Long Range Object Tracking Using Infrared and Ultrasound Optical Sensors

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The recent use of drone technology for recreational and commercial applications has been increasing these days due to its reduction in cost. Although prices are decreasing, the replacement of this technology is still expensive. To limit replacement due to damages when hitting the ground, companies have developed drone mounted parachutes to deploy in the case of power or lift failure. Unfortunately, these parachute systems may not always guarantee a safe touchdown to the ground should the drone fall on to a hard surface or into water. A potential solution to solve this problem would be to employ a tracking system on the ground to follow the falling drone in the sky and safely catch it with a mobile mechanism at its landing location. With respect to the tracking component of this solution, there is interest to see if low-cost range sensors could be used as they have been decreasing in price while being developed to track longer distances. This research sets out to test the hypothesis that low-cost long-range sensors could be used to track an object approximately 0.4m in size within a range of 5m. Three different sensors were tested in this research, the infrared Sharp (5m range), ultrasound UMR37 (5m range) and ultrasound PING (3m range), which all cost less than $30.00. All sensors were tested to understand their signal response behaviour, field of vision size, target identification capabilities and signal response time. These tests were done to aid in the selection of what sensor would be most appropriate to test this hypothesis. Of the three sensors, the PING sensor was chosen to be the most suitable for this application. The PING's consistent and fast signal response made it the best of the three sensors tested in this research. To test the hypothesis, PING sensors were installed on a servo to function as a dynamic object tracking system. This tracking system was able to track a target moving at 0.7m/s within a 3m range, on the condition that the moving target was not turned away such that the sensor signal would not be returned to the PING. The tracking system implemented with the PING failed to prove this hypothesis as it could only detect objects within a 3m range rather than the desired 5m range. However, this testing provided an understanding of performance metrics that are expected of these low-cost long-range sensors to be used in this application. Future work should involve looking into testing the capabilities of other sensor technology such as longer-range ultrasound or laser/Lidar technology. Once an appropriate sensor is selected, further tests should be done to understand the speed limitations of the system when tracking fast moving objects to replicate a realistic descent speed for a drone with a parachute.

Key Words: Drone, PING, Object Tracking

1.0 Introduction

The use of drones in commercial and recreational applications has been increasing as this technology becomes more versatile and affordable. Despite decreasing prices, the replacement of these drones is still costly. Parachute and drone companies have now started to produce drone mounted parachutes to be deployed in the case of power loss or lift failure to reduce or eliminate the cost of replacement. Although drones can now be equipped with one of these parachute systems, their rate of descent could still be fast enough to cause damage upon contact with the ground. These parachutes also do not address the issue of saving the drone should it fall into water. These existing issues, suggest that an additional method of recovery could be used to improve the remote landing of drones. A solution is to employ a ground mounted tracking sensor that could track the falling object and deploy a mobile mechanism to catch the drone at its landing location. This system could be used to recover and save drones from falling into hard terrain or even water to prevent damage.

This catching system is being attempted on a large scale as the private space company SpaceX. In 2018 they tried to catch their Falcon 9 rocket nose cones after launch via a large net on a boat, to reuse them for future launches [1]. This idea of catching rocket nose cones is very similar to the solution of catching drones.

This MECH 461 project set out test the hypothesis that low cost long-range optical sensors would track a falling object with a parachute the size of a small 0.4 m drone at a 5m range. Detecting a falling object with low-cost sensors may be difficult due to the limited capabilities of the sensors available on the market. Short range optical sensors such as the infrared 1m-Sharp are widely available and used for small autonomous mobile robots, but they do not have a useful detection range for this sort of application. Recently, a long-range version of the Sharp infrared (IR) sensor has been produced that has a detection range of 5m, which can be seen in *Figure 1*. Infrared sensors have proved to be effective for dynamic object detection as seen in the Leap Motion IR sensor. The Leap Motion sensor can track static and dynamic movements of an individual's hands for user interface or virtual reality applications but costs approximately $100.00 [2]. There is interest in seeing if the more economic 5m Sharp sensor could be effective for tracking falling objects at long range.

Figure 1: A photo of the 5m Sharp sensor

Initially, only the 5m Sharp was to be tested but other long-range ultrasound (UT) sensors were included in the testing due to their similar detection range and cost. The long-range optical sensors that were tested in this research are the infrared Sharp ($25.00), ultrasonic URM37 ($17.82) and ultrasonic PING ($29.95) which have detection ranges of 5m, 5m, and 3m respectively. Photos of the URM37 and the PING are shown in *Figure 2*. They were all first tested to confirm their range response, field of vision and dynamic object identification and signal response time with respect to small drone targets approximately 0.4m wide. Following these baseline performance tests, the sensor that is most capable and suitable for this small object tracking scenario will be used in a 2D object tracking system to track dynamic targets. This will be to provide a proof of concept for this potential drone recovery system.

Figure 2: Photos of the URM37 (left) and PING (right) ultrasound sensors used in this project

1.1 Sensor Functionality

Before discussing the tests that done with each sensor, the method in which these sensors detect range is necessary to understand the findings in this paper. Of the three sensors, the Sharp sensor will detect range in a different manner than the URM37 and PING. The Sharp sensor will emit an infrared light signal which will then be reflected off an object within its detection range return to the light receiver on the sensor. This receiver is an array sensor that will calculate the objects range using similar triangle geometry depending on the location of the returned light on the array sensor [3]. Since the array sensor is only so large, the Sharp sensor has a minimum detection distance of 100cm and a maximum range of 550cm [5]. Alternatively, the URM37 and PING sensors will measure range based on the ultrasound signal time of flight [4][6]. These ultrasound sensors are like the Sharp in the sense that they consist of a signal emitter on one side of the sensor unit and a receiver on the other. The ultrasound signal will be sent out towards an object of interest and then reflected back to the receiver of the sensor. Based on the speed of sound in air and the time taken to receive the ultrasound signal, the object's range can be calculated. It should be noted that the URM37 and PING will perform this calculation differently. The URM37 will do all range calculations inside sensor's processor and output the target range to the Arduino. Whereas the PING will only output the time of flight for the signal and then the Arduino program must perform the appropriate calculation to determine the measured range. For this research, the output from both the sensors that will be looked at is their measured distance values rather than the signal time of flight or analog value.

2.0 Sensor Testing Procedure

All tests that were done throughout this research was done with the sensors and targets on the ground. This was thought to be a similar situation as if the sensor was facing upwards into the sky searching for a falling drone (target). Performing all the tests on the ground simply allowed for all tests to be set up and repeated much easier, rather than dropping targets from the ceiling. It should be noted that all sensors were not tested concurrently throughout the semester. Initially this all tests were done with the Sharp sensor, then all with the URM37 and finally all with the PING.

2.1 Test #1: Signal Response at Range

The first test performed with all sensors was a test to understand the signal response when targets are placed within the sensors detection range. In this test, the sensor is placed in a stationary position and the target is being moved. Range measurements were taken at every 0.5m, starting at 0.5m from the sensor and ending at the sensor's maximum range. To ensure the signal response was repeatable, measurements were taken as the target was moving away from the sensor (50cm →500cm) and towards the sensor (500cm → 50cm). This test was done with a small target (37.8cm x 30.5cm) and large target (51cm x 76cm) to understand if the signal response would change with the difference in target size. This testing set up is shown in *Figure 3* with the small target places at 1m.

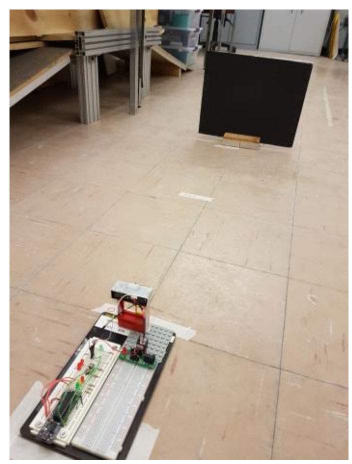

Figure 3: Test#1 set up

2.2 Test #2: Field of Vision Testing

This second test was done to understand the sensor's field of vision throughout its detection range. The location and width of the sensors field of vision were unknown as no information was provided in the sensor's data sheets. This field of vision is necessary to understand as this information could be used to optimize an object tracking system. This was done in a similar way to test #1 in that the sensor was stationary and the target was moved incrementally. This test was performed by moving the small target in and out of the sensor's line of sight at distances of 0.5m, 1m, 2m, and 3m. The target would be moved along a straight line in 0.1m increments with measurements taken from the sensor after every target movement. The target was moved from left to right and right to left of the field of vision to test the repeatability of the signal response. The leading edge of the target was used as a reference point when moving across the sensors field of vision. The signal response would be monitored during the test and once the sensor's signal shows that the target is no longer identified, this would be recognized as the field of vision limit. *Figure 4* shows a portion of the field of vision testing where the target is in a position where it is moving across the sensor's field of vision (note the target is not in line with the red center line of the sensor).

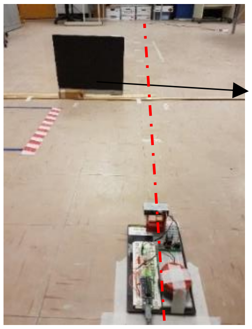

Figure 4: Snapshot of the target moving through sensor's field of vision for test #2

2.3 Test #3: Target Identification

The third test performed was done to test the sensors' ability to see flat objects when they aren't directly perpendicular (normal) to the sensors line of sight. As well as test the sensors output consistency when panning at different speeds on a servo. Test #1 and #2 were done with targets perfectly normal to the line of sight but in the case of a falling drone, it's very unlikely the bottom surface will be perfectly perpendicular to the sensor's line of sight. This test involved mounting the sensor on a servo that was programmed to sweep 180 degrees with the sensor taking measurements every time the angle is increased or decreased. In this test, 5 targets were placed at 0, ±30, and ±60 at 1m from the sensors static location. *Figure 5* is a schematic showing the target set up with respect to the sensor location. This schematic will show the two different test configurations that were done in Test #3. Test configuration #1 had all targets in line with each other, identified as oblique targets that were non-perpendicular to sensor line of sight (left side of *Figure 5*). Whereas test configuration #2 had all targets turned at an angle that would have them perpendicular to the sensors line of sight (right side of *Figure 5*). This test was done with various programmed delays in the Arduino program to slow down the sweeping speed of the servo to allow the sensor to measure the target distance. Delays ranging from 0ms to 120ms. These delays were included to understand if the sensors would track the targets more effectively at slower servo sweeping speeds.

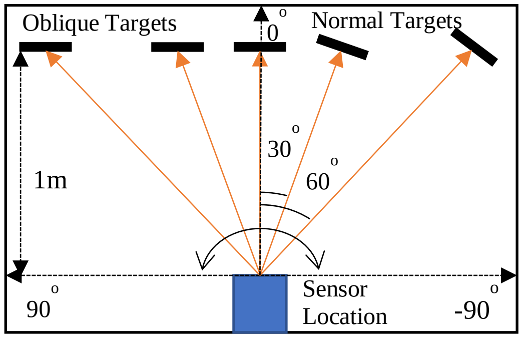

Figure 5: Schematic of oblique and normal target test set-up for Test #3

2.4 Test #4: Signal Response Speed Testing

This final test was only done for the two ultrasound sensors as their signal response time is dependent on the target distance. Testing the Sharp was not a concern for this test as it has a specified signal response time of 16ms and it makes use of infrared light which experiences a negligible time of flight increase within a range of 5m [5]. To measure the signal response time, timing statements were added to the Arduino program to measure the length of time taken to return a range value. One timing statement ahead of the logic to make the range measurement, and a second timing statement at the end of the range measurement. The difference in these timing statements was recognized as the time taken for the sensor to make the distance measurement. This test was done to understand how quick the sensor's signal response would be and if the measurement time would change based on target distance. Since a drone falling is a time-sensitive situation, the sensor used in this application must be able to report a range signal quickly.

3.0 Results & Discussion

The results will be presented by reporting all test results for each sensor in chronological order. The purpose of the order is to describe the selection of a certain sensor, the discovery of why it was unfit for this application and then the procurement of an alternative solution. The first sensor tested was the Sharp, followed by the URM37 and finally the PING.

3.1 Sharp Results

3.1.1 Test #1 Results

Before starting all sensor testing with the 5m Sharp, it was known from prior experience in MECH 452 (Introduction to Mechatronics) that the 5m sharps smaller sibling, the 1m sharp has a non-linear signal response. Since the 5m sharp is simply geometrically scaled up from the 1m sharp, a non-linear signal response should be expected. Seen in *Figure 6* is the signal response in millivolts for the 5m Sharp in test #1 with the two sized targets. It can be seen in this figure that the non-linear signal response is similar between the two sized targets from 100cm to approximately 300cm. The difference in signals becomes more apparent for target distances great than 300cm, as the two signals begin to deviate and become inconsistent with each other. This is due to the effect of the non-linear response as a small change in voltage could imply in a large change in target distance. As the response curve begins to approach the imaginary asymptote around 1000mv the accuracy of the sensor becomes very inconsistent and non-repeatable for measuring targets at these distances.

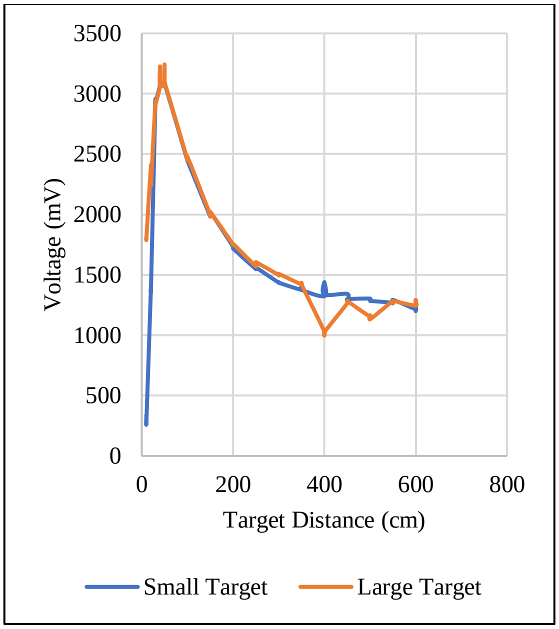

Figure 6: Sharp signal response at range

3.1.2 Test #2 Results

Before getting the results from this test, it was expected that when the sensor started to detect the target that was being moved into its field of vision, the magnitude of the signal response should be identical to what was collected in test #1. *Figure 7* shows the signal response for the Sharp from test #2, where a target was moved in and out of the field of vision of the sharp at 0.5m, 1m, 2m, and 3m. On this figure, there are also horizontal lines representing the expected voltages at each distance collected from test #1. These horizontal lines provide an idea of what the signal response should be when the target is being identified by the Sharp. It can be seen in *Figure 7* that the region in which the signal is at the expected voltages in not at 0cm of the target offset distance, where 0cm was arranged to be the center of the sensor. The signal increase is the point where the sensor is measuring the range to the target. This offset of the field of vision is due to the Sharp not being symmetrical in their design, one side will emit the IR signal and the other will receive the signal. Due to this asymmetry, half of the sensor is technically "blind" as it will never receive a signal if a target is not within the range of the signal emitter.

It can also be seen in *Figure 7* that the Sharp signal is rather inconsistent with the horizontal expected voltage at each distance. The effects of the non-linear signal response are quite evident in the 2m and 3m test response as they are more inconsistent with respect to the expected voltage line than the 0.5m and 1m data.

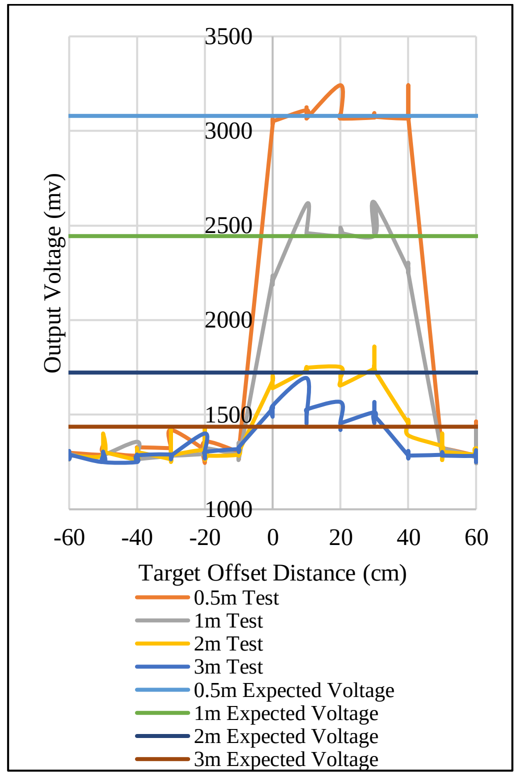

Figure 7: Sharp field of vision test signal response

3.1.3 Test #3 Results

The results from this test truly showed the object identification limitations of the Sharp sensor. These results provide justification that if a flat target is turned away from the sensors line of sight more than 30 degrees than the sensor will not be able to detect its range. The data plot for the Sharp in *Figure 8* shows this failure of oblique target detection. This failure can be identified when comparing to the green date curve to the blue data curve. In this figure, the green curve is when all targets were turned appropriately to face perpendicular (normal) to the sensors line of sight. The green response curve shows regions of consistent signal response (in mv) that corresponded with the expected signal response for the distance of each target. Since portions of the oblique data (blue curve) on *Figures 8* are inconsistent with the normal target signal response (green curve), it is justified that the Sharp failed to identify the some of the targets. The Sharp managed to partially identify the targets at ±30 degrees (circled in yellow) but did not identify the targets at ±60 degrees (circled in red). The plot shown in *Figure 8* is the data taken when the Arduino program was using no delays when sweeping the 180 degrees as fast as it can. It was also found that regardless of the speed of the servo, the output would be very similar. This would imply that the Sharp was able to report back a new range signal very quickly before the servo has moved too far. It is already known that the Sharp has a quick signal response rate of 16ms, so this justifies that the Sharp could sweep quickly with no need for programmed delays.

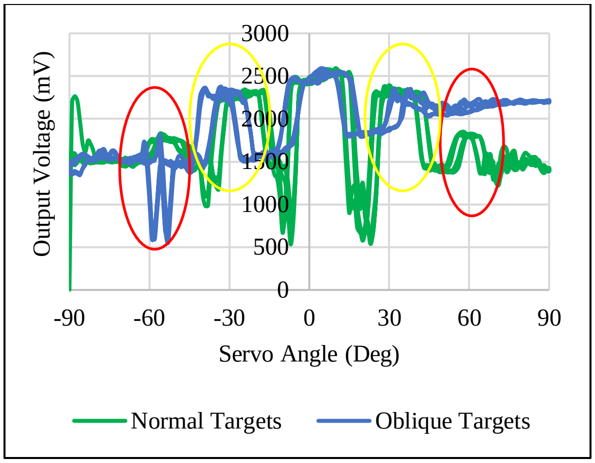

Figure 8: Sharp signal response for the oblique and normal target test

3.1.4 Test #4 Results

This test was never performed with the Sharp sensor as its signal response was identified as 16ms on the Sharps data sheet [5]. Additionally, since the signal from the Sharp is infrared light traveling at the speed of light, the difference in signal time of flight for targets of different ranges is essentially negligible. For these reasons, the signal response time of 16ms was treated as a constant.

3.1.5 Sharp Discussion

Although the Sharp has a specified 5m range and a quick signal response time of 16ms, it has many associated drawbacks. The largest drawback to this sensor is the non-linear signal response as a function of target distance. This non-linearity was the reason the Sharp cannot provide a consistent signal response at ranges larger than 3m. Furthermore, since the Sharp cannot consistently detect objects closer than 1m, the useful range of this sensor is much smaller than what is specified on the data sheet [5]. Although being able to detect some of the targets in Test #3, the Sharp's inconsistent signal response and small useful detection range made it unfit for this object tracking application.

3.2 URM37 Results

Since the Sharp was not selected to be used for this tracking system application, a new sensor with similar technical specifications was selected to be tested. This second sensor to test was the URM37 ultrasound sensor.

3.2.1 Test #1 Results

One difference with the signal response for the URM37 is that it would output the actual measured distance rather than voltage like the Sharp. Due to this, the data plots for the URM37 would show the measured distance plotted against the target distance. This is technically not the direct signal output as the sensor must do a calculation to return range, but considering this is a scaled form of output from the analog signal, it will be considered as the sensor's calibration curve/signal response. It can be seen in *Figure 9* that the calibration curve is very linear as the measured distance from the sensor will correspond almost identically with the target distance. This is the expected response as the sensors should be measuring distance accurately. This figure provides a visual on the degree of accuracy and consistency of the signal response for the URM37.

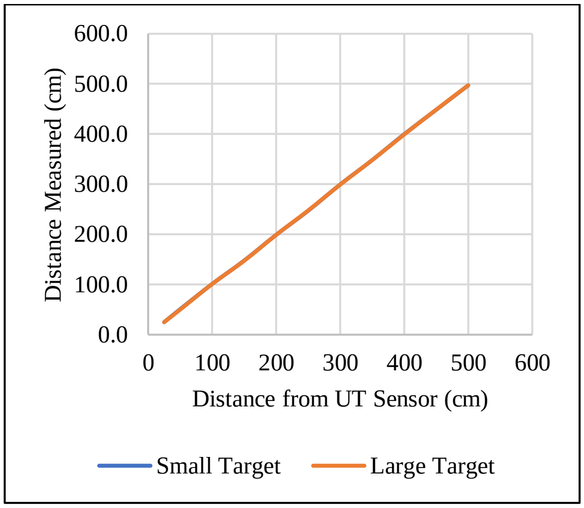

Figure 9: URM37 analog signal response at range

3.2.2 Test #2 Results

The consistency of the URM37 sensor during this test was much more accurate than what was seen with the Sharp. The signal peaks when the target was identified were much more consistent, as seen in *Figure 10*. This width of the field of vision was very similar to the Sharp as it is also approximately 50cm wide. The URM37 also has a field of vision centered around the right side of the sensor (+0.2m offset from 0m), rather than directly in the center of the sensor. Again, this is due to one side of the sensor emitting the ultrasound and the other side receiving.

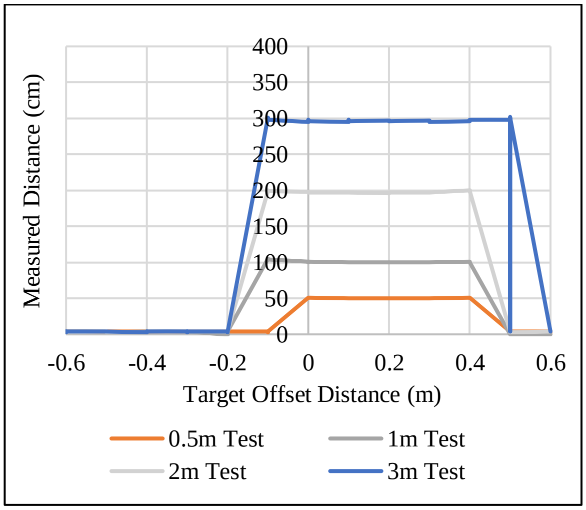

Figure 10: URM37 field of vision test signal response

3.2.3 Test #3 Results

When procuring the ultrasound sensor, there was speculation that the URM37 would outperform the Sharp when identifying oblique targets, since the ultrasound may be more likely to return to the sensor than IR light. In *Figure 11*, the green curve shows the sensor response when identifying normal facing targets and has consistent signal regions corresponding to each target angle. This normal target curve (green curve) will be used to compare to the oblique target curve (blue curve). Unfortunately, the URM37 had a much worse performance than expected as it did not identify the targets ±30 and ±60 degrees (circled in red), which can be seen in the blue curve. This could have been due to the angle of the target being placed at such an oblique angle that the signal was reflected off to another part of the room.

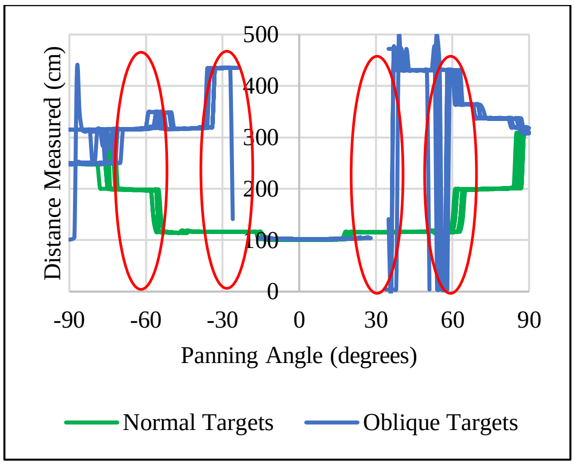

Figure 11: URM37 signal response for the oblique and normal target test

Another thing to note is the URM37 has an associated 100ms signal response time as mentioned in its datasheet [4]. This became very apparent in this test as the programmed delay was increased above and below 100ms to see the effects of the servo moving faster than the URM37 can technically measure. The result of this is that the angles in which the signal would peak up or down would be rather inconsistent at servo speeds where there is a delay less than 100ms. *Figure 11* shows the data from when there was no delay which can be compared to *Figure 12*, which shows a portion of the normal target plot with the URM37 but with a programmed delay of 100ms.

It can be seen in *Figure 12* that the points where the signal increases and decreases (circled in red) there is always two vertical lines separated by approximately 5 degrees. This is due to the one side of the sensor doing the object detection, the URM37 will detect the same target at two different angles depending on its direction of rotation (CCW or CW). The data in *Figure 12* is three measurement cycles (-90 to 90 and back to -90), and something to note is the consistency of the location of these vertical lines. Since they are always in the same angle even despite having three rotations of range data overlaid on the plot, it could be justified that the 100ms delay is allowing the sensor to detect range properly before moving to the following angle.

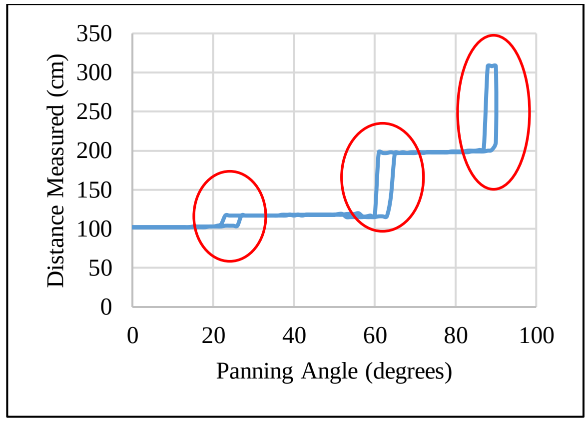

Figure 12: Portion of URM37 servo sweeping in test #3 with a programmed delay of 100ms

This behaviour can be compared to the vertical lines in *Figure 13*, which has much less consistent vertical signal lines. This inconsistent signal rise is due to the servo is moving faster than the URM37 can properly measure target range and is detecting new targets at a variety of different times.

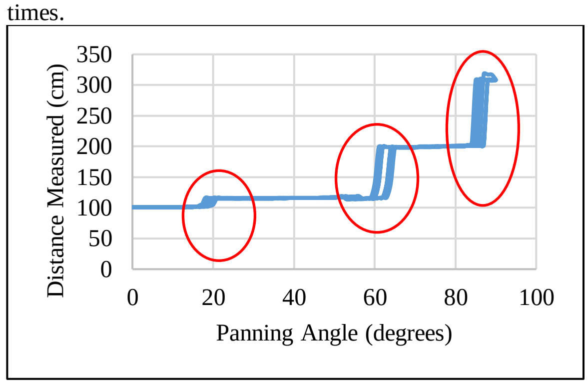

Figure 13: Portion of URM37 servo sweeping in test #3 with a programmed delay of 0ms

3.2.4 Test #4 Results

Performing the timing test was particularly important for the UMR37 as it was the deciding factor for this sensors feasibility for this tracking application. The sensor data sheet did make it clear that there was a 100ms delay time with data acquisition, but it was worth investigating exactly what this time would be. During Test #3, timing statements were programming in the code and the length of the time was taken to measure the distance to the target at 1m away from the URM37. *Table 1* shows some data from the testing when the servo was sweeping towards a normal facing target at 1m. When the distance recorded reports “Invalid”, this means that the URM37 was measuring distance beyond its maximum range, so it would not just identify this as an invalid measurement. But what should be noticed is that the measurement time for a distance that is approximately 5m away from the sensor is ~250ms, not 100ms as specified in the datasheet [4]. Additionally, the data points measuring close to 100cm had measurement times of ~60ms.

Table 1: Portion of URM37 data from measurement timing test

Angle	Distance (cm)	Measurement Time (ms)
117	Invalid	246
116	Invalid	248
115	Invalid	248
114	106	94
113	104	44
112	103	57
111	103	60
110	102	64
105	102	47

Using this information collected from the timing test a measurement time vs target distance plot could be produced. This is shown in *Figure 14*. A forecasted trendline was made on the chart to extrapolate to where the minimum measurement time would be. This theoretical point is approximately 20ms at the closest distance. Seeing this data from *Table 1*, it could be that the 100ms delay time was a general measurement time for the sensor.

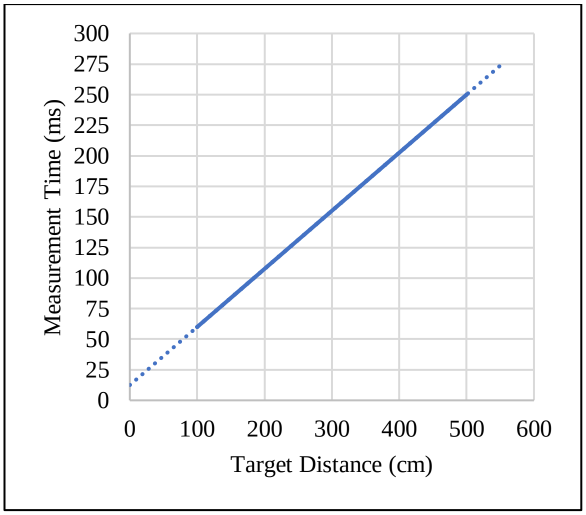

Figure 14: URM37 measurement time as a function of target distance

3.2.5 URM37 Discussion

Even before performing all the tests with the URM37, it was made clear that it had an associated 100ms signal delay time. The hope was that this sensor would outperform the Sharp in these tests, but the signal delay proved to be the biggest drawback for the URM37. Although having a consistent calibration curve and field of vision response, its inability to identify targets at an oblique angle and its slow signal response made it not ideal for this time-sensitive drone tracking application.

3.3 Ping Results

Now that the Sharp and URM37 have been tested and have proven to be not as ideal for this tracking system application, a third sensor was tested. Fortunately, some direction was given from the previous tests to find an ideal sensor for this tracking system. The previous sensor tests highlight that an ideal sensor should have a fast response time like the Sharp but a consistent signal response/calibration curve like the URM37. The third sensor that was tested was believed to satisfy these criteria. The PING ultrasonic sensor functions the same as the URM37 but has no onboard range processing/calculation, so it most likely has a faster signal response. Unfortunately, the PING has a reduced detection range of 3m rather than 5m.

3.3.1 – Test #1 Results

The calibration curve for the PING was found to be very similar to be very similar to the calibration curve of the URM37 as they are both very linear responses. This PING calibration curve can be seen in *Figure 15*¸where it shows the curves for the small and large target, as well as a plot showing a perfect distance calibration. It was noticed that the PING begins to lose accuracy as the target distance approaches its detection range limit (3m). This can be seen in *Figure 15* as the "Small Target" line in grey begins to deviate below the "Expected Distance" line in blue.

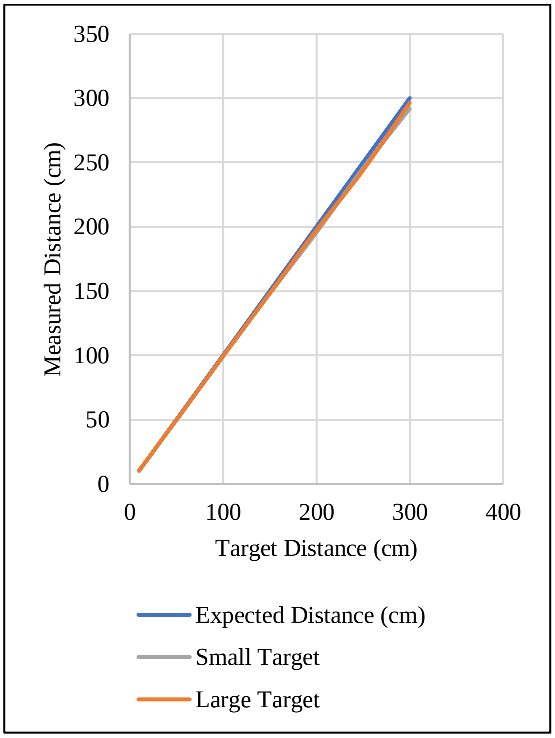

Figure 15: PING signal response at range

3.3.2 – Test #2 Results

It was found that the test results for the PING were slightly less accurate than the signal response seen with the URM37 but still more consistent than the Sharp. This signal response can be seen in *Figure 16*, shows consistency around the measured distance but with slight range fluctuation. This small fluctuation was discovered in the test results from Test #1 as the PING signal response is less accurate with a smaller target, which was the same target used in this test. Some of the fluctuations could be due to the inconsistent testing protocol as the target could have been turned or slightly closer to the sensor in this test when it was positioned manually.

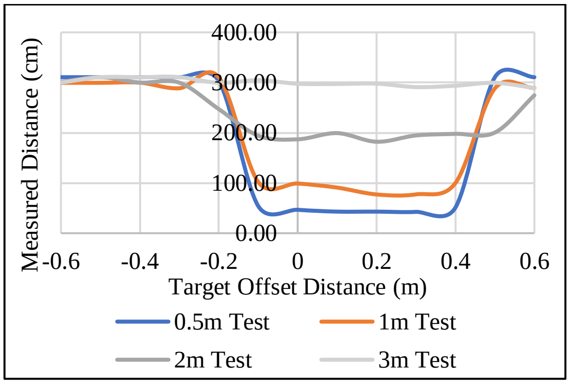

Figure 16: PING field of vision test signal response

3.3.3 – Test #3 Results

Similarly to the URM37, the PING did not perform as expected for the oblique target test. It can be seen in *Figure 17* that the signal response for the oblique target (blue curve) does not stay at the same measured distance value as the normal target signal response (green curve). Since the normal target response has locations of consistently measured distances at the appropriate angles, it is treated as the ideal response for this test. This can also be justified by making the comparison between *Figure 17 and Figure* 11 of the URM37 as they are a similar shape. When comparing to the oblique target data curve, the PING failed to identify targets at ±30 and ±60 degrees (circled in red).

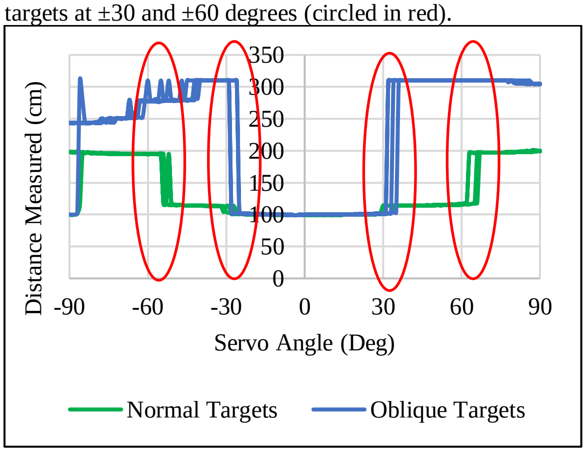

Figure 17: PING signal response for the oblique and normal target test

The justification for the sensor not identifying the oblique targets placed at ±60 degrees from information found in the PING data sheet. The data sheet provides a graphic showing that if an angle between the line of sight of the sensor and a flat object is less than 45 degrees, the signal will not be returned to the PING [6]. This angle is shown as theta (θ) in *Figure 18*. Since the functionality of the URM37 and the PING are essentially identical and performed in a similar way for test #1, #2 and #3, this is most likely the cause of why the URM37 also didn't detect the target at ±60 degrees. Unfortunately, this information from the PING data sheet does not provide justification on why the URM37 and PING did not identify the targets at ±30 degrees. To understand this, further testing should be done by collecting data for targets turned above and below this criteria angle of 45 degrees indicated by the PING data sheet.

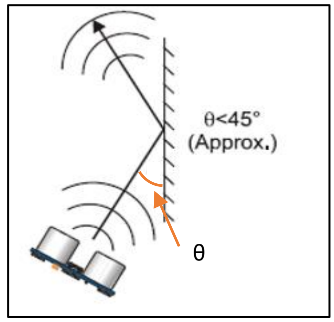

Figure 18: Screenshot from PING data sheet showing oblique identification limitations [6]

With respect to the signal peak consistency, the PING proved to have quite consistent signal peaks while doing several 180-degree sweeps. This consistency is most likely due to the very quick signal response rate of less than 19ms mentioned in the datasheet [6]. These consistent signal responses can be seen circled in red in *Figure 19*.

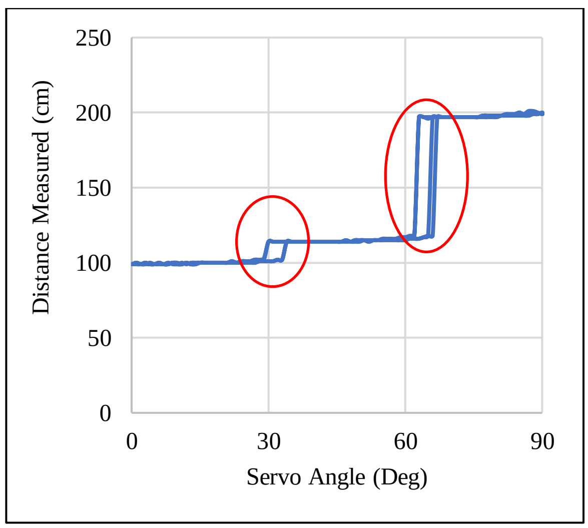

Figure 19: Portion of PING servo sweeping in test #3 with a programmed delay of 0ms

An interesting discovery is that the PING and URM37 had slightly different locations of these signal spikes for the target at 30 degrees. This difference can be seen in *Figure 20* in the red circles. This difference can be found for the target at -30 degrees, but *Figure* 20 is only showing angles 0 to 90 to better see the difference in signal spikes. The reason for this difference only happening for the target placed at 30 degrees and not the target at 60 degrees is rather unknown. It would be expected that the PING and URM37 would identify targets at similar points in their 180 degrees of sweeping since they have very similar fields of vision that are located on the same side of the sensor. This could be investigated in future work with the URM37 and the PING.

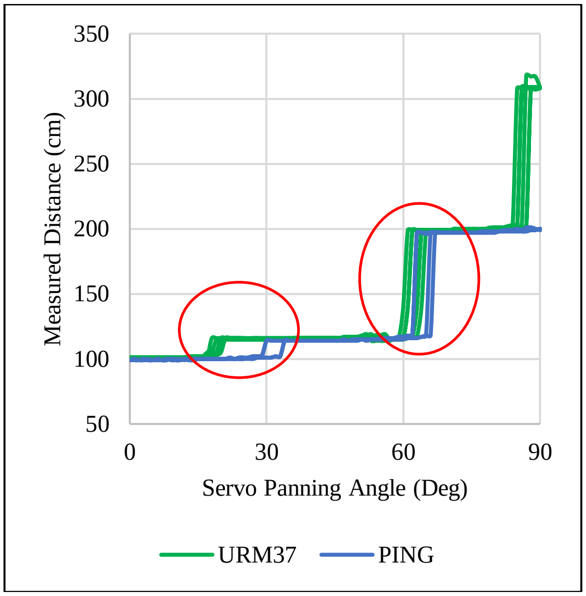

Figure 20: Portion of URM37 and PING servo sweeping in test #3 with a programmed delay of 0ms

3.3.4 – Test #4 Results

Since discovering that ultrasonic signal response time can change depending on target distance, further investigation was done to understand the behavior of the signal response over the PING's detection range. Although being told that the PING can detect range within 19ms, the relationship of measurement time as a function of target distance was still unknown. The was done by performing a similar test like Test #1, but with timing statements before and after the PING measurement logic. The signal response over the sensor's range was found to be very linear as target distance increased which similar to the response of the URM37. This relationship is shown in *Figure 21*.

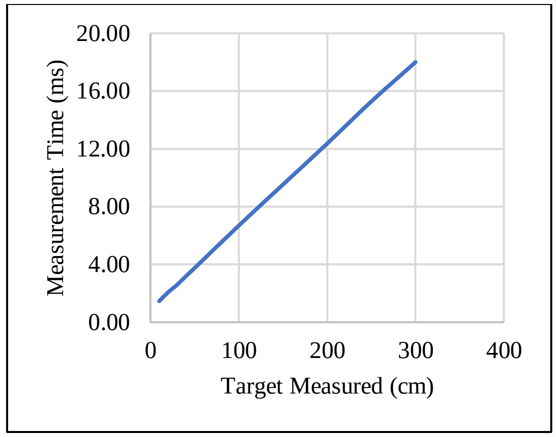

Figure 21: Signal response time as a function of target distance

3.3.5 – PING Discussion

The PING sensor proved to have the functionality that would be ideal for the object tracking system. This is due to its consistent linear calibration curve, relatively consistent field of vision and fast signal response time. The PING made the bridged the gap between the Sharp and the URM37 by having consistent and fast signal response rather than one or the other. For these reasons, the PING will be used for the dynamic target tracking system to realize the proof of concept. Unfortunately, due to the reduced detection range, the scale of the proof of concept will have to be reduced to a range of 3 meters.

4.0 Moving Target Tracking System

This moving target tracking system will be composed of two components to show dynamic object tracking. These components of the system will be the programmable moving target and the PING sensors for the tracking system.

4.1 – Moving Target Set-up

The moving target for this test will use the small target that was used throughout test #1 to #4 and will be mounted to the front of a Lynxbot programmable robot. Shown in *Figure 22* are photos of the Lynxbot robot car and the target mounted on its front via Lego cantilever beams.

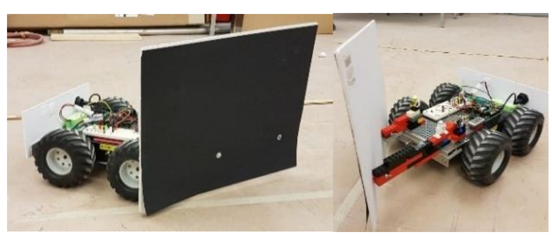

Figure 22: Photos of the target mounted on a Lynxbot robot car

This Lynxbot will be moving diagonally from corner to corner through a 3m x 3m testing space, and the sensor will be placed on a servo at the midpoint of the lengths of this square. The diagonal trajectory is used to test two components of the tracking system's capabilities, these are increasing target proximity and servo sweeping speed. The Lynxbot will also be programmed to stop and move backward through the testing arena to validate that the tracking system can, in fact, track the object in 2 rotational directions (CW & CCW). A schematic is shown in *Figure 23* shows the proposed layout for the object tracking system test, where the grey box is the sensors' location.

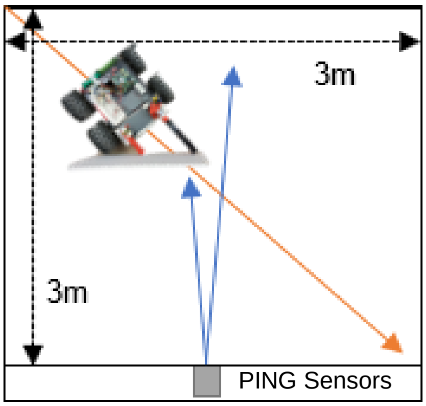

Figure 23: Schematic of 2D tracking system area and robot trajectory

4.2 – Double PING Tracking System

The tracking system would be composed of two PING sensors placed side by side and on a single servo. The Arduino program behind the PINGs would compare the distances measured by the two sensors. Should the distances be different, this would indicate that one sensor is measuring the range to the target when the other could be measuring range beyond the target, this would trigger program to move the servo appropriately to have both sensors looking at the same target. *Figure 24* shows an example of the two sensors on a servo set up.

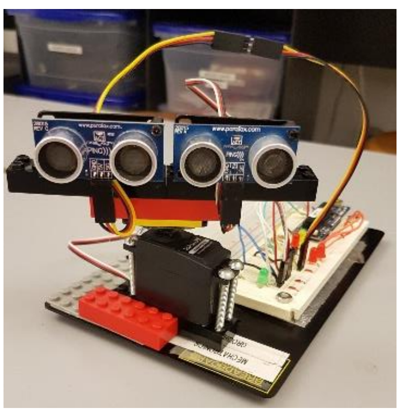

Figure 24: Photo of two sensors set up on the servo

The goal was to develop an object tracking system that could track the target moving back and forth within the sensor's detection range of 3m. An additional goal would be to identify at which point in the servo sweep can will the sensor lose the range of the target.

4.3 – Tracking System Results

It was found during prior servo testing that making print statements (to output servo angle and sensor distance) would slow down the rate in which the servo can sweep through the 180 degrees as this was more computation time per program loop. Knowing that this was an issue for servo speed, the program used for the object tracking system would not make any print statements in the eye of optimizing servo speed to track as fast as possible. Unfortunately, when not outputting numerical information, there was there was no clear way to identify that the sensors were effectively tracking the target. To solve this issue, a Lego mount was made to be installed on the servo to hold a cell phone. This cellphone would be facing in the same direction in which the sensors while recording video of the tracking. This video evidence would give some better insight on how well the sensors are tracking the moving target, simply by seeing how much of the target is in the video frame. Photos of the mount are shown in *Figure 25* of the Lego camera mount.

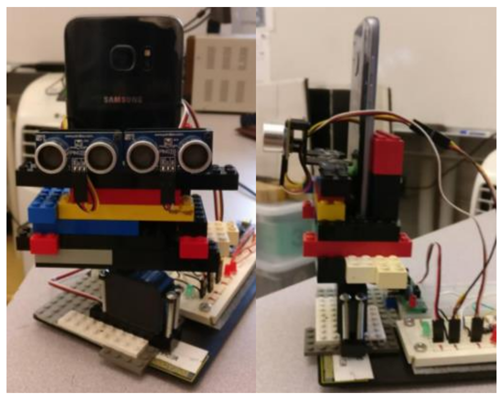

Figure 25: Lego phone mount to allow for video recording in the direction that the sensors are looking

Two test demonstrations were done in testing to show the tracking systems capabilities and limitations. Demonstration #1 had the Lynxbot perform a program routine that would move forward for 2 seconds and backward for 2 seconds along its diagonal path. The Lynxbot starting position will be in the center of the 3m x 3m arena that way the tracking system can see the target most of the time. Demonstration #2 was to have the Lynxbot run a slightly different program routine to move forward for 3 seconds and then move backward for 2 seconds. The purpose of this test was to have the Lynxbot move further out of the sensor's field of vision as it moves along its diagonal. This enabled identification of the angle where the sensor can no longer see the target on the robot.

These two trials were recorded with the phone mounted on the servo and a video was uploaded to *Youtube* to show the two trials. The video can be found at the link below.

https://youtu.be/9RiVoP07ZBw

4.3.1 – Video Test Demonstration #1

In test demonstration #1, the sensors followed the target most of the time, with occasional moments of the sensors missing the target and the robot driving away. Although there are parts in this video where the sensors do lose track of the target, the tracking system was following the robot most of the time which is proof to show that the system is performing as intended. The robot was only moving within approximately 45 degrees of the servo's 180 degrees and was moving back and forth in front straight ahead of the sensor position. The region in which the robot is moving is highlighted in *Figure 26*, this region is the space between the two dashed blue lines.

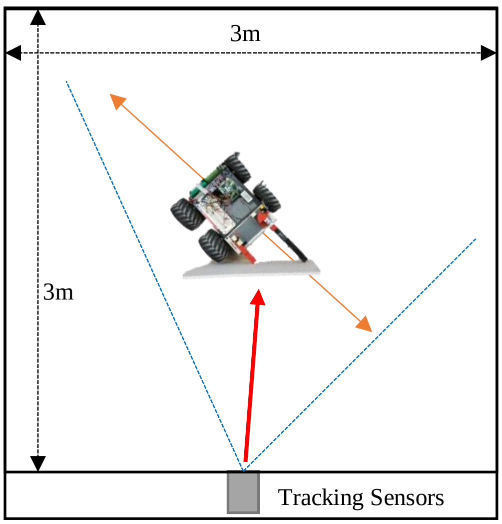

Figure 26: Graphic showing where Lynxbot was moving in demonstration #1

4.3.2 – Video Test Demonstration #2

The second clip in the video is test demonstration #2, which is when the robot is moving further out of the field of vision of the sensor. In this demonstration the target moves far enough to the right of the sensor that the target on the front of the Lynxbot is at such an oblique angle, the tracking system cannot track it. This can be seen multiple times through the video as the Lynxbot will move back into the line of sight of the sensors and then move forward to a point where the sensors lose the target again. Again, this is a similar issue to what was seen in Test #3 as the PING has difficulty identifying oblique targets. The schematic in *Figure 27*, the red arrow shows approximately the point in which the tracking system can no longer receive a signal from the target.

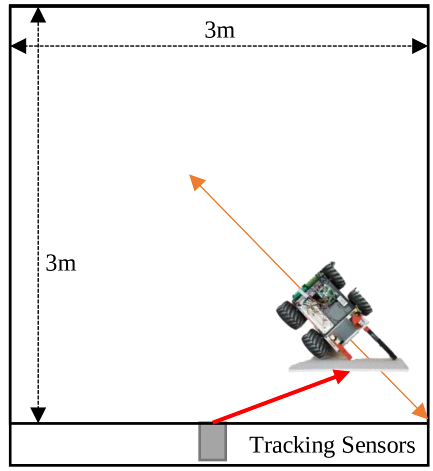

Figure 27: Graphic showing where sensor system will lose the position of the target due to large oblique angle in demonstration #2

4.4 – Tracking System Discussion

Overall the tracking sensor worked as intended but was subject to its functional limitations. In this case, the double PING system was able to follow the moving target within its 3m range for most of the time that the target was moving along its diagonal path. Unfortunately, the sensor no longer was effective to track the target as it was found to be at an angle that was beyond this oblique angle threshold. This problem was faced in Test #3 as well as this tracking application, and it would be expected to happen in a live scenario. It is very unlikely that the sensor would be directly underneath the falling done. Meaning that this tracking system would almost always be faced with an oblique surface when tracking the range of a falling drone. As seen in Test #3, the PING was unable to identify oblique targets when it is turned more than 30 degrees from its vertical position, which could be a crutch to this tracking system. Otherwise, the sensor system was able to track a moving target that is approximately 0.4m wide within a 3m.

Although the PING sensor was chosen to be the ideal sensor of the three tested for this proof of concept, there is a limitation for all ultrasonic sensors should this proof of concept be scaled to larger distances. Since this concept is only testing to track objects within a small range (less than 5m), it is not an issue that an ultrasound sensor's signal response time can change based on target distance because the change in measurement times are very small ($t < 19ms$). But using the known linear relationship between measurement time and target distance for the PING and URM37, the measurement delay could be quite large if the target is very far away. For example, if a target is 100m away, the signal delay time would be approximately 600ms. Despite this delay is less than a second, should a drone with a parachute be falling at a rate of 1m/s, the drone could have moved 0.6m in this time. This displacement over the delay time is large enough that it could be very difficult or impossible to detect the drone again. It should be mentioned that this theoretical displacement of 0.6m is larger than the 0.5m field of vision of the PING. The solution to this timing issue would be using a laser or light-based (IR) sensor like the Sharp or a LIDAR unit. Since the signal is traveling at the speed of light, the signal response will be essentially instantaneous before signal processing time. Perhaps an IR sensor that uses a geometry relationship like the Sharp should not be used, due to the inaccuracies that were found throughout this research. A Lidar or Radar sensor where the time of flight is measured by a light signal would most likely provide a more accurate and fast signal response. This Lidar technology is essentially a combination of the Sharp and PING technology by using light as the signal and time of flight as the measurement of range.

5.0 Conclusions and Recommendations

The tests performed on all three sensors were intended to distinguish characteristics of the sensors to indicate which would be most applicable for a scenario when tracking a falling object at a range of up to 5m. Despite the PING have a smaller detection range compared to the Sharp and URM37, its linear distance response, fast signal response and consistent object detection make it an ideal low-cost sensor for a smaller scale proof of concept of this projectile tracking application. Unfortunately, due to the PING's reduced detection range of 3m, it does not prove the hypothesis that low-cost long-range sensors could be used to track targets of 0.4m within a 5m range. However, this research does provide support that this hypothesis could be true with the use of longer-range sensors similar to the PING.

To improve this tracking system in the future, changes should be made to both hardware and software in the system. With respect to hardware, a faster and stronger servo could be used to improve the speed of the tracking. Another hardware solution could be using different sensors using different range detection methods and extended range. Using longer range ultrasound sensors or even small LIDAR units that are decreasing in price could be worth testing similar to the other sensors to see if they are more suited for this application than the PING. Even longer-range sensors could be used to track objects at further distances than 5m moving at faster speeds. Some software upgrades could involve using programming logic to store information about previous sensor readings. This previously stored information could be analyzed continuously to better understand data trends (peaks or drops in sensor signal) to better track a moving target.

As costs of long-range sensors are decreasing now that the technology is becoming more accessible, the scale of this proof of concept could eventually grow to a useable distance for drones of all sizes and performance. This would be another example of technology that started in the space industry and has been adapted to a commercial and recreational scale. It is simply a matter of time.

6.0 Acknowledgements

I would like to thank my supervisor Dr. Brian Surgenor for overseeing my work throughout this project. Despite my semester of research being rather short, my introduction to research was a positive and valuable experience. Thank you for challenging my ideas and thought processes, as well as giving me the opportunity to learn from my mistakes. I learned that quite often things will go wrong in research and tests will need to be modified, redone or eliminated. I appreciate and value your guidance provided to improve my MECH 461 experience and my newly developed research skills.

7.0 References

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