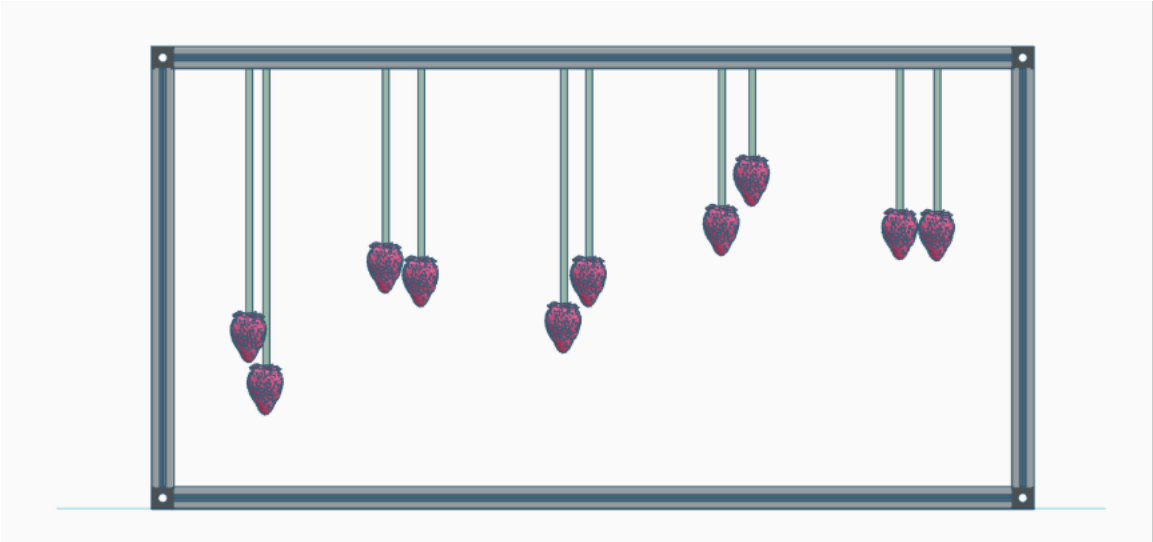

Figure 9. Task Type B Strawberry Arrangement

Task C – Ripe Strawberry Partially Surrounded

This task involves the ripe strawberries with partially surrounded raw strawberries. Some strawberries may be in front of others to create the occlusions. An example arrangement of strawberry pairs is shown in Figure 10.

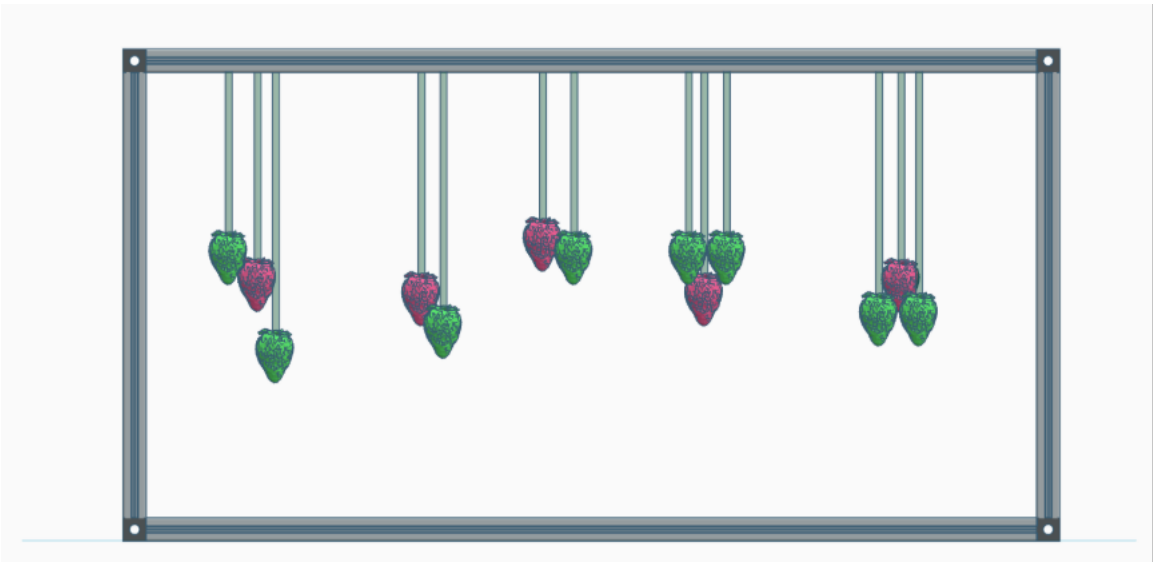

Figure 10. Task Type C Strawberry Arrangement

Task D – Ripe Strawberry Pair Partially Surrounded

This task involves the ripe strawberry pairs partially surrounded by raw strawberries. Some strawberries may be in front of others to create the occlusions. An example arrangement of strawberry pairs is shown in Figure 11.

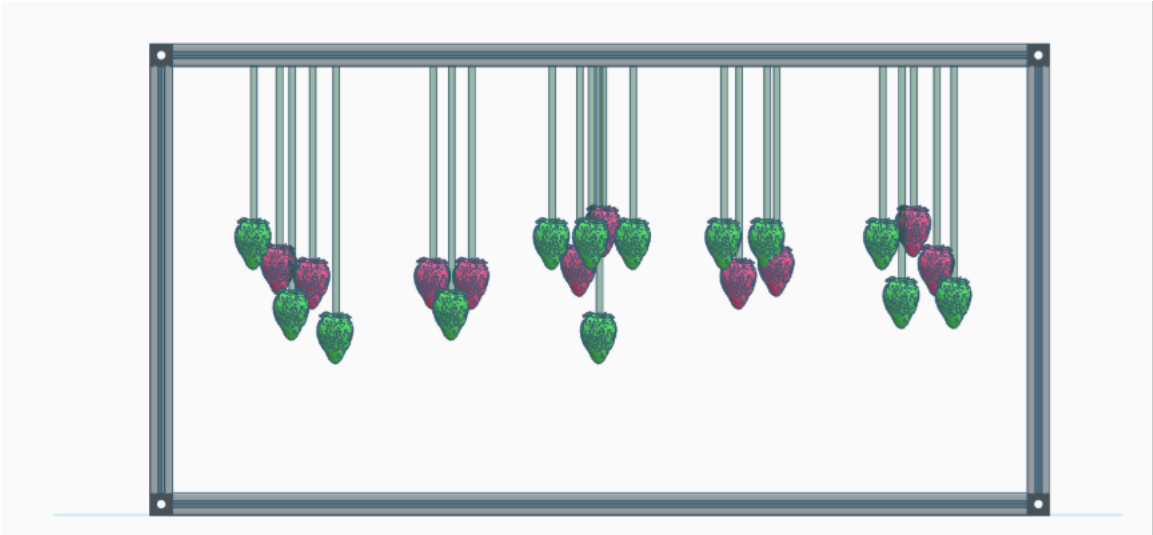

Figure 11. Task Type D Strawberry Arrangement

Task E – Ripe Strawberry Completely Surrounded

This task involves the ripe strawberries completed surrounded by raw strawberries. Some strawberries may be in front of others to create the occlusions. An example arrangement of strawberry pairs is shown in Figure 11.

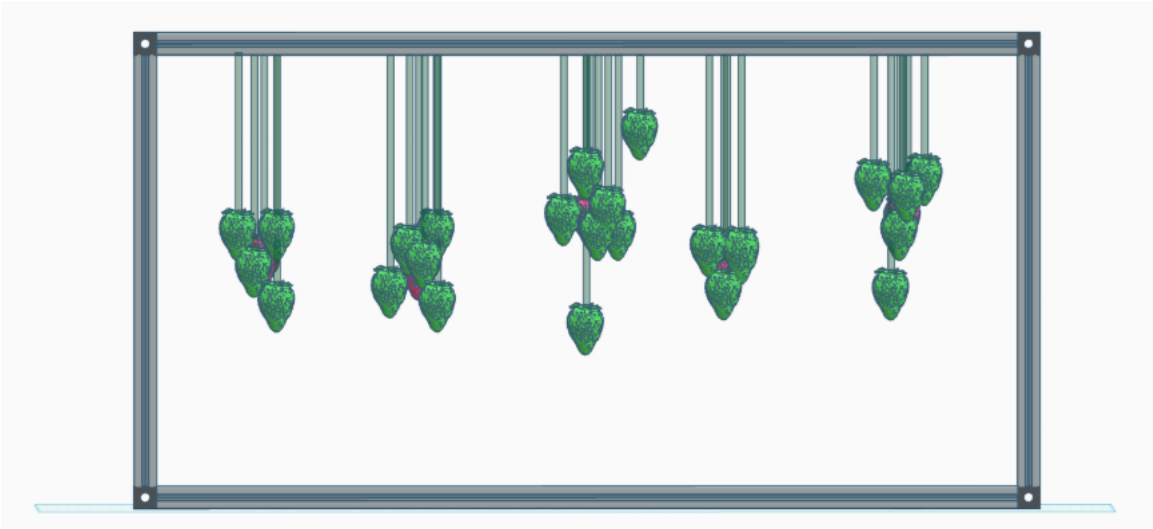

Figure 12. Task Type E Strawberry Arrangement

Evaluation Criteria and Error Conditions

These are the evaluation criteria for the test:

- **Pick Success**. The success rate of picking all of the ripe targets over the repeated trials. Picking a raw strawberry counts as an additional missed target and deducts the pick success by 1. A dropped strawberry may not be picked up again.
- **Throughput.** The second criteria is the time to complete the trial, which is compared to a human completing the trial. The human benchmark will be established prior to the test.

Conditions

The following data is gathered about the robotic system:

- Robotic hardware and software configuration and versions
- Position of the base of the robot system with reference to the Front facing target (a fixed reference point of the test setup).

Each trial is run separately with the ability to reset the robot system as needed.
The following information is recorded for each trial run:

- The robot system is video recorded with full view of each of the targets and the "home" position where the targets are deposited.
- A trial is timed with a limit of 10 minutes each task.
- Each picked strawberry is timestamped and logged.
- The deposit of the strawberry after being picked is timestamped.
- Any dropped strawberries are noted.

Test Result

Each task will have recorded test results and acceptance conditions as follows:

- **Pick Success Results.** A total success rate of for picking all of the targets across the number of trials for a specific task. The acceptable rate is > 95% overall.
- **Throughput Results.** The completion time is averaged across the number of trials for a given task. This is compared as a ratio towards the average human completion time for the trials. The acceptance rate for throughput is TBD and will be based on empirical data.

References

1. Dimeas, Fotios, Dhionis Sako, Vassilis Moulianitis, and Nikos Aspragathos. "Towards Designing a Robot Gripper for Efficient Strawberry Harvesting." Paper presented at RAAD, Portoroz, Slovenia. September 11, 2013.
2. Xiong, Ya, Yuanyue Ge, Lars Grimstad, and Pål J. From. "An Autonomous Strawberry-Harvesting Robot: Design, Development, Integration, and Field Evaluation." *Journal of Field Robotics* 37, no. 2 (2020): 202–24. https://doi.org/10.1002/rob.21889.