An Innovative Method for Obtaining High Detection Rates of Sharks on Ocean Beaches

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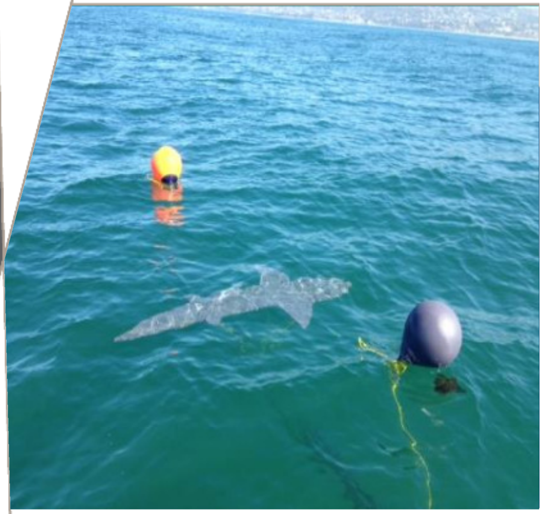

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Shark Alert Pty Ltd

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Executive Summary

Aerial surveillance is used by some authorities to provide early warning of the presence of sharks to bathers and surfers, through communication with surf lifesaving clubs and, in Western Australia(WA), through the 'SharkSmart' program. Aerial patrols receive considerable public support as a perceived form of protection against shark attack and are perceived to be a cost-effective means of protecting large expanses of beaches. Ideally, aerial surveys should detect a large proportion of sharks present in the area overflown but scientific trials that have investigated detectability indicate that detection rates can be alarmingly low, particularly if sharks are not close to the surface, are directly beneath the aircraft (where they cannot be seen by an observer) or if they are further than 200 m from the flight path.

Shark Alert Pty Ltd. (Shark Alert), a WA company, has requested that Cardno NSW/ACT Limited, in collaboration with Advanced Coherent Systems (ACS), investigate and trial a new photographic technology for detecting underwater objects,adapted to enable the detection of potentially dangerous sharks. As part of the investigations, ACS undertook a trial of the Shark Alert system in coastal waters of San Diego in March 2016, accompanied by Cardno staff. The aim of the trial was to test the system using a shark analogue (i.e. a model shark approximately 2.4 m long, with shape and coloration mimicking a real shark). The analogue was towed behind a moving boat and the depth below the water surface of the analogue was systematically adjusted to determine the effectiveness of the system to detect a shark that may be swimming several metres below the surface.The Secchi depth (a measure of the turbidity/clarity of the water estimated by lowering an opaque (Secchi) disc into the water until it ceases to be visible from the surface)during the trialwas approximately 4.27 m. The trial used a helicopter.

The shark analogue was able to be detected 100% of the time when it was placed 4.57 mbelow the surface (the maximum depth tested in the trial). This was much deeper than had been achieved in another study using human observers with a similar sized sharkanalogue. Given the benthic habit of many sharks, it is important that aerial surveys are able to detect sharks swimming several metres below the surface, rather on or just under the surface. The Shark Alert system provides the means for achieving this and is likely to be able to detect sharks swimming at even deeper depths than 4.57 m in New South Wales (NSW)and WA in average conditions.

The range (i.e. perpendicular distance from the aircraft flight path) that sharks can be detected is complicated if detectability drops off with distance. In the current trial, detection rates were very good with distance from the aircraft, with 88% detectability achieved as far as 350 m from the flight path (the limit of the test). This distance is much further than had been achieved previously using human observers. In that study, detection rates diminished with distance, with observers in fixed-wing aircraft seeing only 14% and 9% of analogues at distance of 200-300 m and >300 m, respectively. Further, in that study, detection rates for analogues >300 m from helicopters were less than for observers in fixed-wing aircraft.

Sun glint is the main factor with potential to reduce detectability in the Shark Alert system and it can also cause false positives. The system accounts for glints by selecting an optimal flight path for the conditions, taking multiple looks (images) of the ocean to account for glints and by pointing the camera away from the sun as far as practically as possible during flight. The system can also operate remotely, without manning and can transmit the data to a centralised server.

Given the test results, and its operating process, the Shark Alert system would have considerable advantagesover current observer-based, aerial survey programs, including:

(1) much higher detection rates for sharks that are present;

(2) detection of sharks swimmingat much deeper depths;

(3) automatic, real-time detection of sharks;

(4) amenability to remote operation (e.g. drones); and

(5) ability to store information on specific flights that can be reanalysed and used to improve the method.

The problem of low detectability using human observers is overcome with the Shark Alert system, which is based on:

- multispectral imaging that is far more sensitive than the human eye to contrast between the silhouette of a shark and the background environment;
- image processing software that can search large areas of the ocean simultaneously and process images within seconds;
- a turret fixed beneath the aircraft that can scan a large swath width under the aircraft and that can be tilted away from the sun to reduce glint; and
- shark recognition software that can be 'tuned' to particular shapes and sizesof sharks.

Shark Alert is planning to undertake trials in Australia. The system would be used at beaches with a relatively strong chance of having dangerous sharks present. This will involve ACS staff coming to Australia with the equipment, installing it on suitable aircraft and then running the system and refining the methods for Australian coastal conditions. Several potential sites are being considered at beaches in northern NSW and/or southwestern WA. Shark Alert recognises the importance of partnering with Australian authorities to integrate its shark detection system into existing bather protection programs. This reportoutlines a stepwise process that would include a field trial of the base configuration of the Shark Alert Pty Ltd technology on Australian beaches on analogue sharks and where sharks have been sighted,and where the systemwould be likely to be operated were it to become part of a local bather protection program.

The steps that have been proposed focus on collecting the data required for refining the system to local conditions but the trial could easily be expanded/adapted for additional purposes (e.g. testing the system against human observers or testing remote (unmanned) operation of the system.

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1 Introduction

Unprovoked shark bite incidents have the greatest geographic footprint of human-wildlife interactions and represent a complex challenge for managers, scientists, policymakers and conservationists. Globally, the frequency of unprovoked shark bite is increasing (McPhee 2014). The reasons for this increase are complex. While increasing numbers of water users over time contribute to this trend, it does not explain it entirely, with other natural and anthropogenic factors contributing (Amin et al.2012; McPhee 2014). Over the last 30 years unprovoked shark bite has been recorded from 56 countries and territories, with most (84%) having occurred in the United States, South Africa, Australia, Brazil, the Bahamas and Reunion Island (McPhee 2014).

Globally there are a large number of shark species implicated in unprovoked shark bite. However, where a species can bereliably assigned to an incident, white sharks (*Carcharodoncarcharias*), tiger sharks (*Galeocerdocuvier*) and bull sharks (*Carcharhinusleucas*) account for 55.6% of all bites over a thirty year period (McPhee 2014). In Australian waters, tiger, bull and white sharks occur over a broad geographic area. In Western Australia (WA) in 2011/12 and 2016, and on beaches of the New South Wales (NSW) north coast in 2015,most recent unprovoked bites have been attributed to white sharks.

Government responsesto unprovoked shark biteneed to contend with the needs of public safety, and the responsibility to protect native species in their natural environment, particularly threatened species.The white shark is anationally listed threatened species. Government agencies may implement measures that attempt to reduce the risk posed, placate the public, or provide information aimed at identifying the presence of sharks at a beach in real-time and allowing water users to make more informed decisions about utilising a particular area at a particular time. Responses to unprovoked shark bite need to consider how the various water users utilise a beach area. Bathers may be happy to congregate in a relatively small area on a beach very close to shore (e.g. between the flags), whereas surfers often seek out less crowded areas where good surfing waves can be found and their activities place them in deeper water for longer periods of time.

No single mitigation measure is 100% effective in all circumstances, and it is unrealistic to think that this will ever be the case. Governments generally understand this, and as such, prefer a multipronged approach to the mitigation challenge. The NSW and WA Governments, for example, provide a suite of bather protection measures. Some of the key mitigation measures used in the two jurisdictions include:

- A shark meshing program along 51 NSW beaches between Wollongong and Stockton and baited drum lines at 8 popular WA beaches. These response methods aim to capture and kill large sharks occurring adjacent to selectedbeaches and, in NSW in particular, meshing is a long standing approach aimed at reducing the probability of an unprovoked shark bite. These traditional intervention measures have become highly controversial (Meeuwig and Ferreira 2014; Gibbs and Warren 2015). This is in part due to a realisation of the conservation status of some shark species, the role of sharks in the marine ecosystem as apex predators, and the recognition of the need to reduce the overall anthropogenic mortality on shark species from various sources (Simpfendorfer et al. 2011; O'Connell and deJong 2014; Gibbs and Warren 2015). There is also ongoing concern about the capture of non-dangerous marine species ("bycatch") using these methods, and this bycatch includes species of conservation significance such as cetaceans and marine turtles (e.g. Paterson 1990; Krogh and Reid 1996; Dudley 1997; Gribble et al. 1998; Brazier et al. 2012), despite effort to reduce bycatch through gear modifications and the timing of deployment (e.g. Sumpton et al. 2010);
- Aerial surveillancethat aim to provide early warning of the presence of sharks to bathers, through communication with surf lifesavingclubs and (in WA) through the 'SharkSmart' program (see below);
- The public awareness program 'SharkSmart', designed to inform and educate water sports enthusiasts about ways to reduce the risk of a shark bite incident and, in WA, to provide users with a real time shark activity map showing the latest sightings and detections of tagged sharks. This mapping tool helps beach goers make informed decisions about their water use. Shark tagging itself

also aims to provide long term information on the movement of tagged sharks, which in the long term may provide predictive information on the likelihood of spatial and temporal overlap between sharks and water users;

- Research to investigate better ways to use aerial surveillance and new technologies for detecting or deterring sharks that could potentially be integrated into bather protection programs; and
- Shark enclosures have also been deployed as a means of keeping bathers and sharks separated.

For the full suite of bathers protection measures in NSW and WAsee the websites below:

http://www.sharksmart.com.au/

http://www.dpi.nsw.gov.au/fisheries/info/sharks/tips-to-reduce-your-risk-of-shark-attack

Shark Alert,a WA company, has requested that Cardno, in cooperation with Advanced Coherent Systems (ACS - based in the USA),investigate and trial a new technology for detecting underwater objects that potentially has advantages over observer-based, aerial survey, shark detection programs, namely:

(1) much higher detection rates;

(2) detection of sharks swimming at much deeper depths;

(3) automatic detection; and

(4) amenability to remote operation (e.g. by the use of drones).

The new technologywas trialled in San Diego in March 2016 over a range of operating parameters (including, but not limited to, depth of targets (sharks), operating height and swath width) to optimise the system for shark detection on ocean beaches and understand its effectiveness.

The aim of this report is to:

- outline and disseminate the findings of the trial;
- compare the system to existing programs for shark detection; and
- makerecommendations as to how best to implement the technology into a system for shark detection over a fixed beach or wide area.

2 Review of Existing Information on Shark Detection

2.1 Aerial Observations

Aerial surveys have been usedto studyvery large (≥10 m) sharks, such as whale sharks (*Rhincodon typus*) and basking sharks (*Cetorhinus maximus*) (Cliff et al. 2007, Rowat et al. 2009). These species frequent the surface for feeding and courtship (Wilson 2004, Motta et al. 2010, Harvey-Clark et al. 1999), allowing individuals, or groups, to be readily detected at those times.The species most responsible for shark bite (white, tiger and bull sharks) however, generally do not form aggregations, and spend much of their time below the surface of the water, often close to the seabed(Holland et al. 1999, Bonfilet al. 2005).They are also much smaller, for example, white sharks in the size range of 2-3 m were responsible for the recent attacks on the NSW north coast.In combination with variable water clarity, wind strength and sea chop, such species are a difficult target for aerial observers to detect and identify and therefore assess the risk to beach users. There is also the issue that aircraft spend a very small amount of time over each beach (about two minutes).

Aerial observationsof the coast using human observers are usedby the WA and NSW governments for bather protection. Current aerial observations in WA and NSWare madefrom small, fixed-wing aircraft or from helicopters,in metropolitan and less populated areas. The programs, surveyswhich cover large expanses of beach, receive considerable public support as a perceived form of protection against shark attack and resulting shark sightings and often receive considerable media attention. Robbins et al. (2014) make the point, however,that although these aerial beach patrols are not formal surveys for quantifying the abundances of sharks; their role as a means for protecting swimmers from attack means they should ideally detect a large proportion of sharks present in the area overflown. In simple terms, the efficacy of an aerial survey method is obviously dependent on the ability to detect the target animal.

The detectability of sharks by human observers using aircraft has been investigated in NSW and WA. Robbins et al. (2014) assessed the depths at which 2.5 mlong shark analogues could bedetected by fixed-wing and helicopter observers and, using this information, investigated the effects of aircraft distance and environmental variability on sighting rates under a mode of operation that was very similar to that used in the shark aerial observation program used in NSW. Even with water clarity (Secchi depth) varying to depths of 6 m(as estimated by lowering an opaque (Secchi) disc into the water until it ceases to be visible from the surface), they found that the shark analogues could be detected only at shallow depths, averaging 2.5 m and 2.7 m below the water surface for observers in fixed-wing and helicopter aircraft, respectively. On flying transects, analogues were seen infrequently, with overall sighting rates of only 12.5% and 17.1% for fixed-wing and helicopter observers, respectively. Although helicopter observers had consistently higher success rates of sighting analogues within 250 m of their flight path, neither aircraft observers sighted more than 9% of analogues deployed over 300 m from their flight paths. Robbins et al. (2014) concluded that aerial observers have limited ability to detect the presence of submerged animals such as sharks, particularly when the sharks are deeper than 2.6 m, or over 300 m distant from the aircraft's flight path, especially during sunny and/or windy days. They also indicated that the low rates of detections found in this study cast serious doubts on the use of the standard method of aerial beach patrols (i.e. using human observers) as an effective early-warning system to prevent shark attacks.

In Western Australia, large-scale trials using volunteer pilots and observers in fixed-wing aircraft were conducted between 2001 and 2005. Sharks accounted for only 3% (62) of sightings, with dolphins and seals accounting for more than 90% of sightings, and on average there were 19 sharks sighted per year (McAuley 2006). Only three large sharks (>2.5 m long) were seen in the five years of the trial (McAuley 2006). Relatively large whaler sharks are common along the WA coast (based on the catches of the commercial gillnet fishery), but those sharks were not seen from the air during the trials, and several large sharks sighted by beachgoers and boaters close to shore were also not seen by the trial flights, further highlighting the limited effectiveness of aerial patrols.

The potential for Unmanned Aerial Systems (UAS, also known as drones) to undertake shark spotting is being investigated by NSW Government but results are not yet publically available. Although these devices have potential to help lifeguards with surveillance at individual beaches, the same problems of detectability would apply as above given the operator would need to interpret video footage..

2.2 Shark Tagging

In a review of emerging technologies for detecting or deterring sharks, Cardno (2015) evaluated shark tagging techniques and programs for their potential as early warning indicators to bathers. The following information is summarised from Cardno's report.

The use of acoustic and satellite tagging for assessing movement patterns and habitat use of a range marine animals (including sharks) is well established. The contemporary approach involves the use of arrays of fixed receivers to detect tagged animals.

Acoustic and satellite tagging of sharks in WA provides an early warning system of when a shark is close to popular beaches. The information collected from tagged sharks is also augmented with sightings by the public that are reported via a dedicated phone number. Information on tagged sharks that are detected by the receivers iscommunicated to the public via Twitter and a dedicated website. Potentially a text message could be sent to lifeguards to alert them to the presence of a shark. Information on the activity of tagged sharks; together with sightings by the public, the capture of a relatively large number of sharks in a short period of time for tagging, or other factors which are known to attract sharks to a specific region (e.g. the presence of a whale carcass) is integrated into shark alerts and warnings. The approach in WA involves deployment of satellite-linked (VR4G) acoustic receivers, and data-recording acoustic receivers (VR2W) on the sea floor. Detections by VR2W receivers are not transmitted via satellite but are stored in the receiver's on-board memory. NSW has recently begun a similar tagging program on the north coast but has yet to integrate the tagging results into an early warning program.

The ability of acoustic and satellite tagging to identify the presence of dangerous shark species at beaches where acoustic receivers are in place is a function of the number of sharks that have been captured, tagged and released. The more sharks that are utilising the coastal area that have been tagged, the greater the likelihood that a shark occurring at a beach where a receiver is present will be detected. There may also be location-specific factors which influence the spatial range and the performance of the tag and the ability of the receiver to detect it. Mitigating this may require the placement of receivers closer together in the array to ensure a continuous line of detection. Satellite-linked (VR4G) receivers need fresh batteries and a major service of their buoys and moorings. Data-recording (VR2W) receivers need to be recovered annually by divers so that the stored data can be downloaded and receivers serviced.

2.3 Other Methods

Advances in remote detection methods in the marine environment (e.g. sonar technologies and acoustic tagging and tracking) alsohave applicability to detection of sharks, as well as providing a fuller understanding of the potential role of community-based shark monitoring such as the Cape Town Shark Spotters Program (Oelofse and Kamp 2006; Weltz et al. 2013). These are reviewed for their effectiveness in Cardno (2015).

Of the technologies, Cleverbuoy, an *in situ* sonar-based device, is in a very early stage of development.Parsons et al. (2015) specifically assessed the ability of the Tritech Gemini imaging sonar to observe sharks of 1.4 to 2.7 m in length at ranges from 1 to 50 m adjacent to reef environments. They found that within a 5 m range shark shape, length and swimming action were readily discernible; however beyond this range, and unless swimming pattern could be clearly discerned, reliable identification of a shark was problematic. They identified that for a given frequency and noise level, maximum detection and identification ranges are reliant on system source level, beam pattern, bathymetry, object target size and acoustic reflectivity. In terms of the deployment of a vertical array of sonar units to cover an area, Parsons et al. (2015) identified that issues of interference where beams from more than one unit overlap is an important consideration. Overall, they concluded that a vertical array in shallow waters (< 15 m) may not provide suitable benefits at ranges greater than 75 m. Overall, there is a need to further test the utility of sonar arrays in or directly adjacent to the surf environment. Due to air bubbles and suspended sediment along with the mobile nature of the surf zone seabed, the acoustic profile of the surf environment is different from that where Parsons et al. (2015) undertook their trials. In particular, the surf zone is likely to be a more challenging environment in terms of the effective range of a sonar unit, as well as the ability to reliably discern an object such as a shark. While the latter can be potentially mitigated through image recognition software that 'learns' to reliably recognise a detected object as a shark, the former is a product of the inherent nature of the tool itself and the physical environment of the surf zone. As sonar units are relatively expensive, the number of units potentially needed to provide detection at a beach-scale is an important consideration in terms of the cost effectiveness of the technology if applied in practice. If the technology is to be used in practice, there is an urgent need for independent assessment of its effectiveness in the surf zone environment specifically. Drawing on the work of Parsons et al. (2015), the use of sonar as a practical and cost-effective detection method at an appropriate spatial scale at this time appears limited, although technological advancements may improve the likelihood of success.

Smart Drumline is a baited device that sends a message when a shark has been hooked, but it also has some key issues with technology that would need to be overcome with. Dangerous sharks that were hooked by Smart Drumline would either have to be killed or transported to a place away from the capture location. There would be challenges relocating very large captured sharks safely and with perceptions of moving ‘the problem’ elsewhere. It is also worth noting that a previous review for NSW Government identified significant potential for cameras suspended under tethered balloons as a potential detection technique (Bryson and Williams 2015).

3 Using Multispectral Imaging for Shark Detection

3.1 Background

The advantage that an aerial survey approach has for shark detection is that it can cover a large area very quickly, but to date the limited ability of a human observer to reliably detect a shark has substantially compromised the efficacy of the approach. To address this substantial shortcoming, a more effective and reliable method of automatically detecting sharks present is required that utilises new imaging technologies.

Advanced Coherent Systems (ASC)has developed a multispectral camera system that can provide real-time spectral image processing to facilitate the automatic detection of sharks from an airborne platform (the Shark Alert system). The cameras are spectrally filtered to enhance the contrast between the shark and the ocean background and real time image processing is used toautomatically detect sharkseven when there are such things as sun glints, surface clutter, and kelp that often substantially reduce performance of human observers or standard video cameras. The system includes a high performance airborne turret that can point and stabilize the cameras to optimize the data collection and an airborne computer/power supply to conduct the real-time processing and shark detection output to the operator. The turret and computer are shown in **Figure 3-1(a)** and **(b)**, respectively.The system can be easily mounted onto small airplanes, helicopters and unmanned air vehicles. The four smaller apertures in the turret are the spectral cameras used for shark detection, and the larger aperture is for a video camera that provides standard video that can be recorded for contextual purposes or for live viewing by the user.

(a) (b)

Figure 3-1 (a) The fully assembled turret showing the four narrow spectral band cameras used in the Shark Alert system which can be optimized for individual locations and (b) the computer

The Shark Alert system exploits a process that calibrates all images to enable accurate image processing, and then apply spectral, spatial and temporal processing to identify sharks in real time. The general process usedis:

- Collect four spectral images simultaneously;
- Apply flat field corrections to the images to remove lens effects;
- Apply radiometric calibration to each image to get each in quantitative reflectivity units;
- Spatially register all bands into an image cube with four layers;
- Apply spectral and spatial algorithms to automatically detect sharks; and
- Create image verification of detected targets forsensor operator.

Figure 3-2 shows these processing steps where the images are acquired and corrected, then through a series of image processing steps, potential sharks are identified and after a series of filters, the highest scoring sections of the images are highlighted with detection boxes and provided to the operator. In this example two surrogate sharks were deployed and both were detected.

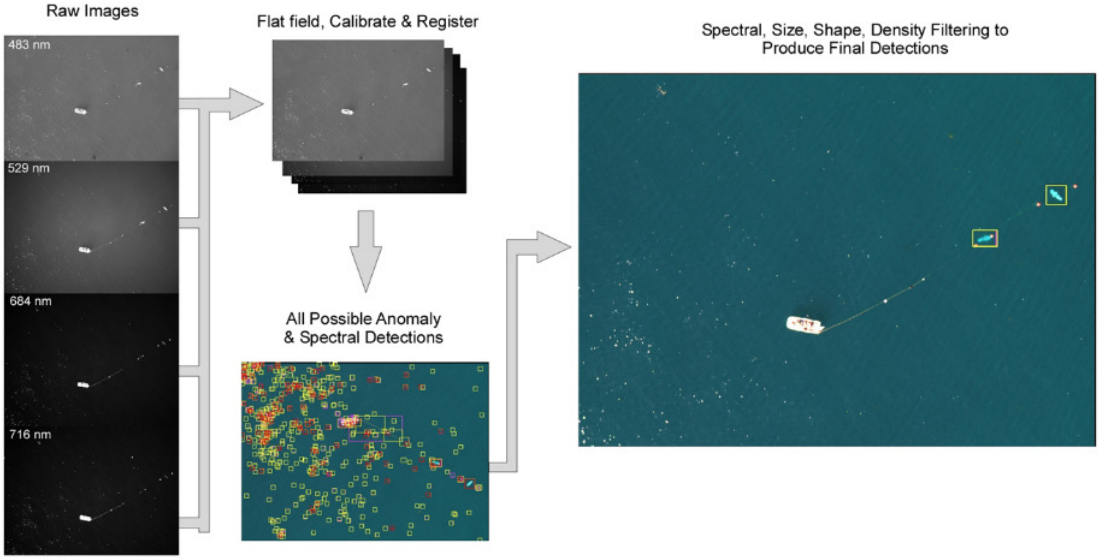


Figure 3-2 Processing path for spectral/spatial real-time target detection. Boxes in right hand panel show shark analogues.

3.2 Field Trial of Detection Methodon Shark Analogue

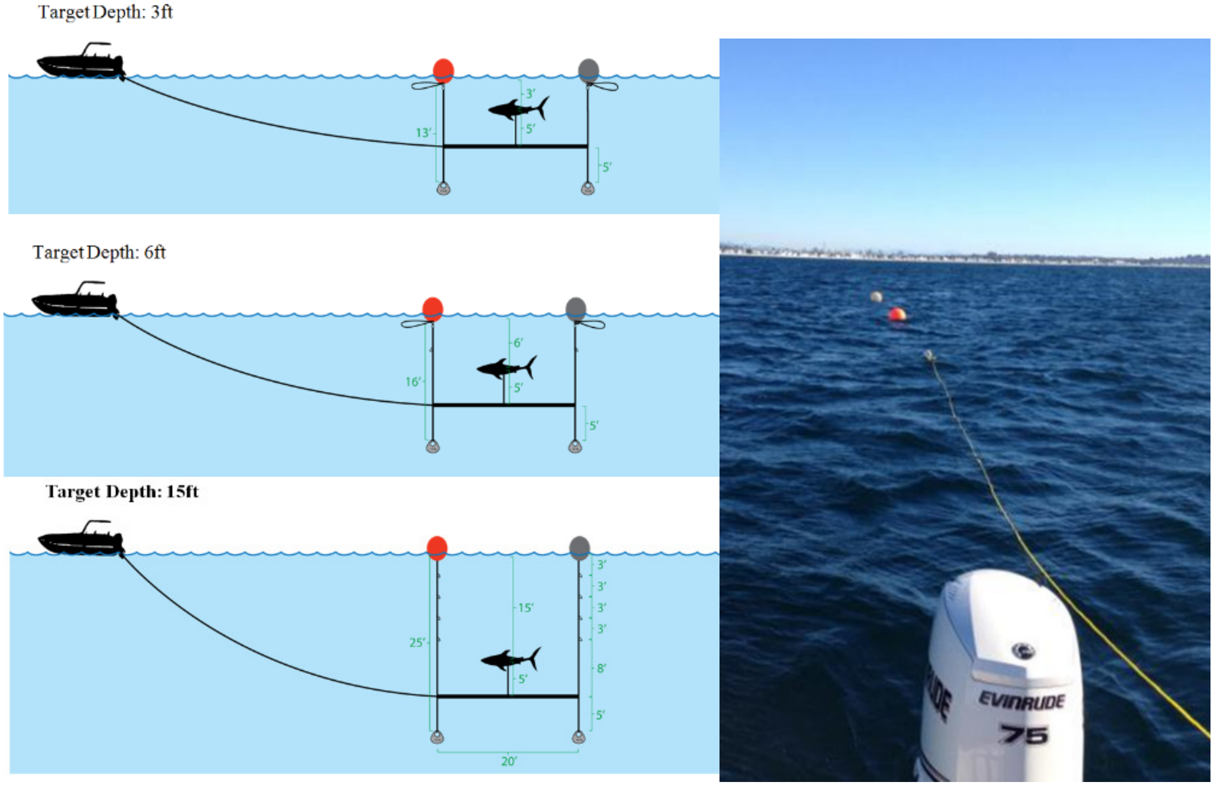
3.2.1 Purpose

The purpose of the field trial was to verify the performance of the automated system for the detection of sharks and to provide real-world data to assist in the development of a dedicated camera system designed specifically to monitor coastlines for the presence of sharks. Initially, the sensor system was designed in a very general way so that it could be applied to a variety of applications. For a very specific uses, like shark detection along coastlines, the system hardware and software can be optimized. For example, flying very high would create images with a wide field of view that could see many hundreds of meters from the shoreline. Fly too high, however, and the image resolution decreases and the automatic shark detection algorithms willhave difficulty in reliably identifying sharks. The optimized design has to fall within a range that allows for good image quality along with a wide field of view to detect a large swath into the ocean. A portion of the current test was designed to help answer some of thequestions regarding required resolution, and a second portion of the test was developed to begin to assess the performance of the system as a function of range and shark depths tocompare withknown performance metrics of prior studies based on human visual detection of shark analogues from airborne platforms.

3.2.2 Trial Set-up

Test Plan Objectives:The first objective of the trial using the shark analogue was to collect data at a range of altitudes to obtain imagery of the analogue at a variety of pixel resolutions with our cameras. This information would be valuable during camera/lens design and also for determining the most effective altitude to fly the sensor. The second objective was to obtain data of the analogue at various depths and distances from the flight path to assess the limits of performance. All the tests would be useful to assist in the design of a dedicated shark detection system.

Shark Deployment System:For trials of depth of detection beneath the water surface, it is imperative that the shark analogue was placed at a known depth in order to properly evaluate the performance of the detection system. If ananalogue is attached to the ocean floor and floated just under the surface, the ocean swells will place the target at variable unknown depths relative to the sea surface as a function of time and the movement of the swell from crest-to-crest above the analogue. Therefore, ACS developed a deployment method of buoys with adjustable depths for deploying subsurface analogues at known depths relative to the surface. **Figure 3-3** shows the method. The shark analogue was attached to a 6.10 m (20 ft) long, black bar and was always floated above that bar by 1.52 m (5 ft). The ends of the bar were weighted down and attached to buoys at the surface with ropes such that the depth could be adjusted by varying the lengths of these ropes. The weights ensuredthat the analogue and bar were pulled downward to counteract the buoyancy of the analogue and to ensure it extended to the farthest depth allowed by the ropes under the buoys. To place the analogue at a depth of 0.91 m (3ft), for example, 243 m (8 ft) lengths of ropes were used between the buoy and the bar to set the analogue at1.8 m (6ft) depth, the ropeswere extended to 3.35 m (11 ft) and the analogue then dropped to the 1.83 m (6 ft) depth. As the ocean swell moved up/down, the buoys stayed at the surface and locked the shark analogue to a specific depth. For this test, depth was varied from 0.91 – 4.57 m (3 - 15ft).

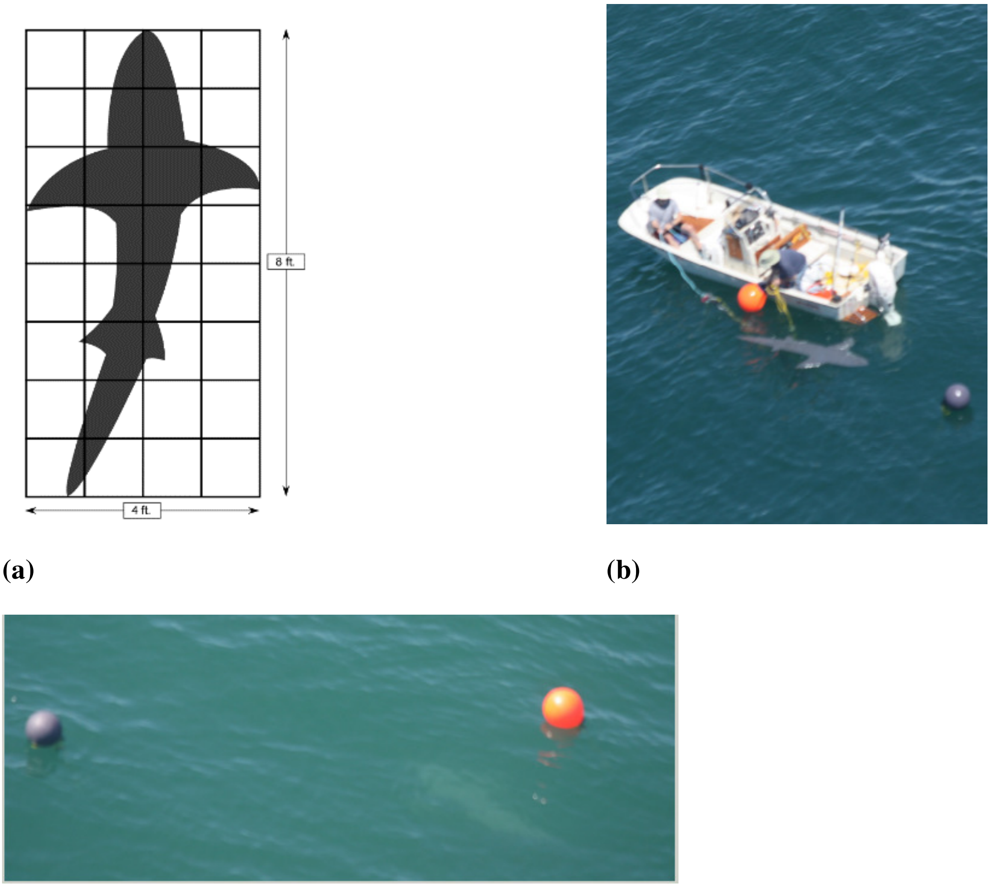


(a) **(b)**

Figure 3-3 (a) The buoy system to deploy shark analogues at variable, but known depths, and (b) view of the deployed buoy system from stern of the boat.

The shark analogue was fabricated from a standard 1.22 x 2.43 m (4ft x 8ft) plywood and painted dark grey. **Figure 3-4(a)** shows the template used to create the shark outline and **Figure 3-4 (b)** is an aerial image of the analogue at the surface as it was being deployed from the boat. **Figure 3-4(c)** shows the deployed analogue1.83 m (6 ft) below the surface (seen closer to the orange buoy).

Sensor Deployment System:The sensor was mounted onto a helicopter as shown in **Figure 3-5**. The helicopter was equipped with a custom turret mount that allowed the sensor to be mounted in a horizontal position so the ocean surface could be scanned directly below the helicopter. This configuration is very advantageous for compensating for pitch and roll of the aircraft while scanning. The turret shown in Figure 1 was used for this test and the computer was placed inside the helicopter with the pilot and sensor operator.



(a) **(b)**

(c)

Figure 3-4 (a) the template used to cut a 1.22 x 2.43 m (4 ft x 8 ft) plywood shark analogue and (b) the analogueduring deployment and (c) the analogue deployed to a depth of 1.8 m (6 ft).

Figure 3-5 Helicopter deployment of the multispectral turret shown in Figure 3-1

Test Locations: Selection of test locations was constrained by local air traffic on the day of the test, requiring testing at midday.On the morning of Thursday, 24 March 24, the target was deployed at the Location #1 shown in **Figure 3-6**, just 2km west of the coast just north of San Diego. At this site, the shark analogue was deployed 0.91 m (3ft)below the surface and the helicopter was flown at a range of altitudes from (500 ft to

2000 ft). For the second portion of the test in the afternoon, the target was deployed at Location #2, approximately 800 m off the coast, west of La Jolla. Here the analogue was deployed at depths below the surface of 1.83 m, 2.74 m, 3.66 m and 4.57 m (6ft, 9ft, 12ft, and 15ft) with the aircraft flown at ~305 m (~1000ft) at a speed of about 55.5 km/hr (30kts). This speed was slower then would normally be used so that to enable collection of ample data for analysis.

Weather/Ocean Conditions: The swell height over the course of the testing was low and varied from 0.8 to 1.1 m, with a period of 12-15sec. This was considered to be very calm and excellent conditions. There were little or no clouds and the Secchi depth was 4.27 m (14ft)throughout the test period.

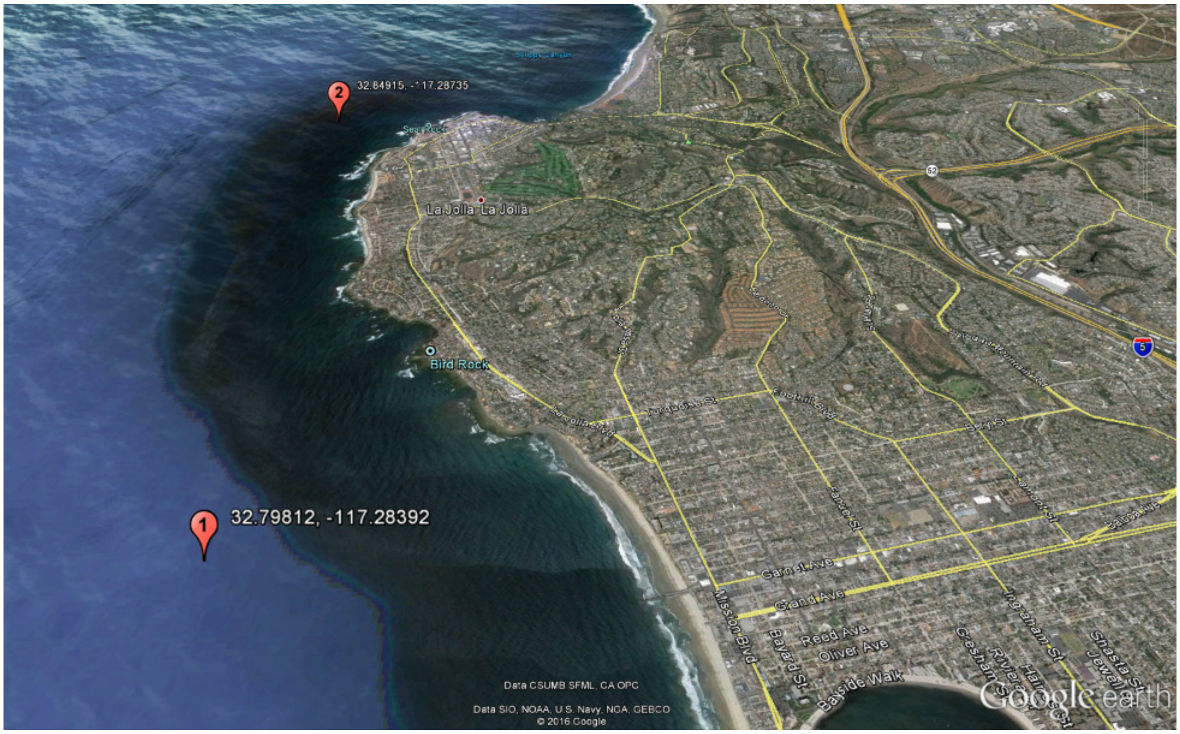


Figure 3-6 Locations for the two tests on the coast of San Diego

Test Flight Documentation: One of the advantages of using a turret for the data collection is the ability to record all of the GPS locations and pointing angles during the image acquisition. **Figure 3-7** shows the type of data stored during data collection,enabling replaysof the test and evaluation of system performance. This image shows that theaircraft location could be plotted throughout the entire pass (green line) and the specific location when an individual picture is taken (red plane icon). The turret can be pointed in any location so the data shows exactly where the turret is viewing at any time during the data collection and the camera path (yellow line) is known. The camera field of view is also known (green box) and if there is a shark analogue detection in the image, its location can be automatically marked (blue icon).

In the example shown, the shark analogue was detected in the upper left corner of the image, as shown by the picture on the lower right, and then placed correctly on the surface of the ocean.

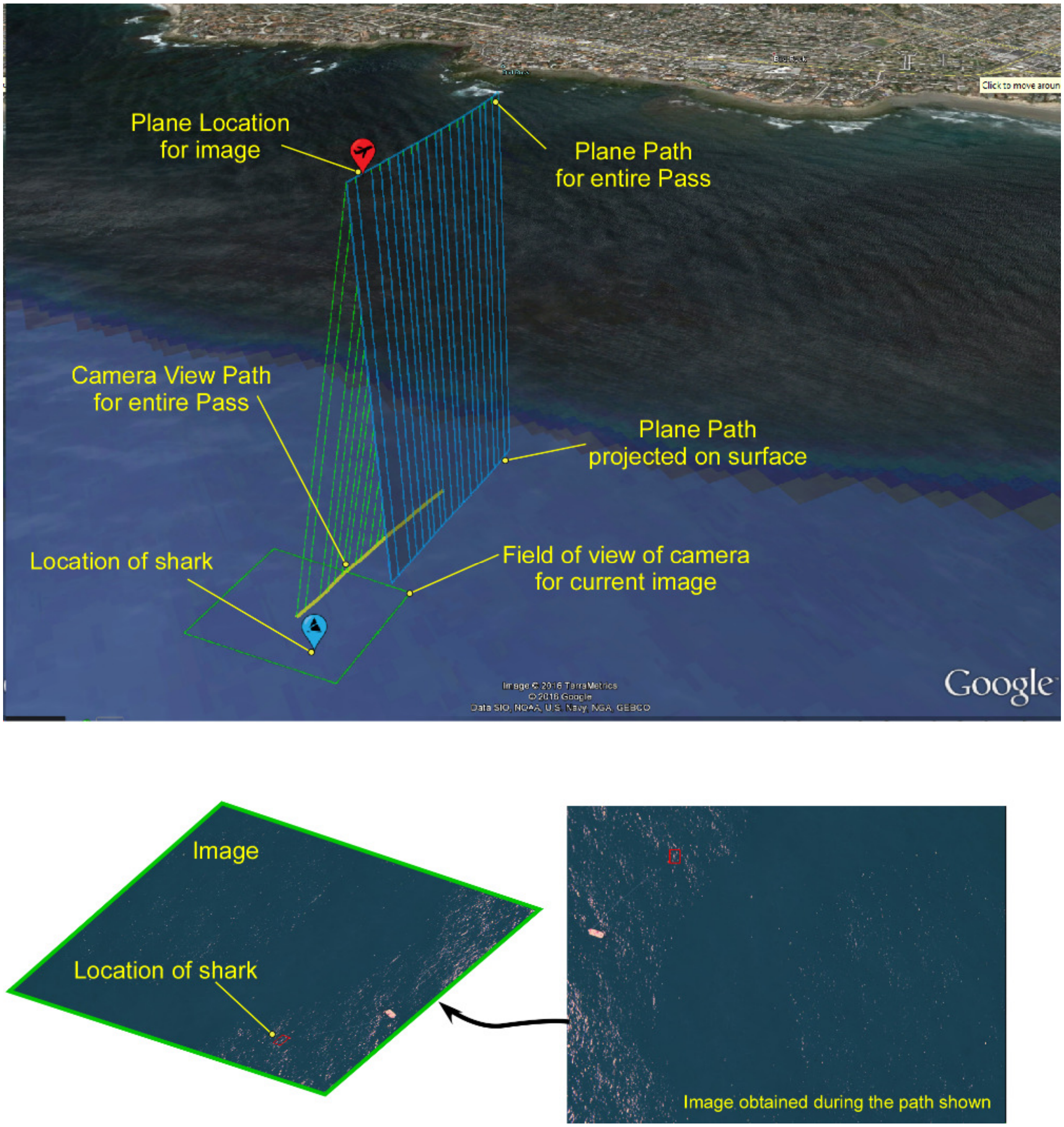


Figure 3-7 The turret GPS readings and point angles can be used to document the test with great detail. The images collected can be placed onto the ocean surface and the locations of detection calculated.

This information is very useful to assess ability to locate the shark analogue as a function of distance from the camera system. For the test at location #2, the aircraft wasintentionally flown over the analogues at a variety of distances to assess performance. **Figure 3-8** shows two different passes over the target. In the first pass shown on the left, the aircraft is flown very close to the shark target and, by knowing the exact location of the aircraft and the analogue,it is easy to calculate the distance from the camera to the shark. The image on the right shows another pass that was conducted farther away from the analogue and the turret was pointed left at a much higher angle. Again, the distance can be readily calculated using the GPS locations of the plane and the target at the moment the image was collected.

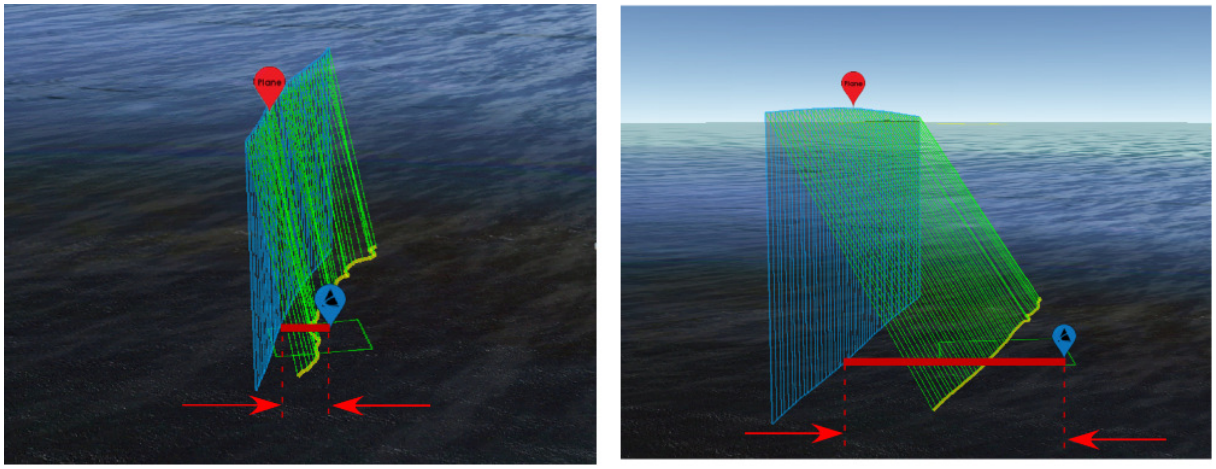


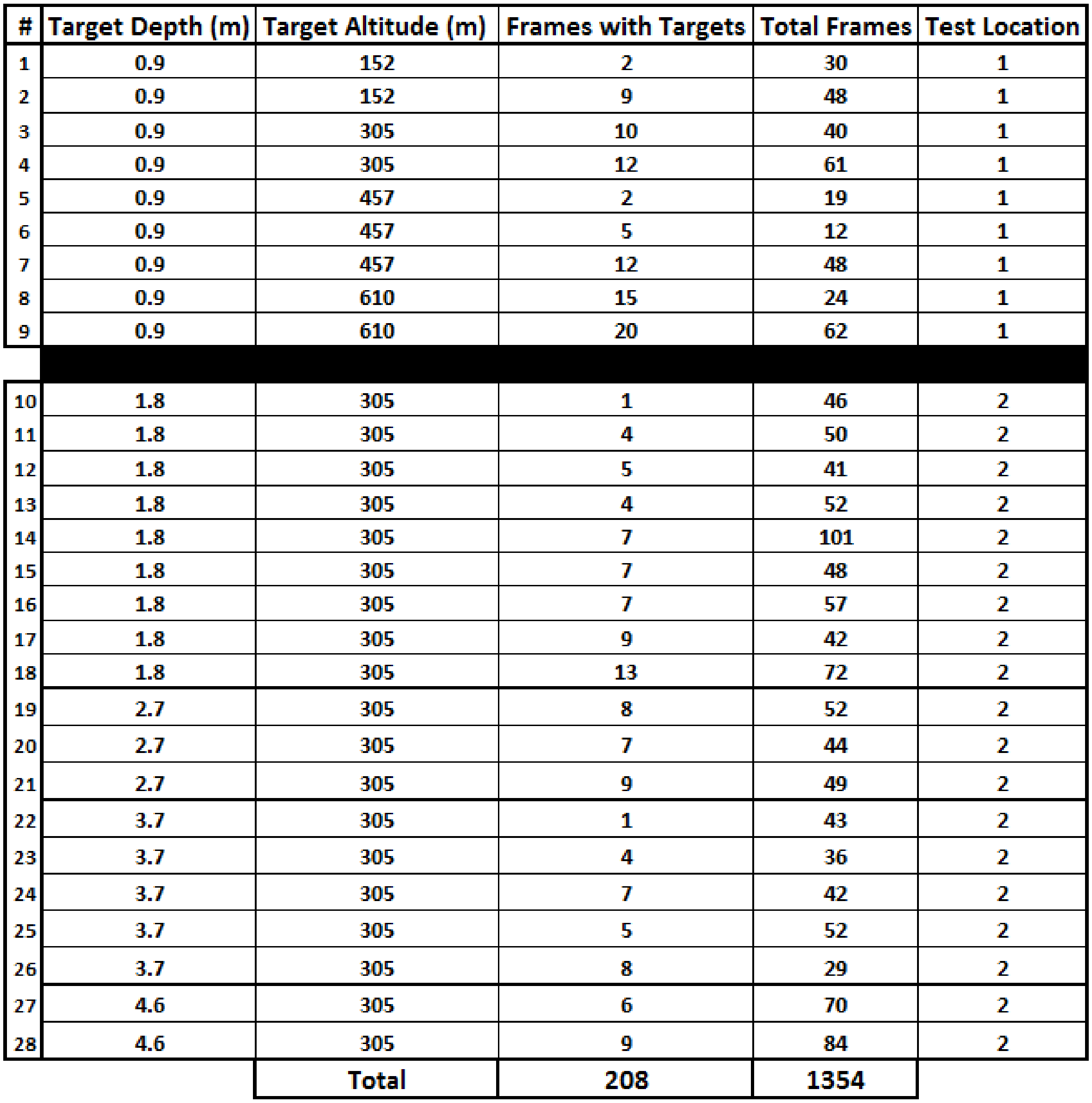
Figure 3-8 The distance between the camera and the target can be calculated from the turret data

It is interesting to note that the distance to the target can change substantially even during a single pass. **Figure 3-9** shows an example pass where the shark analogue is at a very close range for Image #1 early in the pass and the analogue is at one of its longest ranges at plane position #2, under very similar altitudes and plane paths.

Figure 3-9 The distance between the camera and the target can vary considerably even within one pass and within a single image.

Pass Summary: For this one-day test, 39 passeswere completed, with a total of 1807 images acquired. The shark analogue, however, was not always in the field of view of the camera: this occurred in 29 passes for a total of 208 images. **Table 3-1** summarizes the target depths and altitudes for the test, along with the frames with targets we obtained. The speed of the helicopter was about 55 km/hr (30kts) to allow for multiple views of the analogue. The large variation in frames with targets per pass is attributed to whether the shark target passed through the middle of the image or along the edge.

Table 3-1 Summary of Test Passes over the shark target



#	Target Depth (m)	Target Altitude (m)	Frames with Targets	Total Frames	Test Location
1	0.9	152	2	30	1
2	0.9	152	9	48	1
3	0.9	305	10	40	1
4	0.9	305	12	61	1
5	0.9	457	2	19	1
6	0.9	457	5	12	1
7	0.9	457	12	48	1
8	0.9	610	15	24	1
9	0.9	610	20	62	1
10	1.8	305	1	46	2
11	1.8	305	4	50	2
12	1.8	305	5	41	2
13	1.8	305	4	52	2
14	1.8	305	7	101	2
15	1.8	305	7	48	2
16	1.8	305	7	57	2
17	1.8	305	9	42	2
18	1.8	305	13	72	2
19	2.7	305	8	52	2
20	2.7	305	7	44	2
21	2.7	305	9	49	2
22	3.7	305	1	43	2
23	3.7	305	4	36	2
24	3.7	305	7	42	2
25	3.7	305	5	52	2
26	3.7	305	8	29	2
27	4.6	305	6	70	2
28	4.6	305	9	84	2
		Total	**208**	**1354**	

3.3 Test Results

When the sensor system collects imagery, all the raw data can be saved for additional examination after the flight. When the data were run through the system again on the ground, it operated identically to when airborne, providing the ability to monitor the real-time image processing algorithms and alter the input parameters to improve performance. This ability has a distinct advantage over other types of shark detection systems that cannot be quantitatively validated after the fact or have the diagnostic ability to assist in improving performance.

For this test, the entire dataset was run through ACS's standard algorithms, and performance was investigated on every frame collected to identify the causes of any analogue misses or false positive readings (i.e. recording the analogue within a frame when it was not actually present in that frame) and then identify solutions for each one. As shown below, the performance of the system was very good and the reasons for analogue misses were correctable. The next step was to implement the improved settings to enhance the system performance. The intent will be to formalize this process so that the system can be optimized for local conditions (i.e. water conditions, shark types, sizes, beach, ocean floor, etc.). The specific reasons for analogue misses and how they were addressed are as follows:

- **Input size parameters out of range –** the current software has set limitations on the size of the target expected (number of pixels and shape). As altitude changed, or look angle increased, the range varied and the apparent size of the analogue will vary. If it varies too much, the software will not recognize it as a valid analogue.Since the test was flown at a variety of altitudes, the expected size of the target was adjusted accordingly.
- **Shark Analogue Obscured –** the buoys that were used to deploy shark analogues (shown in **Figure 3-4b and c**) may obscure the analogue if the depth and viewing angle is in a certain range. When this occurs, the analogue appears smaller or is completely obscured. If the analogue is completely obscured,thedata would be discarded. In these tests, they were left in and determined ifthe system could pick up a partial analogue (sometimes two detects, one on each side of the buoy). Since thiswas an artefact of the testing arrangement this should not be a longer term concern. For future testing, the deployment hardware has been redesigned to ensure that obscuration does not occur. Of course, in detecting real sharks, there would be no obscuring by the buoys.
- **Sun Glints –** sun glints are an issue that typicallycan be controlled by adjusting the flight path and hence viewing angle tominimize the amount of sun glint seen. Misses due to sun glint are still counted, but are notedto improve flight planning to minimize the occurrence of glints. Glints can obscure the analogue but most often they cause false positive detections.
- **Shark Analogue Depth –** As the depth of the analogue increases, (1) the optical contrastbetween the target and the background ocean decreases and (2) the spectral signature changes since the light is passing through more water. The contrast decrease with depth will depend upon the water clarity and this is addressed by utilizing the most efficient camera system available. Much like the input size parameters, the spectral signature of the target has pre-set limits. Typically several spectral filters wererun simultaneously to represent the signature for both shallow and deeper analogues. Improvements can be made to refine the spectral signatures to accommodate local conditions (water background, analogue colour, etc.) and better characterize the spectral changes with analogue depth. In this test several filters were run and the shallow and deeper analogues were detected.

3.3.1 Analogue Detection

As previously discussed, each pixel in the image was scored with one or more spectral match filters; then a threshold to the image was applied to identify objects that are spectrally close to our target. The resultant image was evaluated for objects that have the size, shape and pixel density that most resemble the analogue of interest, in this case mimicking a 2.43 m-long (8 ft) shark. A typical result is shown in **Figure 3-10**. **Figure 3-10(a)** shows a JPEG of the entire scene with the shark analogue automatically contained in a blue box. Immediately upon acquiring the raw image, all the calibration, radiometric corrections and image processing to detect the analogue occurs before next image is collected, which occurs ~every 0.8 sec with the current data acquisition hardware. When the analogue is detected, the operator automatically receives the detection “chip” that shows just the area around the detection (left) and the detection “score” of the same area (right), as shown in **Figure 3-10(b)**. The pixel brightness indicates how well the pixel scored in the image processing, thus brighter is better. Here the water scores low and the analogue scores high. Also, the buoys in the image score very low and virtually disappear in the score image. The ropes used to secure the analogue score highly, but would not be detected as a shark due to the ropes’ very high aspect ratio. The high contrast score image often provided the best view of the analogue since it suppressed the background. If there were multiple detections in the single image, all of them would show up in the upper full image (a) and each detection would have a chip created, as shown by (b), for analysis by the operator.

As previously stated, the first objective of this test was to collect imagery of the shark analogue at a variety of pixel resolutions with the cameras to understand resolution limitations. The second objective was to assess the limits of performance as a function of target depths and range.

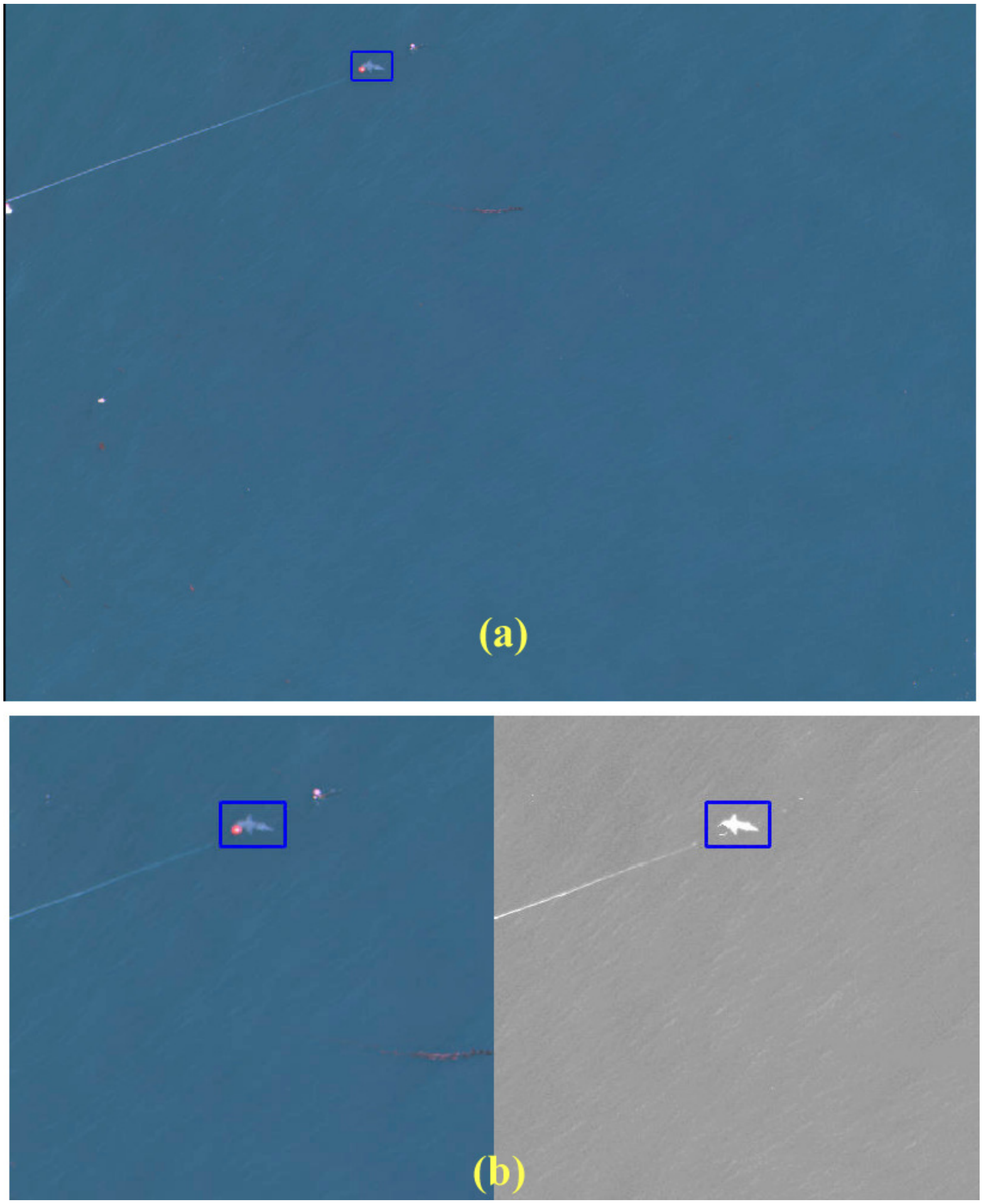


Figure 3-10 Example image processing output for shark detection, (a) colour image of detection showing the entire image, and (b) the detection chip that shows just the detection area and the “score” of the area.

3.3.2 Evaluating System Performance

During system operation, the aircraft would fly along a flight path and image the ocean below. When an image is collected and analysed, the camera is triggered again and the process continues as the plane travels forward. If the frame rate is fast enough, there will be overlap of the images and multiple pictures will have an opportunity to detect the sameshark (in this case, the analogue). **Figure 3-11**presents one collection for this test and it shows the aircraft location and the field of view of the camera for a series of four images. At the altitude, speed and optical configuration used for this test, there were often 4 to 5 chances to detect the analogue. When performanceis evaluated, a key issue is the ability of the system to detect the analogue at least once during a pass and for every frame. The goal is not to have a detection for every frame in which the analogue occurs, but rather to have a detection in at least one frame during the pass– this latter outcome would be considered a success. If the performance by frames is very high, a system can be designed that does not have a lot of overlap. If the performance by frames is low, the system must be designed to operate with many overlapping pictures to insure a detection. This design philosophy is addressed further in **Section 5**.

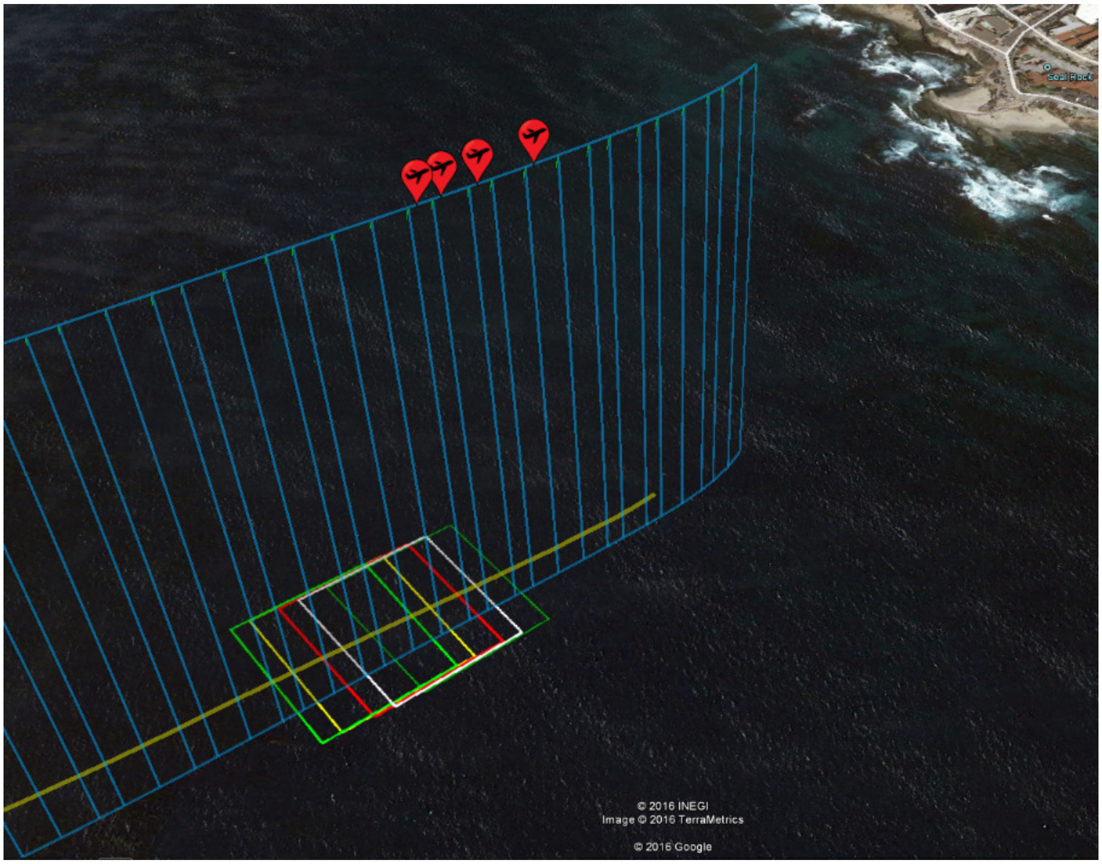


Figure 3-11 Example plane track data that shows the overlap of subsequent images

3.3.3 Pixel Resolution Testing Results

For Passes 1-9 shown in **Table 3-1**, the shark analogue was placed at 0.91 m (3 ft) below the surface and the camera system was flown at increasing altitudes from 152 m (500 ft) to 610 m (2000ft). The ground-sample –distance (GSD), which is a measure of the size of the camera pixel on the shark, grows from4.3cm at an altitude of 152 m (500ft) to 17.1 cm at 915 m (3000 ft). **Figure 3-12** shows how this affects the ability of the method to image the 2.43 m long (8 ft) shark analogue. At the low altitudes there are >500 pixels on the shark and by an altitude of 610 m (2000 ft), there are ~30. The reduced contrast and ability to discern shapes at the higher altitudes will impact the performance of the automatic detection algorithms.The current detection algorithms used fixed levels that will allow a blob of pixels to “pass” the size constraint of the detection process. For this test the size is constrained to 25 pixels to 700 pixels.

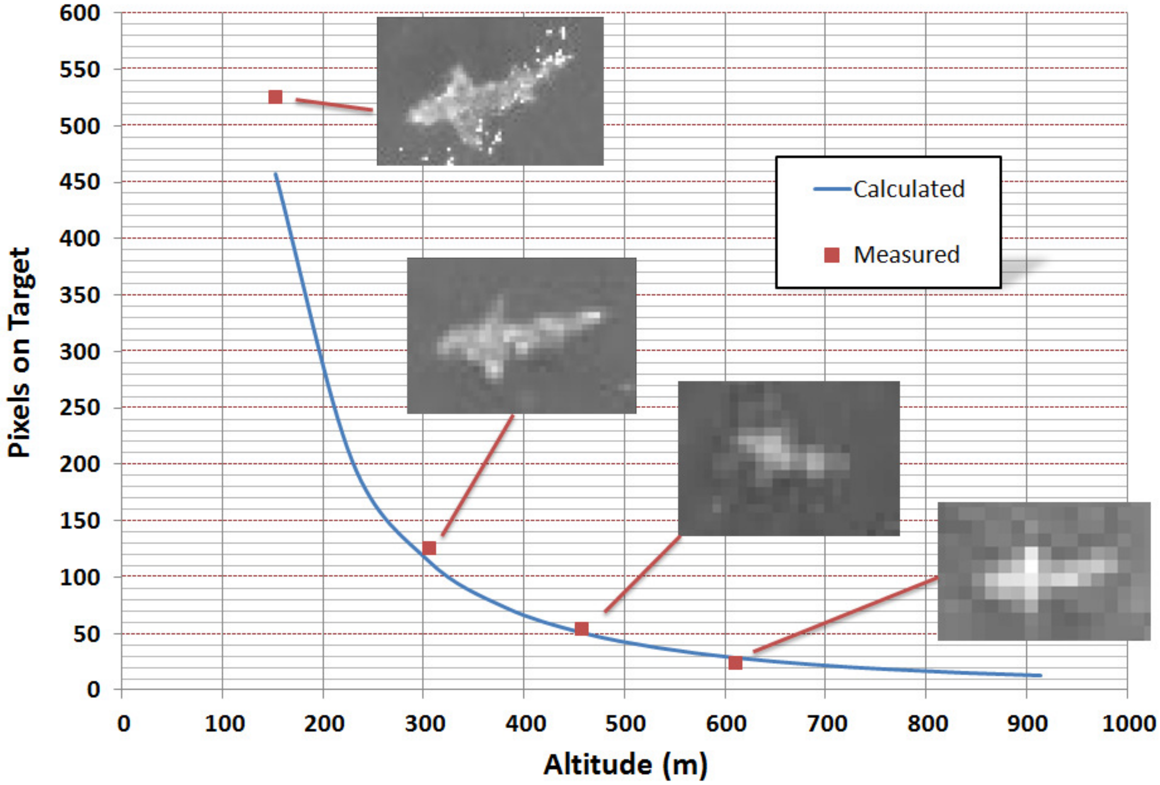


Figure 3-12 The number of pixels on the 2.43 m (8ft) long shark target as a function of aircraft altitude. Actual images from the test are shown to indicate the shark image created at each altitude.

Table 3-2 shows the results of the automatic detection algorithms for this data set and it is seen that the performance decreases at the higher altitudes where the number of pixels on target may start to fall outside the pre-set limits. This fixed range of sizes for the detection algorithm works well when the size of the target and aircraft altitude are fixed, which was what the system was originally designed for. Methods are currently being implemented to allow these limits to change in real-time to reflect altitude changes. In fact, the goal would be to tighten up the limit for a specific application to minimize false alarms. The reduced performance at the 457 m (1500 ft)altitude is primarily due to a single run that had a large glint percentage in the picture. Again, this should be resolved by better flight planning to orient the flight path/camera view to reduce this effect.

Table 3-2 Summary of altitude tests with different size limits for the automatic algorithms

Altitude (m (ft))	Number of analogues	% Automatically Detected (by Pass)	% Automatically Detected (by Frames)
152 (500)	9	100%	91%
305 (1000)	22	100%	100%
457 (1500)	19	100%	68%
609 (2000)	33	100%	89%

Once the system is designed specifically for shark detection, the image quality of the shark will be of utmost importance. Based upon the data collected during this test,the system should be designed such that the pixels on target number a minimum of 75. This will affect the selection of cameras, lenses and flying altitude (discussed in **Section 5**).

The system performance for all of the passes listed in **Table3-1** is provided in **Table 3-3** on both a Pass-basis and a Frame-basis. When using the entire pass, 100% of the analogues were detected; on a frame-by-frame basis, 85% of the analogues were detected. This includes all altitudes and all analogue depths.

Table 3-3 Performance of System for All Depths

	All Data
Shark Detection Rate (PassBasis)	100%
Shark Detection Rate (FrameBasis)	85%
False Positive Rate (FrameBasis)	1.6%

3.3.4 Analogue Depth Testing Results

The performance of the system as a function of depth is shown in **Table 3-4(a)** for cumulative depth performance and **3-4(b)**performance at specific depths, respectively. Recall that Secchi depth was 4.27 m (14 ft) during the test, so data were collected for analogues to approximately oneSecchi depth. As expected, the performance is better at shallower depths.

Table 3-4 Performance of System for (a) Cumulative Depths and (b) Discrete Depths

(a)

	Surface to 0.91 m (3 ft)	Surface to 1.83 m (6ft)	Surface to 2.74 m (9ft)	Surface to 3.66 m (12ft)	Surface to 4.57 m (15 ft)
Shark Detection Rate (Pass Basis)	100%	100%	100%	100%	100%
Shark Detection Rate (Frame Basis)	87%	91%	85%	83%	85%
False Positive Rate (Frame Basis)	0.9%	1.4%	1.2%	1.7%	1.6%

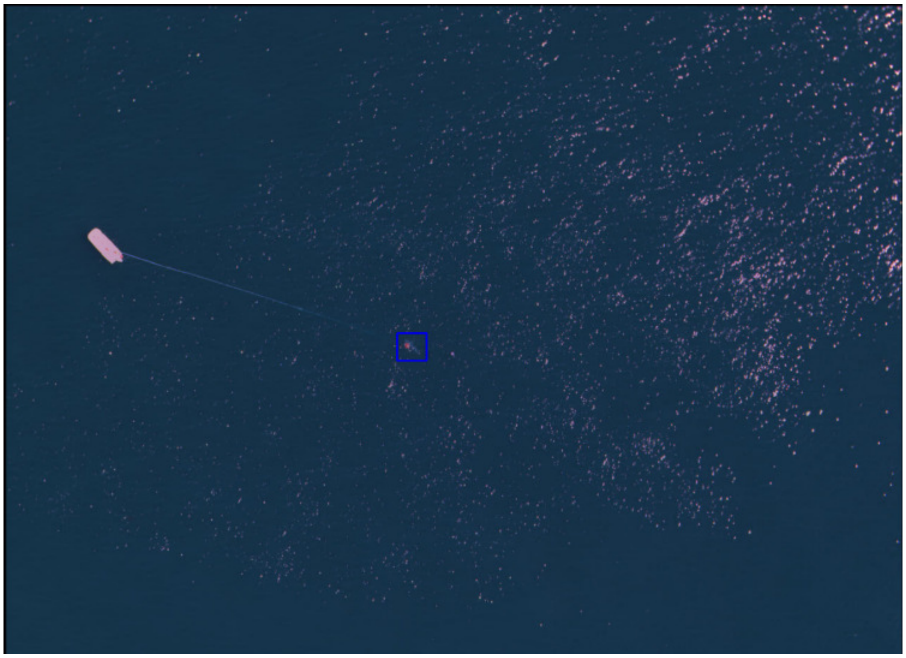
(b)

	0.91 m (3 ft)	1.83 m (6ft)	3.05 m (9ft)	3.66 m (12ft)	4.57 m (15 ft)
Shark Detection Rate (Pass Basis)	100%	100%	100%	100%	100%
Shark Detection Rate (Frame Basis)	87%	96%	46%	76%	100%
False Positive Rate (Frame Basis)	0.9%	1.8%	0.0%	4.0%	1.3%

The data that that the system works very well to the depths tested (i.e. ~ oneSecchi depth). The poor performance at 3.05 m (9 ft), was not due to the depth of the target, but to sun glints. **Figure 3-13(a)** shows an example of an image where glints have obscured the target from the 3.05 m (9ft) depth and

Figure 3-13(b) shows an image of the same target (different run) where the sun glints where properly controlled by angling the camera away from the sun.

(a)



(b)

Figure 3-13 (a) Example of target obscuration by sun glints and *(b) the same target under better flight path/camera angle conditions.*

3.3.5 Analogue Range Testing Results

As shown previously (**Figure 3-9**), the distance from the aircraft to every analogue can be calculated using the GPS locations of each. The distance is not always left/right from the plane, but this data was used to evaluate scan patterns and to determine what swath widths can be achieved. **Figure 3-14** shows the detection rate as a function of range and the system performs very well out to 350 m. Also included is the number of analogues on the graph, since the detection rate is affected more by the smaller sampling at the higher images than the range itself. One image with sun glints, for example, would affect the detection rate more than the distance to the target. Clearly, this performance is very good and encouraging, but more data collection would be required to fully evaluate the performance.

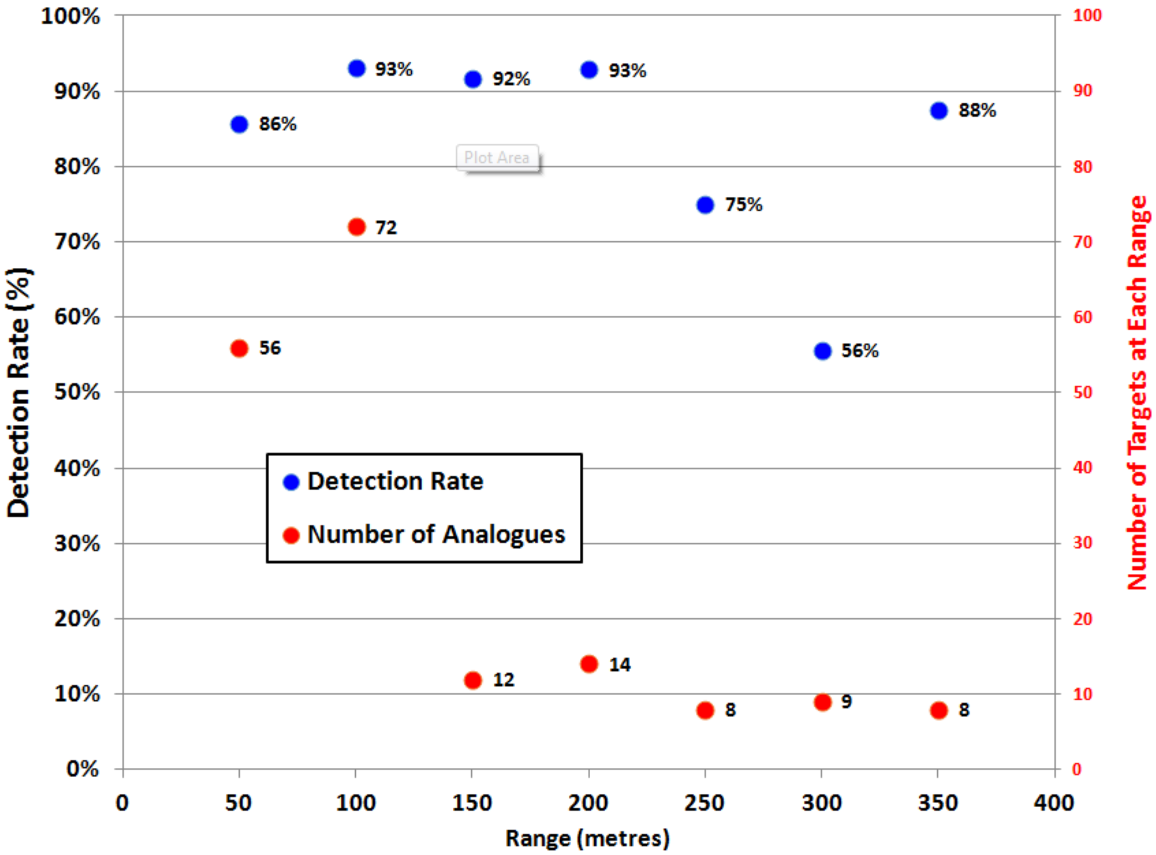


Figure 3-14 The detection rate as a function of range. The figure also shows the number of analogues at that range. (Note: ranges represent 50m increments)

4 Detection Rates of Multispectral Systems vs Observer-based Aerial Surveys

The detectability of sharks by human observers using aircraft is reviewed in **Section 2.1**. In summary, Robbins et al. (2014) concluded that aerial observers have limited ability to detect the presence of submerged animals such as sharks, particularly when the sharks are in water deeper than 2.6 m, or over 300 m distant from the aircraft's flight path, especially during sunny or windy days. Trials of theShark Alert system, however, indicate detectability of sharks can be increased to close to 100% using multispectral imaging rather than with human observers. Thus, it has clear and significant potential to be the centrepiece of real time reporting on the presence of large sharks along coastlines.

4.1 Depth of Detection

During the Shark Alert trial, Secchi depth was 4.27 m (14 ft), which was in the middle of the range of Secchi depth (2.9 – 6.1 m) recorded during the detectability trial done by Robbins et al. (2014). Given Secchi depths in both trials were generally similar, and used a shark analogue of a similar size, some comparisons can be made between the two datasets. In the Robbins et al. (2014) trial, the shark analogue was raised from a depth of around 5-6 m (16.40 – 19.69 ft) until the observer was able to see it. The average depth below sea surface at which the white shark analogue was able to be seen was less than 3 mand there were few sightings of it below 3 m, and none below 4.3 m.

In the Shark Alert trial, the shark analogue could be detected 100% of the time (on a pass basis) when it was placed at depthsas far below sea surface as4.57 m (15 ft) (i.e. the limit of the trial).

Importantly, observers in the Robbins et al. (2014) trial were unable to see the shark analogue to the Secchi depth and concluded that turbidity was not limiting the aircraft observers' sightings of the analogues. In the Shark Alert trial, we were able to detect the analogue with confidence (i.e. 100% of the time) to the Secchi depth,thus the latter system yielded much greater depth penetration than achieved using human observers. Turbidity is considered to be not as limitingusing multispectral imagery because the cameras (and software) are able to discern contrast between the shark and the background environment with much greater sensitivity than the human eye. Theoretically, the Shark Alert system should be able to detect sharks in the field at least to Secchi depth, and potentially beyond it, meaning much greater detectability of sharks in the water column than would be currently occurring using human observers. In the San Diego trial the Secchi depth was not great, but given Secchi depth in coastal waters in NSW and WA would generally be much greater it would be expected that the Shark Alert system could routinely detect sharks swimming in the water column,possibly as deep as 5 - 10 m below the surface, in average conditions. Given where the most dangerous shark species are in the water column, it is important that aerial surveys are able to detect sharks swimming a few metres or more beneath the surface rather than on the surface, or just under it and the Shark Alert system provides the means for doing so.

4.2 Range of Detection

The range (away from the flight path) that sharks can be detected is complicated if detectability drops off with distance.In the Robbins et al. (2014) trial, the observers' most effective sighting range was between 100 and 200 m from the flight path for fixed-wing aircraft and 100 m for helicopters, but even at these optimal distances the detectability was only 33% for fixed-wing aircraft and 50% for helicopters. Importantly, both types of aircraft had reduced detectability when theshark analogues were directly beneath the aircraft. Detection rates dropped off with distance, with observers in fixed-wing aircraft seeing only 14% and 9% of analogues at distance of 200-300 m and >300 m, respectively. Detection rates for analogues >300 m from helicopters were less than for observers in fixed-wing aircraft.

In the trial of the Shark Alert system, detection rates were very good with distance from the aircraft, with 88% detectability achieved as far as 350 m from the flight path (the limit of the test).Unlike observers in aircraft, whose view of the sea surface is obstructed directly beneath the aircraft, the Shark Alert turret, which is attached to the underside of aircraft, is able to make an uninterruptedscan the surface of the ocean across a pre-set swath width.

4.3 Accounting for Sunny or WindyConditions

Robbins et al. (2014) recognised that the position of the sun in relation to the flight path could affect detectability of shark analogues as well as windy conditions. Sun glint is the main factor with potential to reduce detectability in the Shark Alert system and it can also cause false positives. The system accounts for glints by choosingan appropriate flight path, taking multiple looks (images) at the oceanto account for glints and by pointing the camera away from the sun as practically as possible during flight.

5 Optimising the Design of a Multispectral System for Shark Detection

5.1 Minimum Requirements

The Shark Alert system design must balance a number of minimum requirements and perform within several constraints to effectively perform the Shark Alert task. The requirements of the system design are:

- Provide the collection of imagery from an airborne platform such that complete coverage is obtained;
- Collect multispectral imagery to enhance the contrast of the sharks from the ocean background;
- Collect imagery with adequate resolution for the automatic detection of sharks;
- Provide a large field of view (FOV) so that maximal coverage can be acquired for a single pass of the beach;
- Maximize the number of looks (images) at the ocean to improve probability of detection;
- Stay within viewing angles that still permit visibility below the surface;
- Fly at altitudes that are within acceptable local aviation rules;
- Perform un-attended, real-time image processing to identify the presence of sharks; and
- Output a GPS location and imagery of shark detections for review and dissemination.

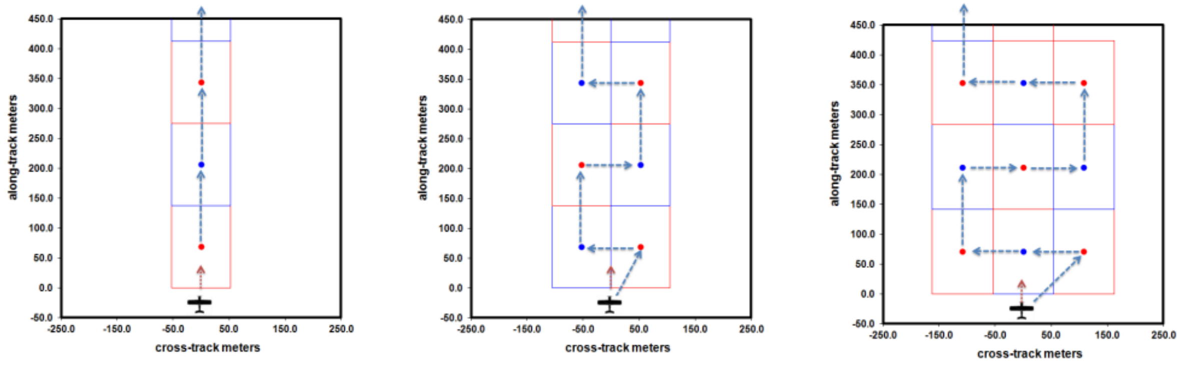
The system would be deployed via an aircraft to maximize the amount of coastline covered. Deploying cameras from an aircraft sounds relatively straightforward with the advent of camera equipped quad-copters, but there are a number of factors that need to be addressed to be successful. In an application such as this, where absolute full coverage of the ocean without gaps is required, proper design of the flight pattern, system optics, electronics and image processing algorithms is imperative. How each of those elements affects the others is not intuitive and ACS has developed a variety of system models to describe how all the components interact to achieve the desired results.

5.2 Image Collection

The basics of how the image collection would be conducted are shown in the following graphs. In the graphs, the aircraft is always flying along the centreline, as shown in **Figure 5-1(a)**. In this figure, the camera collects an image when the aircraft reaches the location of each dot and the image size (field-of-view or FOV of the camera) is indicated by the red and blue rectangles. In this example, the cameras are identical to those flown in the San Diego test and the altitude is 366 m. As the aircraft continues, a second image is taken, and this continues as the aircraft flies forward. In this case the swath width is about 100 mand three images are collected as the aircraft flies over a distance of about 400 m.

The swath width can be increased if the camera can be swept horizontally to acquire multiple pictures as the plane flies forward. This is called a step-stare pattern, since the turret can direct the camera at a given location, stare while the image is collected, then step to the next location where the process continues. In **Figure 5-1(b)** the aircraft is flying along the centre of the graph as before, but it takes two pictures to increase the width of the ocean searched. The swath width is doubled over the single image pattern, but now six pictures are taken in the same 400 m, thus the frame rate of the camera system is doubled over the previous example. **Figure 5-1(c)** continues with this logic for a three step pattern where the swath width is tripled over the original single column of images, but requires nine images to be collected within 400 m.

With the plane flying at 110 km/hr (60kts), the frame rate of the camera system required to collect these images is approximately 0.22 frames/sec (fps) for the single step pattern, and 0.44 fps and 0.67 fps for the two and three step patterns, respectively. The speed for framing is not simply just the snapping of an image, but it includes image acquisition, data transfer to the computer, image calibration and spectral/spatial processing to identify sharks. This will all occur in real-time and shark “hits” will be determined and output to the users prior to the collection of the next image.



(a) Single Step (b) Two Step (c) Three Step

Figure 5-1 The swath width can be increased by using a turret that can step-stare.(a) one step, (b) two step and (c) three step pattern.

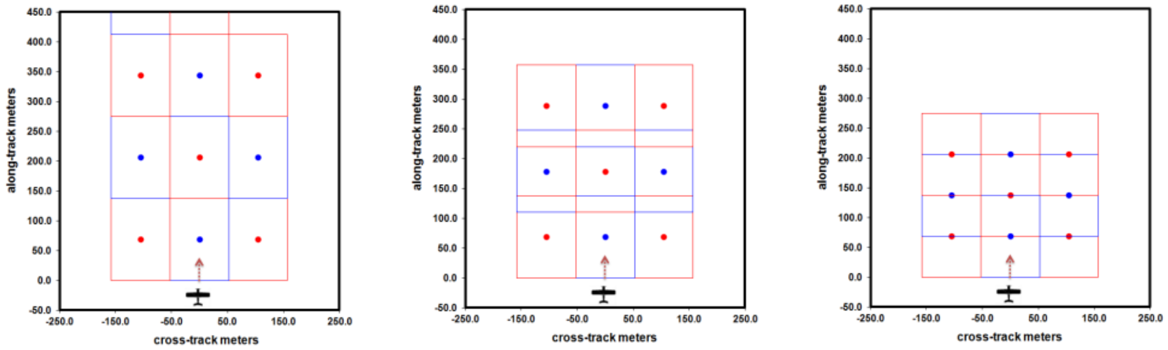
5.3 Overlap for Improved Detection Probability

If there was a shark underneath the aircraft during the above types of patterns, it would be necessary to detect it with a very high certainty because it would be possibleto collect only a single image for any spot over the ocean. The probability of detection can be increased by acquiring multiple images of the same spot over the ocean. For example, assume there is an 80% chance of detecting a shark (i.e. there is a 20% chance of missing a shark). If data can be collected such that imagery is acquired from every spot twice, then the likelihood of missing is reduced from 20% to 4% (e.g. 20% x 20%). A third look drops the probability of missing the shark to <1%. There is an advantage, therefore, to collecting imagery at a faster rate and designing overlap into the collection pattern. **Figure 5-2** shows how the pattern changes by collecting images faster and getting overlap between subsequent rows of images. **Figure 5-2(a)** shows a three-step pattern as before with no overlap;**5-2(b)** shows a 20% overlap in the flight direction; and **5-2(c)** shows a 50% overlap where the next new row starts at the midpoint of the prior row. At this 50% overlap two images are acquired for each spot on the ocean. A 67.7% overlap would provide three chances and a 75% and 80% overlap would provide four and five chances, respectively.

The frame rate will limit how much overlap that can be achieved. With the 50% overlap shown in **Figure 5-2(c)**, the frame rate is doubled to 1.35 fps. As long as the system can keep up with this rate of image collection, these scan patterns improve the search performance of the system. Another benefit of having the data rate to acquire multiple looks is the potential for tracking the shark.

The last element of a scan pattern is to increase the overlap in the horizontal direction. While an aircraft is collecting data, the aircraft will normally exhibit a slight angular roll of several degrees that the turret should compensate for. If there are sudden motions, however, it might not be possible to compensate fast enough; this is accounted for by building in a minor overlap in the horizontal direction to ensure that no portion of the ocean is missed. **Figure 5-3** shows the 50% overlap pattern in the along-track flight direction, with a 20% overlap in the horizontal cross-track lateral scan direction. Having the cross track overlap ensures full coverage, and does not impact the frame rate, but it does reduce the field of view by 20%.

The scan pattern shown in **Figure 5-3** is the basic search pattern used for the Shark Alert system and the goal is to align the aircraft as close as possible to the beach along one of the edges of the pattern and scan out into the ocean as far as possible. In the example shown, the aircraft would cover from the shoreline offshore to 400 m.



(a) No Overlap (b) 20% Overlap (c) 50% Overlap

Figure 5-2 The probability of detection can be increased by using patterns that overlap. (a) no overlap, (b) 20% overlap and (c) 50% overlap two looks

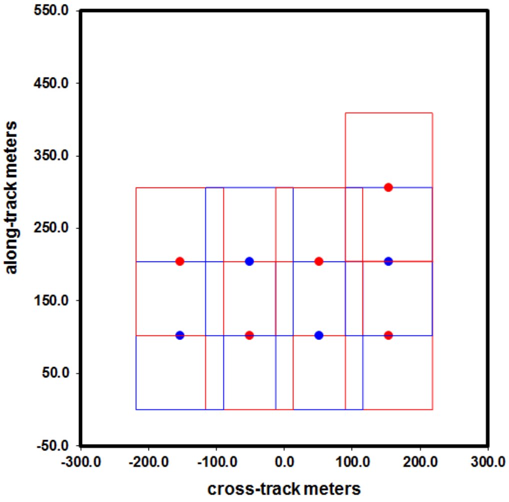
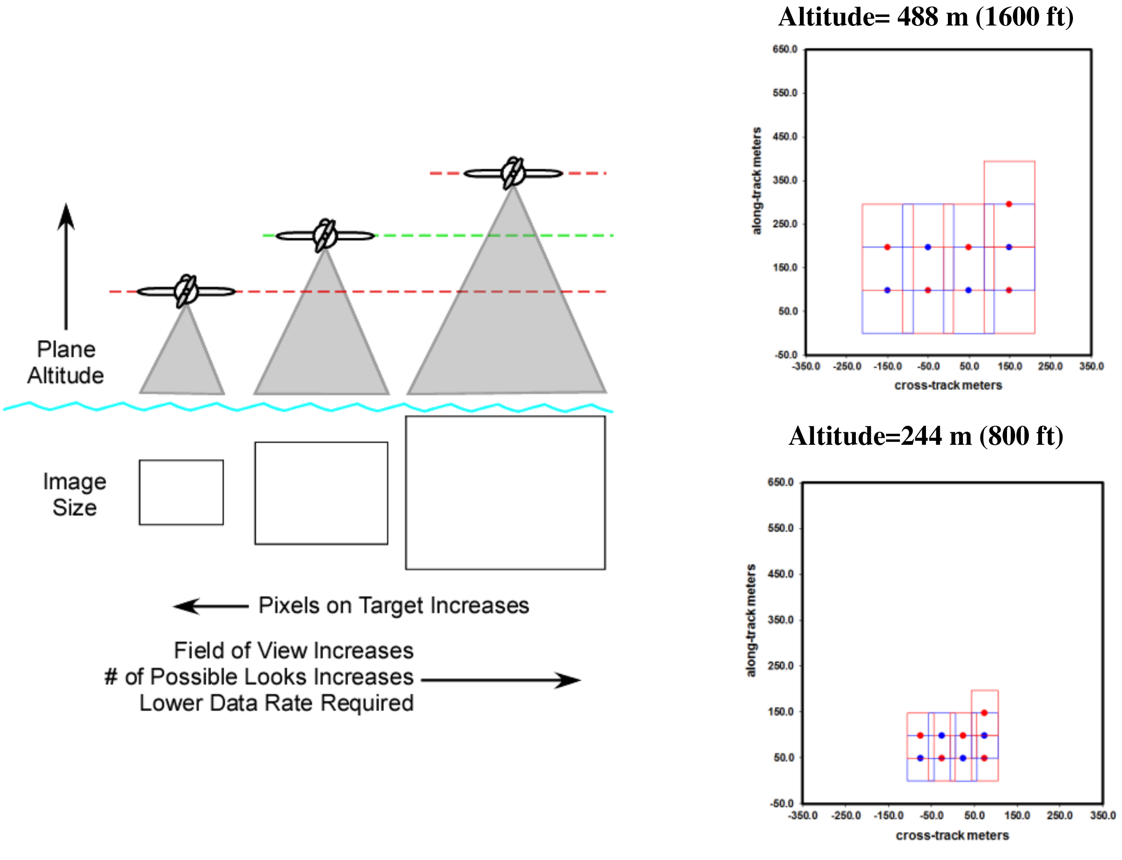


Figure 5-3 Scan pattern with both cross-track and along-track overlap

5.4 Aircraft Altitude

The scan pattern ensures maximal coverage with no missing gaps and provision of multiple looks (i.e. images) to improve the probability of automatic detection. The next variable considered is aircraft altitude. **Figure 5-4(a)** shows that image resolution is increased for any given camera with a fixed focal length as altitude is reduced. High resolution is advantageous for the automatic detection algorithms. This advantage, however, comes at the expense of reduced field of view and reduced amount of time available to collect data. This is because, at low altitude, the aircraft will reach the forward edge of the camera field of view much sooner, requiring images to be acquired quickly. **Figure 5-4 (b)** shows how the scan pattern is affected by altitude. When keeping all conditions constant but changing the altitude from 488 m (1600 ft) to 244 m (800 ft), it becomes apparent that the system must work much faster at the lower altitudes and would cover much less area. The higher altitudes provide more aerial coverage and more time to factor in overlap and multiple images. The upper limit of altitude will be set by the number of pixels needed to detect a shark.



(a) (b)

Figure 5-4 How the altitude affects scan pattern (everything else being constant)

5.5 Camera Focal Length

Figure 5-5 shows the relationship between lens focal length and altitude for the Shark Alert system. In general, the graph defines the specific altitude that should be flown at for any chosen focal length to meet the minimum resolution requirement and maximize the system field of view. In order to achieve a 75 pixels per 2.43 m (8 ft) shark, to the system must be designed to operate at or below the dashed line shown in

Figure 5-5 for the focal length used. For example, if a 25 mm FL lens is selected, the aircraft can fly up to 457 m (1500 ft). Flying at higher altitudeswill fall below the required pixel density on the shark; whilst altitudes below that will have ample resolution but will not optimize the field of view. The dotted line in **Figure 5-5**, therefore, specifies the exact altitude to fly for optimal resolution and field of viewperformance.

The entire range of focal lengths could be utilized and perform similarly because every combination of altitude/focal length creates the same size image on the ocean (**Figure 5-5**). There are, however, several other factors to consider. For example, flying is constrained to altitudes >152 m (500 ft) for safety reasons, so focal lengths less than approximately 10 mm would not be used (**Figure 5-5**). Lower altitudes also create potential issues with the systems' viewing angle to the ocean. The scan patterns shown in the examples above have all assumed that the plane was flying down the centre of the pattern. This is not a requirement and it would be possible to fly such that the camera is looking away from the sun (say, off to one side of the aircraft). This may create dramatic angles if the plane is flying low. For example, if the aircraft is flying at 244 m (800 ft) and looking out 457 m (1500 ft)perpendicular to the aircraft, the farthest portion of the image is at an angle of 62 degrees from nadir (the point on the sea surface directly below the aircraft). If a focal length is chosen to that would be suitable for flying at 457 m (1500 ft), then the same pattern can be conducted with a maximum angle of 45 degrees. Focal lengths of between 20mm – 35mm are considered to be appropriate for this application for a range of altitudes from 366 m – 610 m (1200ft – 2000ft). Flying higher than 610 m would risk not having the pilot perform a visual confirmation, if required, and higher altitudes may also need higher performance turrets.

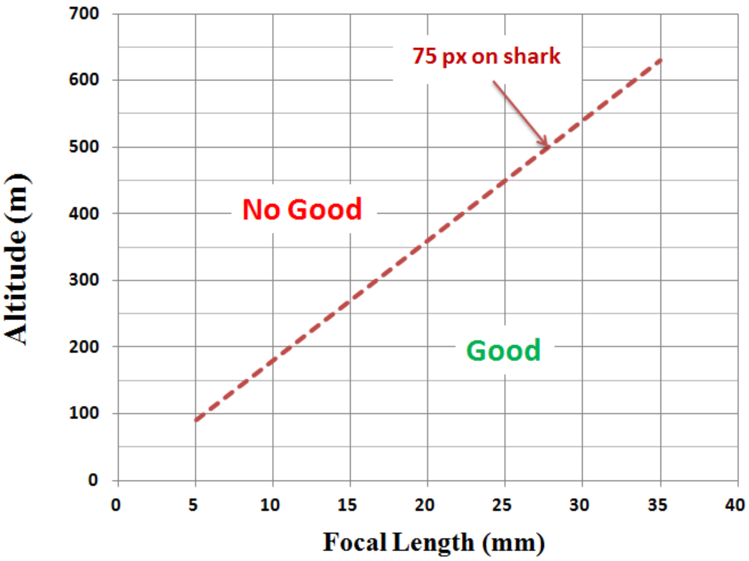


Figure 5-5 The focal length vs altitude relationship for various amounts of pixels in target

5.6 System Design

ACS has developed a number of real-time multispectral system designs prior to the current trials. The San Diego test results provided valuable input to the system design and the intent is to conduct further tests in Australia on both surrogate and real sharks for system validation (see below). Based on ACS' prior experience, system level modelling and the availability of newer components, there are potential modifications that should improve the system availability and performance.

The primary subsystems and the improvement plan for each are:

- **Turret -** the current 17.8 cm (7-inch) turret is military-grade and cannot be exported outside of the USA. ACS plans to design a multispectral payload for a 12.7 cm (5-inch) turret that will be smaller, lighter, and less expensive in the long term which has already been approved for export. This turret will also have the software to perform step-stare patterns, a function that is not supported in the current software but will be implemented for this effort.

- **Cameras** - ACS has identified a newer camera that has superior specifications to those in current use (i.e. improved Signal-to-noise performance, smaller pixels for better resolution, more pixels for wider fields of view, and smaller physical dimensions). These cameras will enable the use of the smaller turret. The software required to integrate these cameras is identical to the current ones, but the sensor format has higher pixel count, so modifications will be made to allow their use.
- **Lenses -**the new cameras that are available have a larger chip size, therefore, the Schneider Optics 23mm FL lenses currently in use will not be adequate. Schneider offers a 28mm lens that works with the new cameras and falls within the acceptable focal length range (**Figure 5-5**).
- **Optical Filters -** ACS has tested a number of combinations of spectral bands and will continue to use the same bands used during the San Diego tests. Additional trials will be usedto evaluate whether different bands are better suited for the optical characteristics of coastal waters in Australia. The design of the system will allow for filter changes and several options will be acquired to test variations after the initial set is evaluated.
- **Computer hardware -** to reduce cost and complexity, ACS plans to design and build a simplified computer system suitable for the manned aircraft used for Shark Alert. The PPM-100 (combination computer/power supply) used in the San Diego test was originally designed for operation on an unmanned air vehicle for military applications. This level of complexity is not required by Shark Alert, enabling asimpler system to be developed.
- **Image processing software -** the current system uses both spectral and spatial algorithms to automatically detect sharks. To date, the coefficients that are used to optimize the algorithms for specific applications were developed for shark analogues in San Diego ocean waters. It is likely that further effort will be required to optimize these coefficients for Australian waters, including the possibility that customization required for various locations.
- **Control Software** - it is not consideredto modify the user interface and/or control software for the proposed initial round of testing in Australia other than the modifications required to interface with a new turret and cameras. The goal is to collect data and verify performance on real sharks. Validating the accuracy and utility of the step-stare profile is another primary goal of this preliminary effort. Once that has been completed and the concept of operations (CONOPS) has been developed, ACS will then focus resources on simplifying the system control s/w and data product output specifically for the Shark Alert system.

5.7 Test System Specifications

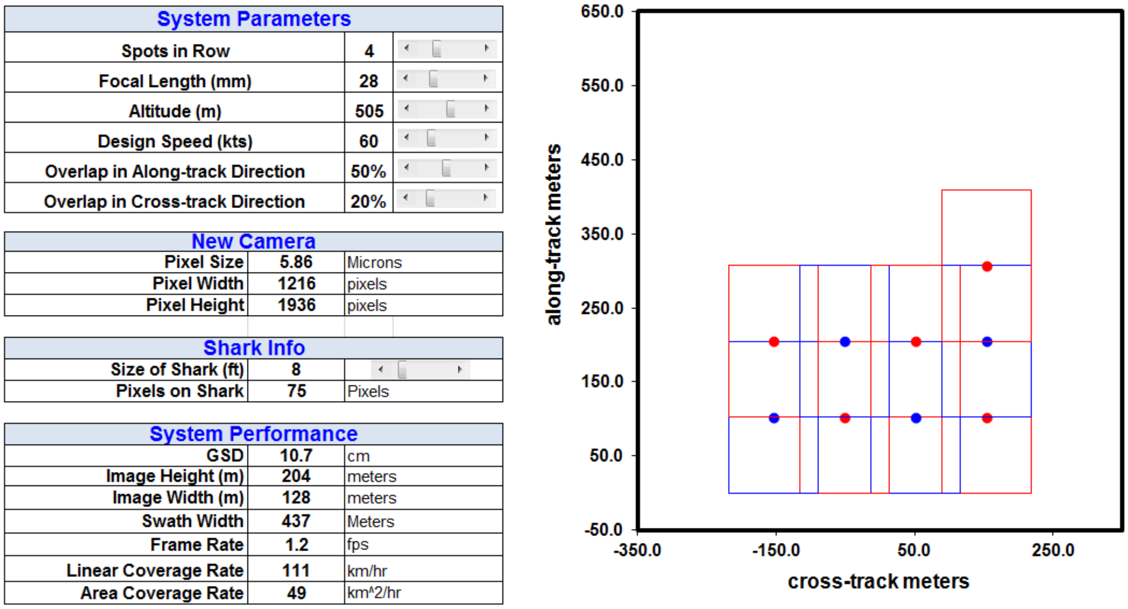
Table 5.1 shows the specifications of a system designed for testing in Australia on real sharks and it provides the currently achievable values with the values sought to be achievedfollowing further development. The 75 pixels on a shark image is considered at this point to be conservative. It is likely that the number of pixels could be reduced below 75, with further algorithm development and field testing. Getting to 50 pixels would allow flying at higher altitudes and would attain wider swaths. Until further testing is conducted to demonstrate that sharks can be detected routinely with 50 pixels on target, the system will be operated to achieve 75 pixels.

The number of looks (images) is set to at least two to increase the likelihood of detection and this is limited by the current frame rate of the computer hardware at 1.25 frames per second (fps). The limitation on frame rate is a function of the turret, computer and image algorithms. The minimum swath width of 400 m provides a good starting point to achieve coverage along most beaches, with a goal of 700 m. Achieving these parameters, will be a primary goal of the Australian tests.

Table 5-1 System Design Parameters

Parameter	Current Achievable Values	Goal Values
Pixels on Target	75	50
Number of Looks	2 (50% overlap)	5 (80% overlap)
Max Frame Rate	1.25 fps	4 fps
Minimum Swath Width	400 m	700 m

Figure 5-6(a) shows a snapshot of the system level model with the currently achievable system parameters for the first 9 images. Some key parameters to note that are calculated from the model are pixels on shark (=75 for this scan pattern), frame rate (=1.2 fps), swath width (=437 meters), two looks (50% along-track overlap) and beach coverage rate (=111 km/hr). **Figure 5-6(b)** shows a snapshot of the system level model with the goal system parameters. The pixels on shark of 50, frame rate (=3.7 fps), swath width (=784 meters), five looks (80% along-track overlap) and beach coverage rate also at 111 km/hr. This extremely wide swath width is primarily achievable by assuming that the 50 pixels per shark is valid. Once the performance characteristics of the systemdetermined, and the optimal CONOPS for Shark Alert is developed, the number of steps in each row, altitude and image overlaps can be adjusted accordingly to optimize Shark Alert performance.



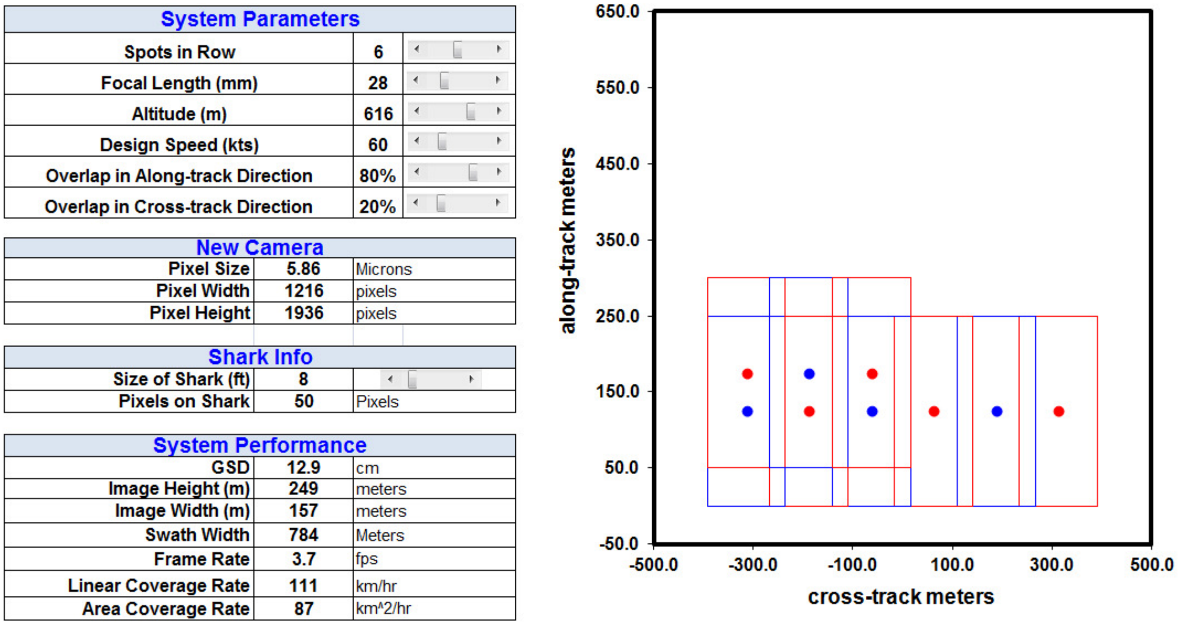
System Parameters		
Spots in Row	4	
Focal Length (mm)	28	
Altitude (m)	505	
Design Speed (kts)	60	
Overlap in Along-track Direction	50%	
Overlap in Cross-track Direction	20%	

New Camera		
Pixel Size	5.86	Microns
Pixel Width	1216	pixels
Pixel Height	1936	pixels

Shark Info		
Size of Shark (ft)	8	
Pixels on Shark	75	Pixels

System Performance		
GSD	10.7	cm
Image Height (m)	204	meters
Image Width (m)	128	meters
Swath Width	437	Meters
Frame Rate	1.2	fps
Linear Coverage Rate	111	km/hr
Area Coverage Rate	49	km^2/hr

(a) Currently Achievable Scan



System Parameters		
Spots in Row	6	
Focal Length (mm)	28	
Altitude (m)	616	
Design Speed (kts)	60	
Overlap in Along-track Direction	80%	
Overlap in Cross-track Direction	20%	

New Camera		
Pixel Size	5.86	Microns
Pixel Width	1216	pixels
Pixel Height	1936	pixels

Shark Info		
Size of Shark (ft)	8	
Pixels on Shark	50	Pixels

System Performance		
GSD	12.9	cm
Image Height (m)	249	meters
Image Width (m)	157	meters
Swath Width	784	Meters
Frame Rate	3.7	fps
Linear Coverage Rate	111	km/hr
Area Coverage Rate	87	km^2/hr

(b) Scan with Goal Parameters

Figure 5-6 (a) System performance for current system parameters and (b) for goal parameters

5.8 Final Turret

Figure 5-7 shows a comparison of the current system that was tested in San Diego and the size of the next generation system for continuation with the Shark Alert testing. The new system will have a ~10cm reduction in overall length and should be at least 50% of the weight. The upgraded cameras shouldenable an increase in the field of view of the system by 55% over the current cameras for the same yield of 75 pixels/shark.

The testing in Australia will focus initially on the performance of the camera system for the automated detection of real sharks in Australian coastal waters and the testing/development of scan patterns that achieve the objectives shown in **Table 5.1**. Once these technical objectives are met, the overall system CONOPScan be developed further, from the deployment of the sensor hardware and data products to data dissemination. . Further adjustments to the turret hardware can be made following this testing, as required, and then the computer hardware and software will be further refined to meet the needs of the Shark Alert system.

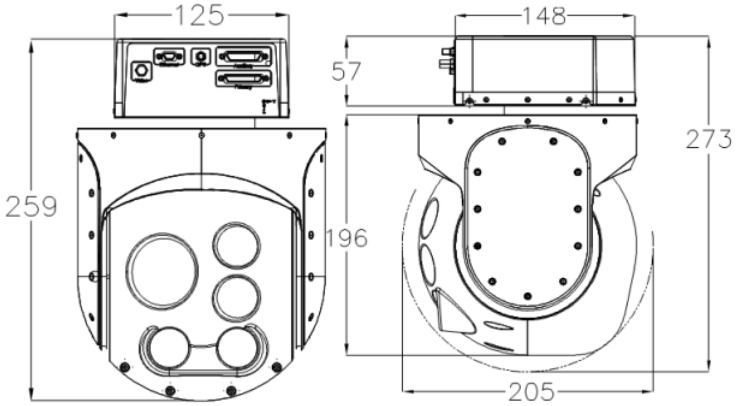
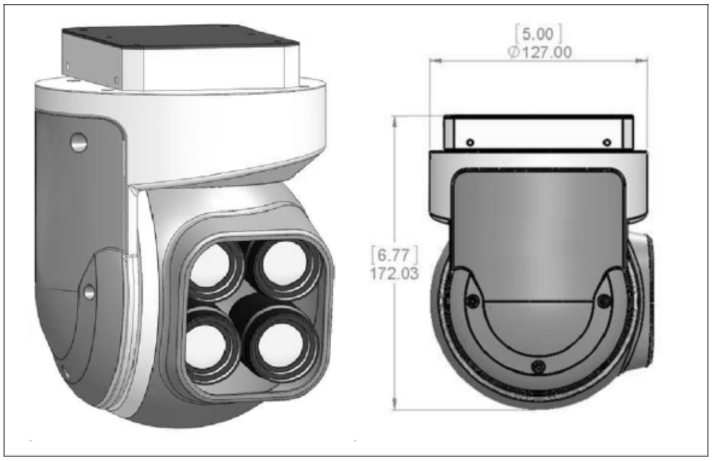
Current system evaluated in this test (units in mm)	
Proposed system for testing in Australia **(units in [inches], mm)**	

Figure 5-7 Comparison of the current and new Shark Alert turrets.

6 Proposed Strategy for Field Tests in Australia

6.1 Aims

Shark Alert is offering to partner with Australian agencies to integrate the shark detection system into existing programs for bather protection. The first task in this process would be to field-trial the system on ocean beaches on shark analogues and where there is a strong chance of sharks being present and where the system would be likely to be operated were it to become part of a local bather protection program.

The primary aim of the trial would be to refine the system for Australian conditions, and particularly the local environment of the trial area. The steps given below are primarily focused on collecting the data required for refining the system, but the trial could readily be expanded or adapted for additional purposes (e.g. testing the system against human observers; testing remote (unmanned operation of the system)).

6.2 Steps in the Field Trial

a. *Choose a base configuration of the system*

A basic configuration would be chosen for trial. The base configuration would consider:

- lens filters;
- the desired search area (width of patrol); and
- how many looks (images)at the ocean were desirable on a pass (as per **Section 5).**

It should be noted that the base configuration would not change significantly during the trial and that data collected would be used to guide the final configuration for routine deployment.

b. *Select the test location*

Ideally, this would include multiple beaches in a region where sharks sightings are frequent and where the Shark Alert Pty Ltd technology is likely to be used aspart of the system for bather protection. At this stage, beaches incentral or northern NSW, or southwest WA would be most appropriate.

c. *Select the aircraft*

The turret needs to be mounted on an aircraft with a suitable power supply and can fly at the required (slow) speed. A Cessna 172 would be appropriate. In the trial, the unit would be manually operated with a payload operator and not remotely controlled.

d. *Data outputs*

When a shark is spotted by the system, the time, a GPS location, with colour and high contrast pictures would be stored along with other measurements (e.g. size of shark). When a shark is spotted the trial could involve the aircraft circling to confirm the shark etc.

e. *Cost the trial*

The cost of a trial would require consideration for the following components:

- Location;
- Aircraft;
- Duration of trial; and
- No. of trial days.

f. *Refine theconfiguration of the system*

The trial would provide data that would allow selection of optimal hardware and software settings for the local environment and patrol needs.

g. *Lessons-learned report*

A lessons-learned report would be provided to the client justifying the choice of the final configuration of the Shark Alert Pty Ltd technology as well as the cost of using the system in the local bather protection program.

6.3 Next Steps

The system is designed to operate remotely and beam the data to a centralised server. In the event that the system were to be integrated into a local bather protection program, Shark Alert would run the system remotely with only minor maintenance of the equipment.Shark Alert could make available more than one set of equipment if more than one region were to be surveyed.

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