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JRC - Alenia Aeronautica Coupled UAS and Spaceborne SAR Campaign in Italy

Results of the coupled UAS & Spaceborne SAR Small Boat Detection campaign carried out by the EC-JRC and Alenia Aeronautica in Sardinia-Italy in October 2010

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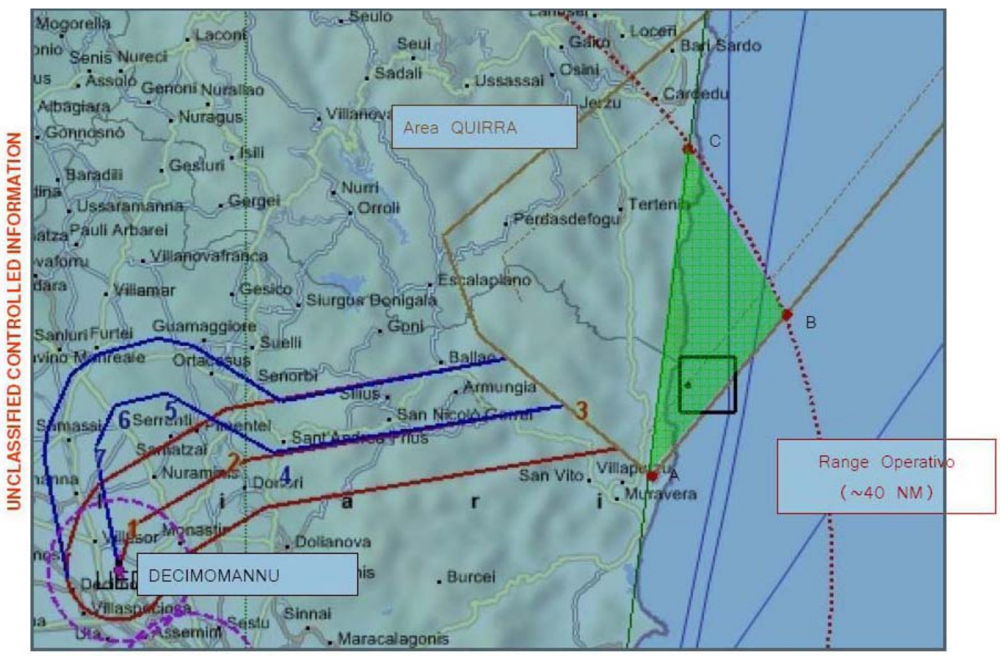

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EXECUTIVE SUMMARY

The European maritime area is one of Europe's most important assets with regard to resources, security and ultimately prosperity of the Member States. A significant part of Europe's economy relies directly or indirectly on it. It is not just the shipping or fisheries industries and their related activities. It is also shipbuilding and ports, marine equipment and offshore energy, maritime and coastal tourism, aquaculture, submarine telecommunications, blue biotech and the protection of the marine environment. The European maritime area faces several risks and threats posed by unlawful activities, such as drugs trafficking, smuggling, illegal immigration, organised crime and terrorism. Piracy in international waters also constitutes a threat to Europe since it can disrupt the maritime transport chain. These risks and threats can endanger human lives, marine resources and the environment, as well as significantly disrupt the transport chain and global and local security. It is anticipated that these risks and threats will endure in the mid and long run. In order to keep Europe as a world leader in the global maritime economy, an effective integrated/interoperable, sustainable maritime surveillance system and situational awareness are needed.

A significant number of unlawful maritime activities, such as illegal immigration, drugs trafficking, smuggling, piracy and terrorism involve mainly small boats, because small boats are faster and more difficult to detect using conventional means. Hence, it is very important to find out the feasibility of using SAR Satellite images for small boat detection. Since 2008 the EC-JRC has carried out a number of SAR Small Boat detection experiments to assess the feasibility of using Spaceborne SAR for Small Boat detection. This report presents the results and conclusions of the coupled UAS and spaceborne SAR small boat detection campaign on coastal waters carried out by the EC-JRC in Porto Corallo, Sardinia, Italy from on 29 October 2010.

The results of this coupled UAS/Spaceborne SAR small boat detection experiment show the potential of UAS for maritime surveillance and that small boat detection in spaceborne SAR is possible under suitable conditions of sea state, wind speed and incidence angle. In fact, the experiment highlights how a UAS can fill in the maritime surveillance gap between ship-borne and land-based surveillance assets and spaceborne SAR. For instance, spaceborne SAR allows small boat detection under suitable sea and wind conditions. However, it neither allows classification nor identification of small boats. A UAS besides detection also allows classification and identification. Hence, since most unlawful activities in the maritime domain, such as illegal immigration, drugs trafficking, smuggling, terrorism and piracy involve small boats the potential of UAS for maritime surveillance is very high. However, Before UAS can be routinely used for maritime surveillance in non-segregated airspace, a significant number of key issues related to critical UAS systems have to be addressed, namely command and control issues, telecommunications (e.g. change over from Line of Sight (LOS) to Beyond Line of Sight (BLOS) Satcom), hand over of Air Traffic Control (ATC) between military and civil, collision avoidance systems, cross-border issues, flight plan modifications, contingency procedures, legal framework and regulations, etc.. Other interesting lines of research are UAS formation flying issues, patterns for optimal surveillance, onboard data fusion, full autonomy and endurance and altitude issues.

1. – Introduction

1.1 – Scope

This report presents the key findings of the coupled UAS and Spaceborne SAR Small Boat Detection Campaign, led by the EC-JRC and conducted jointly with Alenia Aeronautica in Quirra, Sardinia-Italy in October 2010.

This study addresses the potential of Unmanned Aerial Systems (UAS) for maritime surveillance and the feasibility of using UAS as a complementary technology on an operational basis.

To answer this statement of work, a multinational cross-disciplinary consortium with research and operational expertise in maritime surveillance and Unmanned Aerial Systems (UAS) was assembled with organisations involved in:

1.- research in maritime surveillance using Spaceborne SAR imagery and in the processing and analysis of SAR imagery, as well as coordination and management of maritime surveillance campaigns (European Commission-JRC).

2.- experience with Unmanned Aerial Systems (UAS) campaigns (Alenia Aeronautica).

1.2 – Main Objectives

The work was performed with the following main objectives:

- To acquire hands-on experience with UAS technologies, in particular with its possible applications to maritime surveillance.
- To assess the potential of UAS for maritime surveillance, including small boat detection, illegal immigration and drugs trafficking mitigation.
- To study the feasibility of using UAS as a complementary maritime surveillance technology on an operational basis together with currently used technologies.
- To identify the main limiting factors preventing the use of UAS and enabling factors that could help to facilitate the operational use of UAS for maritime surveillance.

1.3 – Context

Problem Statement – The European maritime area is one of Europe's most important assets with regard to resources, security and ultimately prosperity of the Member States. A significant part of Europe's economy relies directly or indirectly on it. It is not just the shipping or fisheries industries and their related activities. It is also shipbuilding and ports, marine equipment and offshore energy, maritime and coastal tourism, aquaculture, submarine telecommunications, blue biotech and the protection of the marine environment. The European maritime area faces several risks and threats posed by unlawful activities, such as drugs trafficking, smuggling, illegal immigration, organised crime and terrorism. Piracy in international waters also constitutes a threat to Europe since it can disrupt the maritime transport chain. These risks and threats can endanger human lives, marine resources and the environment, as well as significantly disrupt the transport chain and global and local security. It is anticipated that these risks and threats will endure in the mid and long run. In order to keep Europe as a world leader in the global maritime economy, an effective integrated/interoperable, sustainable maritime surveillance system and situational awareness are needed.

A significant number of unlawful maritime activities, such as illegal immigration, drugs trafficking, smuggling, piracy and terrorism involve mainly small boats, because small boats are faster and more difficult to detect using conventional means. Hence, it is very important to find out the feasibility of using Unmanned Aerial Systems (UAS) on an operational basis as a complementary maritime surveillance technology to currently used maritime surveillance assets, such as spaceborne SAR, coastal radars, ship-borne radars, etc.

2. – Research Method

In order to find out the potential and feasibility of using Unmanned Aerial Systems (UAS) for maritime surveillance, including small boat detection, a controlled experiment on open sea and along the coast was designed, set up and executed. The controlled experiment is briefly described next.

The controlled experiment consisted of a UAS (Alenia Aeronautica Sky-Y) flight over the area of the Poligono di Tiro in Porto Corallo, Sardinia at the approximate time of a SAR Satellite pass (TerraSAR-X). The Sky-Y took-off from Decimomanu military airbase in Sardinia, Italy and flew about 75Km towards the Poligono di Tiro of the Italian Air Force in Porto Corallo were the experiment tests took place.

The experiment was divided into two phases, namely:

1.) an open sea/coastal waters phase and
2.) an along the coast phase. These two phases are described next.

2.1 – Controlled Experiment on Open Sea / Coastal Waters

One of the main objectives of this controlled experiment was to find out the potential of using UAS for maritime surveillance on open sea/coastal waters. To that end, two small boats, namely an 8-meter rubber boat and a 16-meter fishing boat were deployed on open sea/coastal waters within the area of the Poligono di Tiro of Porto Corallo. The UAS capabilities were then tested. The tests comprised flying over the above mentioned area and the detection, tracking, classification and identification of the two boats deployed.

2.2 – Controlled Experiment Along the Coast and Beach

Another objective of this controlled experiment was to find out the potential of using UAS for maritime surveillance along the coast and beach. The rationales behind it being testing the capabilities of UAS to detect, classify and identify targets on land (e.g. small boats, people, etc.). To that end, three people, were deployed on land near the sea walking along the coast within the area of the the Poligono di Tiro of Porto Corallo. The UAS capabilities were then tested. The tests comprised flying over the above mentioned area and the detection, tracking, classification and identification of the three human targets deployed, as well as an attempt to detect other moving and stationary targets, such as other people, cars and any other targets of interest.

3. – Experiment Set Up

In this section we describe the experiment set up, namely the experiment site selection, the SAR Satellite Imagery planning and the partners involved and their roles.

3.1 – Experiment Site Selection

Bearing in mind that most unlawful maritime activities involving small boats, such as illegal immigration, drugs trafficking, smuggling and terrorist activities can be better mitigated if the small boats are detected at an earlier stage while on open sea, the selection of open sea site scenarios for the experiment was an obvious option. The open sea trials were carried out a few nautical miles off the coast of Porto Corallo. This site was selected because it is under the jurisdiction of the Italian Air Force, which made the authorisation to fly easier to obtain and reduced the risk of incidents involving people since the area is closed to the public. For the same reason the tests along the coast also took place in the same area.

3.1.1 – Open Sea/Coastal Waters Site in Porto Corallo

The open sea/coastal waters site selected in Porto Corallo near Muravera and Villaputza, a few nautical miles off the coast, is illustrated in fig.1 in Green. The UAS flight plan and the Italian Airforce military airbase are also illustrated in fig.1.

3.1.2 – Site Along the Coast in Porto Corallo

For the same reasons the selected site for the tests along the coast is also the Porto Corallo area close to the coast indicated in Green in Figure 1.

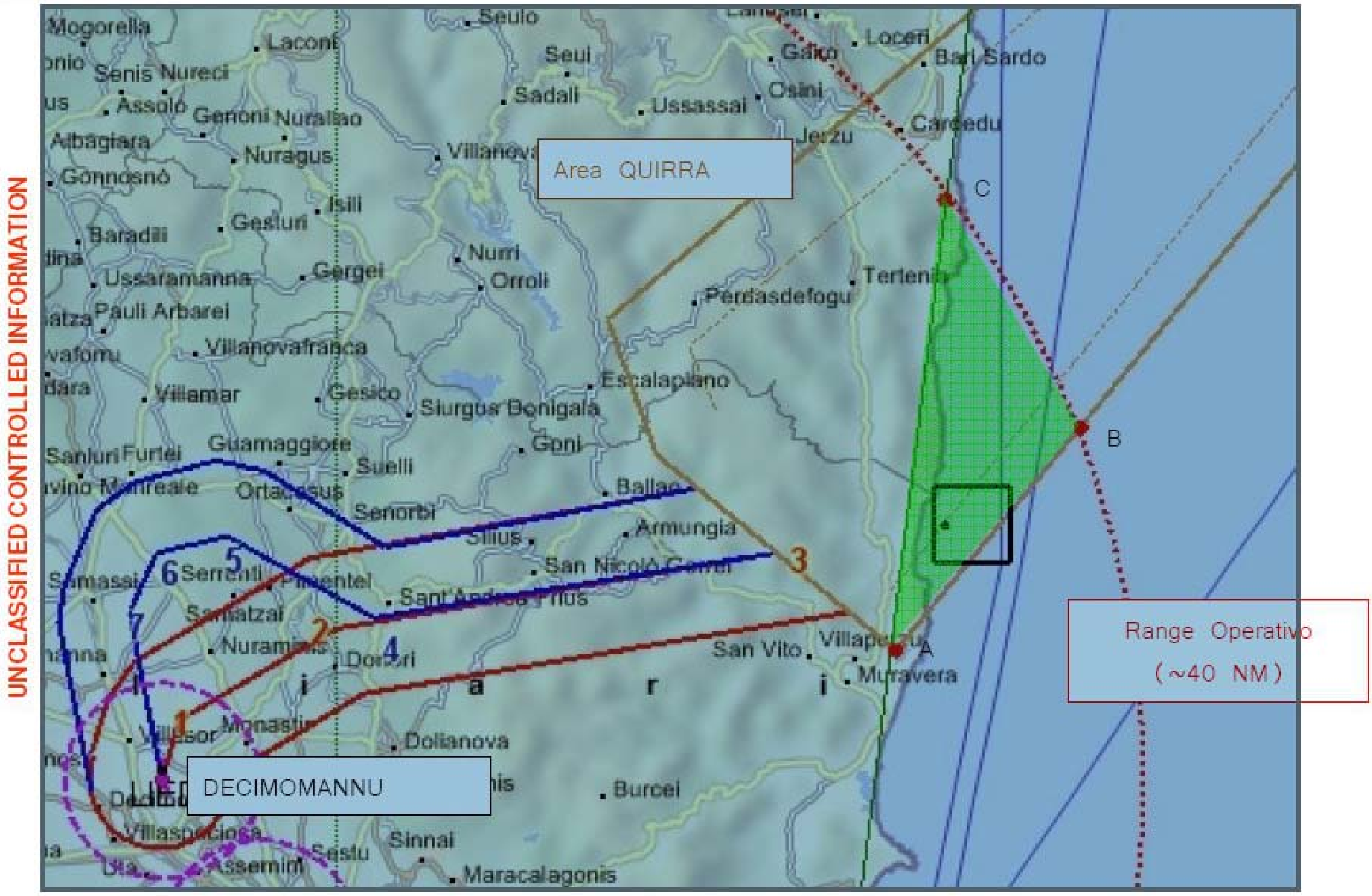

Figure 1 – The site of the experiment in Porto Corallo, Sardinia is the area in Green with vertices ABC, near Villaputza. The Italian Air Force military airbase of Decimomannu is also indicated in the map, as well as the UAS flight plan.

Figure 2 illustrates a square within the Green area where the experiment was carried out, indicating the coordinates of the vertices ABC of the Green triangle, as well as the vertices of a smaller area of operations represented by a square with vertices 1,2,3 and 4.

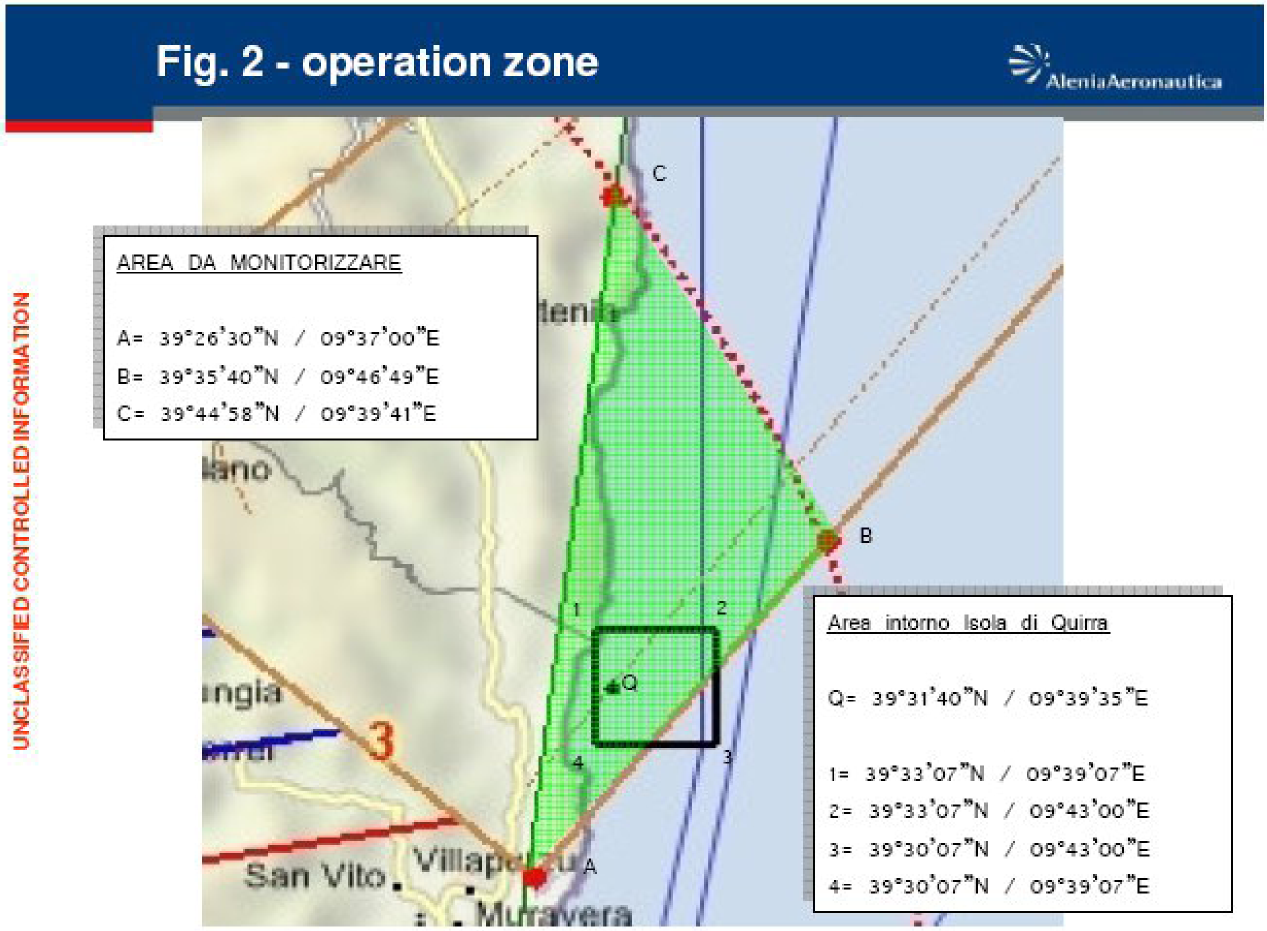

Figure 2 – Flight test area in Green with vertices ABC and operation zone represented by a square with vertices 1,2,3 and 4.

3.3 – SAR Satellite Imagery Planning

Figures 3 and 4 illustrate the spaceborne SAR imagery planning. The footprints of the SAR Satellite images selected are shown in the google earth image of the region of Porto Corallo, Sardinia, Italy.

The Synthetic Aperture Radar (SAR) satellite imagery available at the time the planning was done comprised Radarsat2 (Spotlight and Ultrafine) and TerraSAR-X (Spotlight and Stripmap). Figure 3 illustrates the Radarsat2 images available. Table-1 illustrates the SAR satellite images and image modes used in the different days of the experiment.

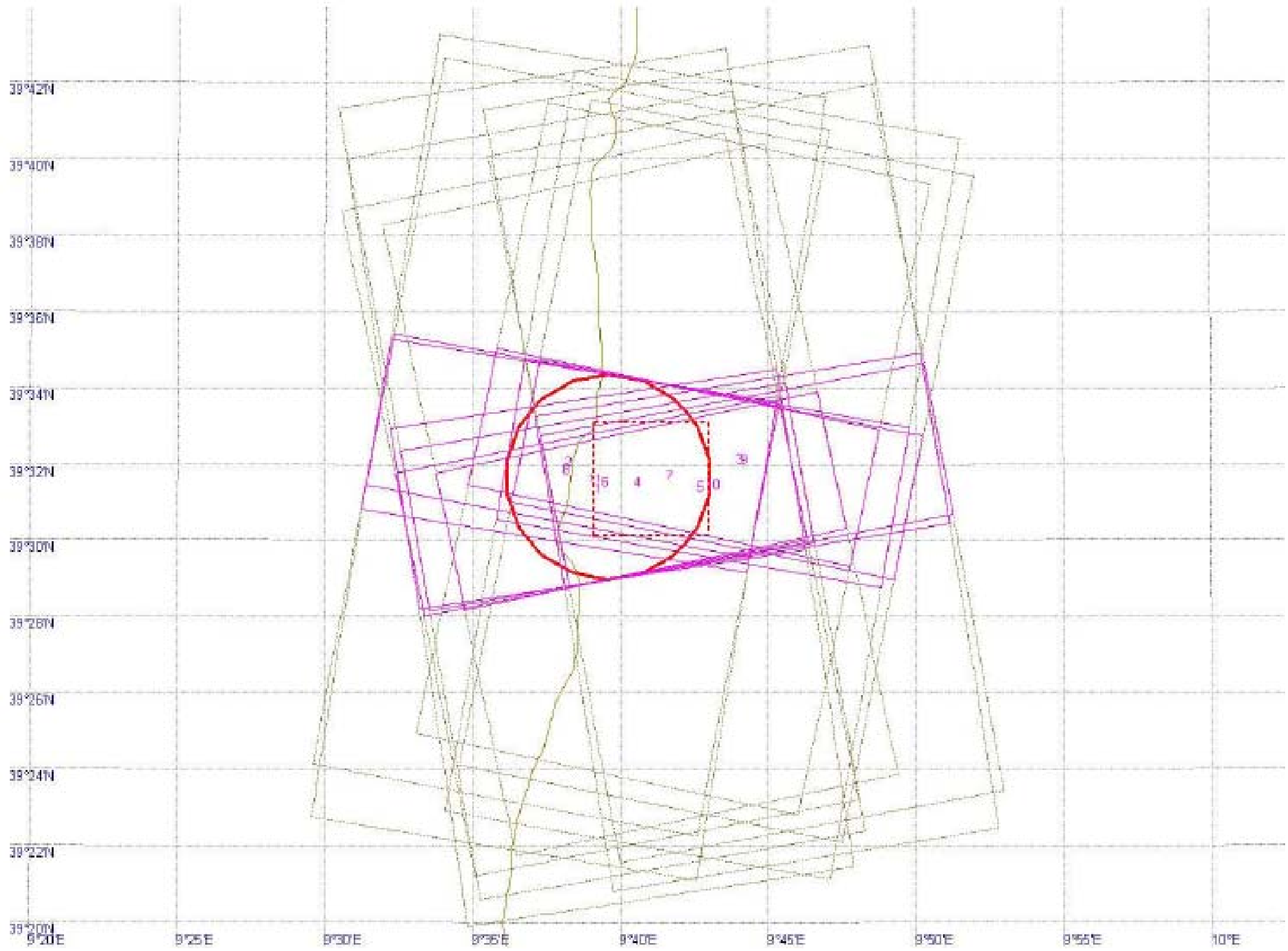

Figure 3 – The square in red corresponds to the area defined by Alenia Aeronautica. The circle in red is centred at the point Q with coordinates (39° 31' 40"N / 09° 39' 35"E) given by Alenia Aeronautica with radius of 5km. The rectangles in magenta are the Radarsat2-Spotlight images available in the period between 25Oct-15Nov. 2010. The frames are 10km x 5km. The dates and times are given bellow in Table-1.

Table 1- Radarsat2- Spotlight High Resolution 25-Oct.-15-Nov.-2010

#	Morning Satellite Pass	Evening Satellite Pass
1		2010-Oct-25 17:13:02.939 Ascending
2	2010-Oct-26 05:26:51.424 DES	
3		2010-Oct-28 17:25:31.415 Ascending
4		2010-Nov-01 17:08:53.725 Ascending
5	2010-Nov-02 05:22:41.915 DES	
6		2010-Nov-04 17:21:21.781 Ascending
7	2010-Nov-05 05:35:09.994 DES	
8	2010-Nov-09 05:18:32.266 DES	
9		2010-Nov-11 17:17:12.288 Ascending
10	2010-Nov-12 05:31:00.781 DES	
11		2010-Nov-14 17:29:41.201 Ascending

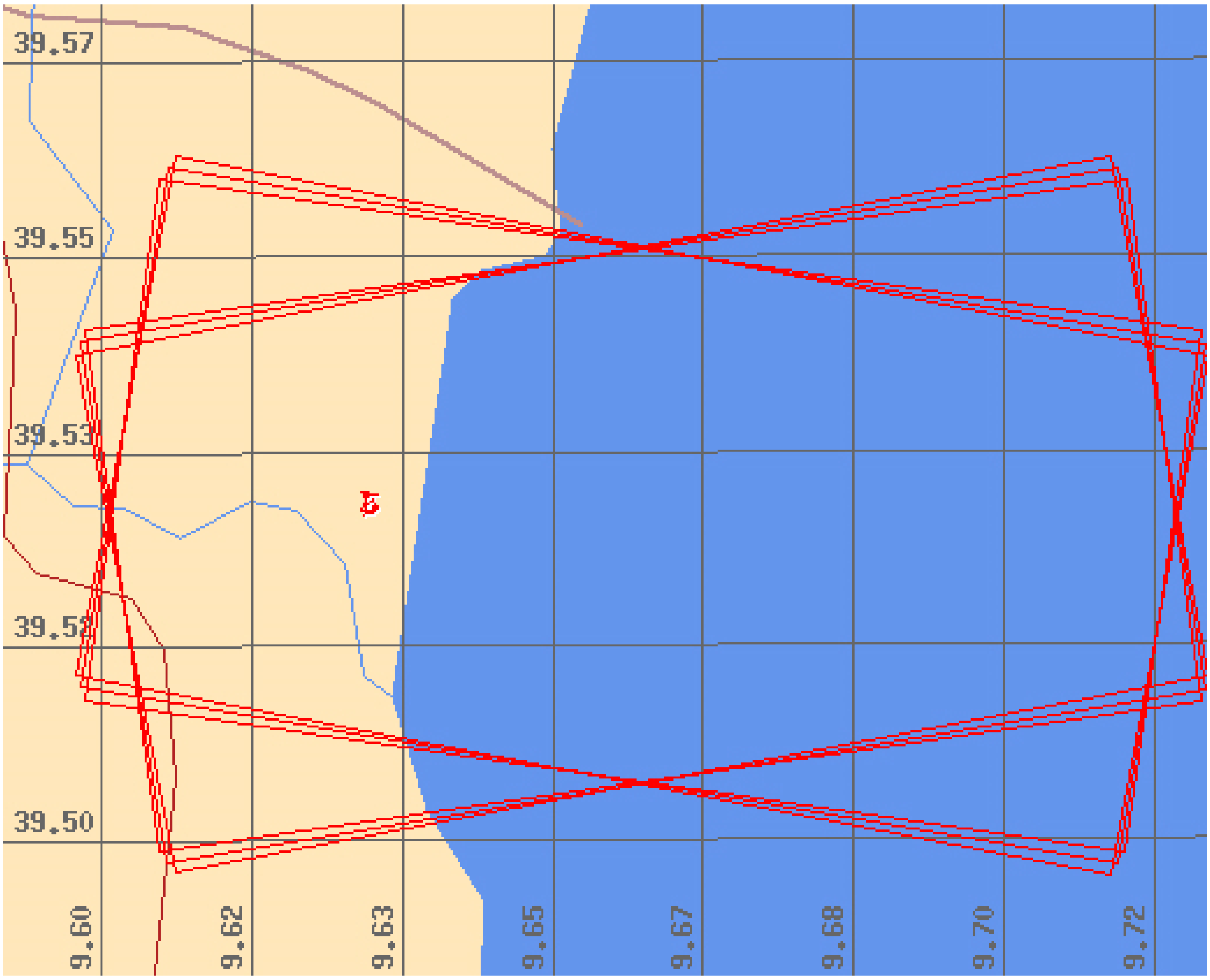

Figure 4 – TerraSAR-X / Spotlight High Resolution frames centred at the point Q with coordinates (39° 31' 40"N / 09° 39' 35"E) given by Alenia Aeronautica. The rectangles in red are the TerraSAR-X-Spotlight High Resolution images available in the period between 25Oct-15Nov. 2010. The frames are 10km x 5km. The dates and times are given bellow in Table-2.

Table 2 – TerraSAR - Spotlight High Resolution 25-Oct.-15-Nov.-2010.

#	Morning Satellite Pass	Evening Satellite Pass
1		Start Date: 2010-10-25T17:14:46.078
2	Start Date: 2010-10-29T05:28:36.182	
3		Start Date: 2010-10-30T17:23:19.111
4		Start Date: 2010-10-31T17:06:13.240
5	Start Date: 2010-11-03T05:37:08.788	
6	Start Date: 2010-11-04T05:20:03.032	
7		Start Date: 2010-11-05T17:14:46.078
8	Start Date: 2010-11-09T05:28:36.182	
9		Start Date: 2010-11-10T17:23:19.111
10		Start Date: 2010-11-11T17:06:13.240

The Radarsat2 and TerraSAR-X image modes used in the present experiment will be briefly reviewed in the next paragraphs.

Radarsat2 - Spotlight Mode – The Spotlight Beams are intended for applications which require the best spatial resolution available from the RADARSAT-2 SAR system. In this mode the radar operates with the highest sampling rate, and so the ground swath coverage is limited to keep data rate within the recorder limits. Unlike the other modes, Spotlight images are also of fixed size in the along track direction.

The ser of Spotlight Beams cover any area within the incidence angle range from 20 to 49 degrees. Each beam within the set images a swath width of at least 18 km. Spotlight images can only be generated in a single polarization, which can be either a linear co-polarization (HH or VV) or a linear cross-polarization (HV or VH).

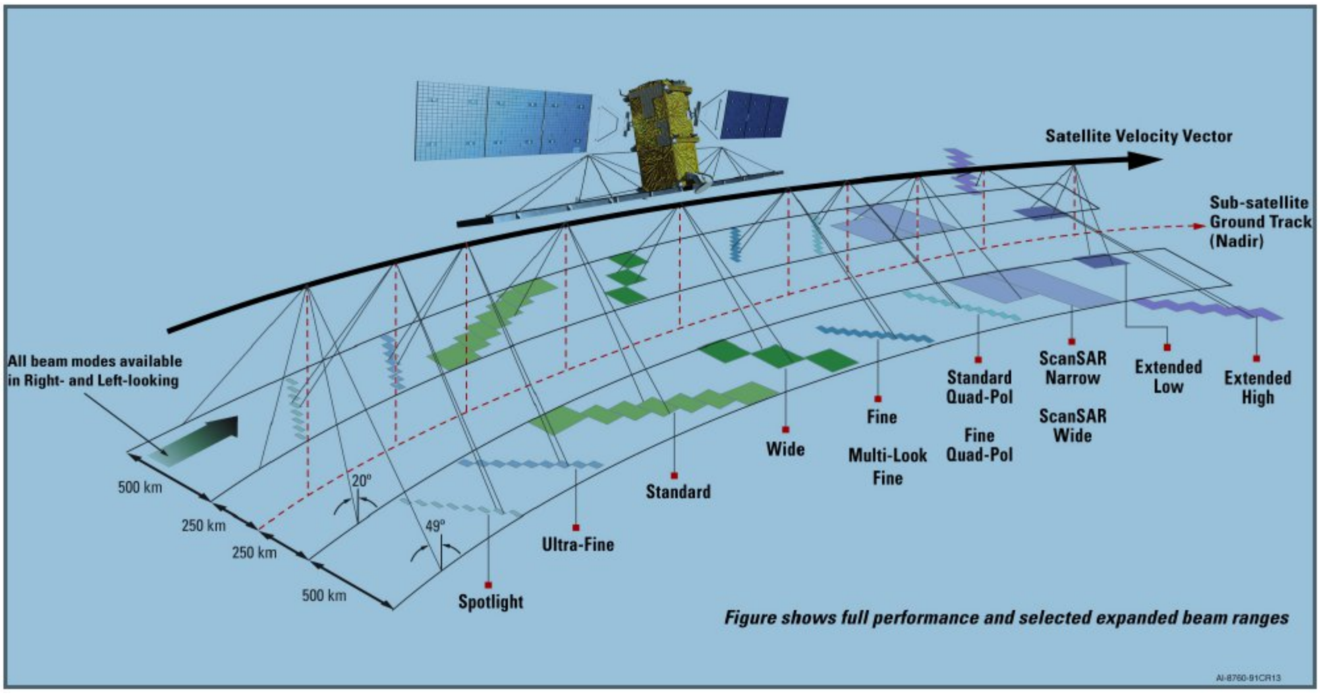

Figure 5 – Radarsart2 image modes. The Ultrafine and the Spotlight modes have been identified as the most suitable modes for this particular experiment.

Radarsat2 - Single Beam Mode – Single beam mode is a stripmap SAR mode. In Single Beam operation, the beam elevation and profile are maintained constant throughout the data collection period. The following Single Beam modes are available: Standard, Wide, Fine, Multi-Look Fine, Ultra-Fine, Extended High (High Incidence), Extended Low (Low Incidence), Standard Quad Polarization and Fine Quad Polarization. We selected Ultra-Fine because it is the best compromise between swath coverage and resolution.

Radarsat2 - Ultra-Fine – The Ultra-Fine Resolution Beams are intended for applications which require very high spatial resolution. In this mode the radar operates with the highest sampling rate, and so the ground swath coverage is limited to keep data rate within the incidence angle from 20 to 49 degrees. Each beam within the set images a swath width of at least 20 km. Ultra-Fine Resolution images can only be generated in a single cross-polarization , which can be either a linear co-polarization (HH or VV) or a linear cross-polarization (HV or VH).

The **standard TerraSAR-X operational mode** is the single receive antenna mode from which the following imaging modes can be retrieved: High Resolution Spotlight and Spotlight, StripMap, and ScanSAR. The single receive antenna mode uses a chirp
bandwidth of up to 300 MHz.

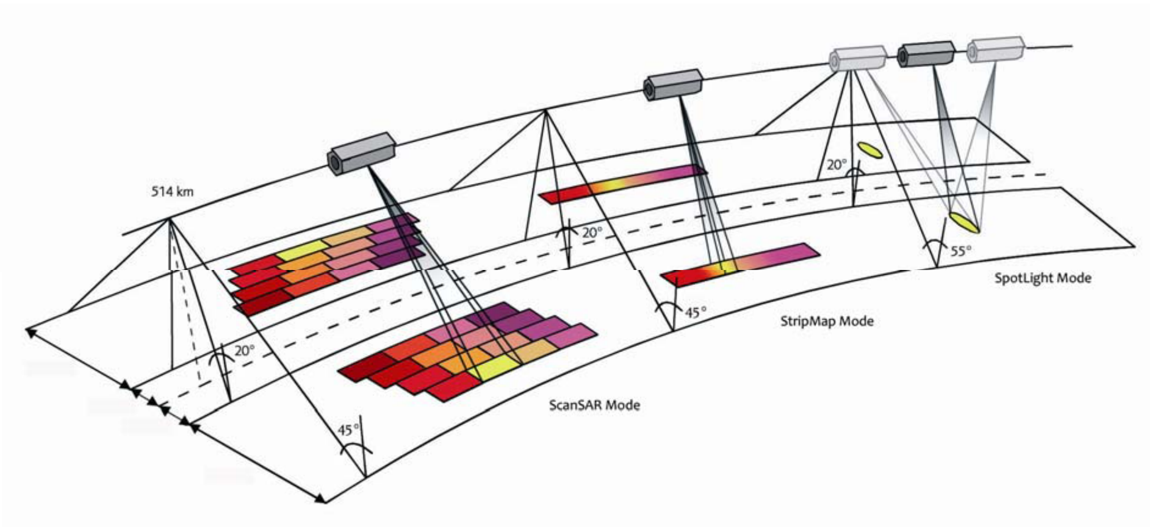

Figure 6 – Radarsart2 image modes. The Ultrafine and the Spotlight modes have been identified as the most suitable modes for this particular experiment.

The **SpotLight (SL)** imaging modes use phased array beam steering in azimuth direction to increase the illumination time, i.e. the size of the synthetic aperture. This leads to a restriction in the image / scene size. Thus, the scene size is technically restricted to a defined size: 10 km x 10 km for the SpotLight mode and 10 km x 5 km (width x length) in the HighResolution SpotLight (HS) mode.

This sophisticated imaging mode makes it possible to acquire data with up to 1 m resolution in the HighResolution SpotLight mode (acquired with a bandwidth of 300 MHz) and 2 m in the standard SpotLight mode.

StripMap (SM) is the basic SAR imaging mode as known e.g. from ERS-1 and other radar satellites. The ground swath is illuminated with continuous sequence of pulses while the antenna beam is fixed in elevation and azimuth. This results in an image strip with a continuous image quality (in flight direction). StripMap dual polarisation data have a slightly lower spatial resolution and smaller swath than the single polarisation data.

In StripMap mode, a spatial resolution of up to 3 m can be achieved. The standard scene size is 30 km x 50 m (width x length) in order to obtain manageable image files; however, acquisition length is extendable up to 1,650 km.

The spaceborne SAR image selected was a TerraSAR-X-Spotlight acquired on 29 Oct.2010 by 05:28 UTC. Table 3 gives the basic characteristics of the SAR image.

Table 3 – Spaceborne SAR image acquired over Porto Corallo, Sardinia, Italy.

Date/Time	Area	Satellite / Mode	Polarization	Pass
29.Oct. 2010 (AM) T 05:28:36.182	**Porto Corallo- Sardinia**	**TerraSAR-X / Spotlight**	**HH**	**Descending**

3.4 – Partners Involved and their Roles

The partners involved in this experiment comprised the European Commission (EC) – Joint Research Centre (JRC). The role of each partner is briefly described next.

3.4.1 - European Commission (EC) – Joint Research Centre (JRC)

– The main role of the EC-JRC was the planning, set up, execution and the analysis of the data together with Alenia Aeronautica. This comprised:

a.) the definition of the objectives,
b.) the research methods used,
c.) the ground truth data collection,
d.) the analysis of the data and the conclusions of the experiment.

3.4.2 – Alenia Aeronautica

– The main role of Alenia Aeronautica comprised:

a.) the deployment and operation of the boats used as targets.
b.) the deployment and operation of the UAS Sky-Y.
c.) the contacts with the Italian authorities, namely the Italian Air Force at Decimomannu Airbase.
d.) the collection of ground truth data.
e.) The analysis of the data and conclusions of the experiment.

4. – Experiment Execution

4.1 – Modus Operandi

The modus operandi of the trial was as follows:

1.- JRC supplied Alenia Aeronautica with the footprint (frame) of the spaceborne SAR image to be acquired (TerraSAR-X-Spotlight), as well as the time of the SAR satellite pass.

2.- Two boats were deployed in Porto Corallo, namely a 8-meter rubber boat and a 16-meter fishing boat, as well as the UAS Sky-Y, Sardinia. The 8-meter boat had a crew of two (Geremia Pepicelli from Alenia and Victor Silva from EC-JRC). The fishing boat had a crew of two fishermen.

3.- The 2 boats travelled a couple of nautical miles to reach the test site. Once the test site was reached the 2 boats were steered at different speeds to allow the testing of the UAS detection and tracking systems under different conditions.

4.2 – Ground Truth Data Collection

The ground truth data collected comprised:

a.) the sea state.
b.) Data from the UAS sensors.
b.) the weather conditions and wind speed.
e.) Photos and movies of the boats involved in the experiment.

4.3 – Means Involved in the Experiment

The means involved in the experiment comprised a spaceborne SAR image (TerraSAR-X-Spotlight), 2 boats (a 8-meter rubber boat and a 16-meter fishing boat) and the UAS Sky-Y.

4.3.1 – Boats Deployed During the Experiment

Figures 7 and 8 illustrate the 2 boats deployed as targets during the experiment.

Figure 7 – The 8-meter rubber boat at Porto Corallo marina just before the deployment by 6AM.

Figure 8 – The 16-meter fishing boat at Porto Corallo marina after the experiment.

4.3.2 – UAS Sky-Y Alenia Aeronautica

SKY-Y is a Medium Altitude Long Endurance (MALE) Technologies Demonstrator. It is a dedicated platform for validating several key enabling technologies for a surveillance Unmanned Aerial System to be used in either a military and civil operational scenario. These include: innovative carbon ber composite construction, heavy fuel/JP-8 engine (automotive diesel derivative), advanced datalinks, surveillance sensor (EO/IR, Hyperspectral, Synthetic Aperture Radar) and mission management system able to relevant data treatment, elaboration, fusion and distribution by means of an interoperable Tactical Control Station.

The SKY-Y is the system testbed for Alenia Aeronautica MALE product, now in early development. Finally, SKY-Y is the starting point for Molynx, the research project that aims to develop a High Altitude Long Endurance (HALE) system for civil and military applications.

Table 4 gives a summary of the SKY-Y main characteristics and figures 9 and 10 illustrate the UAS SKY-Y deployed during the experiment.

Table 4 – Summary of SKY-Y main characteristics.

Dimensions	
Length 9.725 m	9.725 m
Span 9.937 m	9.937 m
Wing Area 10.785 m2	10.785 m2
Weights	
MTOW 1200 Kg	1200 Kg
OEW 800 Kg	800 Kg
Max Fuel 250 Kg	250 Kg
Max Payload 150 Kg	150 Kg
Performance	
LOS Radius 100 nm	100 nm
Max Range 500 nm	500 nm
Altitude >25 kft	>25 kft
Endurance 14 h	14 h
Payloads	
E0/IR Sensor	
Hyper-spectral sensor	
Synthetic Aperture Radar	
ESM/Elint	

Figure 9 – The UAS Sky-Y at Decimomannu military airbase after the experiment.


Figure 10 – The payload of the Sky-Y was the Selex Galileo EOST Galileo 45, which comprises an Electro-Optical InfraRed (EO/IR) stabilized Turret, stabilization (4 axis), 20 µrad, an IR Camera (2 FOV) 3-5µm, Colour TV Camera (Visible), Spotter (Visible) and a Laser Designator (option). The total weight is 35kg.

5. – Preliminary Data Analysis

5.1 – SAR Satellite Imagery Processing

The high resolution spaceborne SAR image was analysed visually, since the resolution is good enough to allow visual analysis and the site it is too close to the coast, which makes automatic processing more difficult and prone to error due to artefacts caused by land targets.

The SKY-Y images were also analysed visually.

5.2 – Ground Truth Data

This section briefly describes the Ground Truth data, namely the GPS positions of the boats deployed as targets during the experiment, photos of the boats, as well as other relevant ground truth data collected, including the weather conditions.

5.2.1 – GPS coordinates of the boats deployed

Tables 5 and 6 give the GPS coordinates of each boat deployed during the experiment.

Table 5 – Ground Truth data collected during the experiment on 29 October 2010.

Date: 29.Oct.2010 **Time:** 5:28 UTC **-** (7:28AM LT) **/ Pass:** Descending		**Satellite/Mode:** TerraSAR-X / Spotlight **Polarisation :** Dual	
Boats	**Type / Size**	**Latitude**	**Longitude**
8-meter Rubber Boat		N 39° 31' 21.2"	E 09° 39' 31.7"
16-meter Fishing Boat		N 39 30.664 N 39°30'39.84"	E 09 39.108 E 09°39'6.48"

5.2.1 – SKY-Y Ground Truth Data

Table 6 shows the 16-meter fishing boat as detected by the optical sensor of the SKY-Y.

Table 6 – SKY-Y Ground Truth Data.

Date: 29.Oct.2010 **Time:** 5:28 UTC **-** (7:28AM LT)		**Platform:** SKY-Y	
Boats	**Type / Size**	**Latitude**	**Longitude**
16-meter Fishing Boat		N 39° 30.664' N 39°30'39.84"	E 09° 39.108' E 09°39'6.48"

5.3 – Weather Conditions and Sea State

The weather conditions in Porto Corallo are summarized in Table 7 bellow.

Table 7 – Wind speed, wind direction and Temperature.

Wind Speed	3 m/s
Wind Direction	East
Temperature	14°C

The Sea State can be estimated based on the photos and videos taken during the experiment. Figure 11 shows a photo taken on 29 Oct. 2010 by 5:28 UTC (7:28AM LT), the approximate time of the SAR satellite pass. As it can be seen, the Seat State can be classified as a Beaufort Force 2, which corresponds to wave height between 0.2-0.5m and a wind speed of about 2-3m/s.

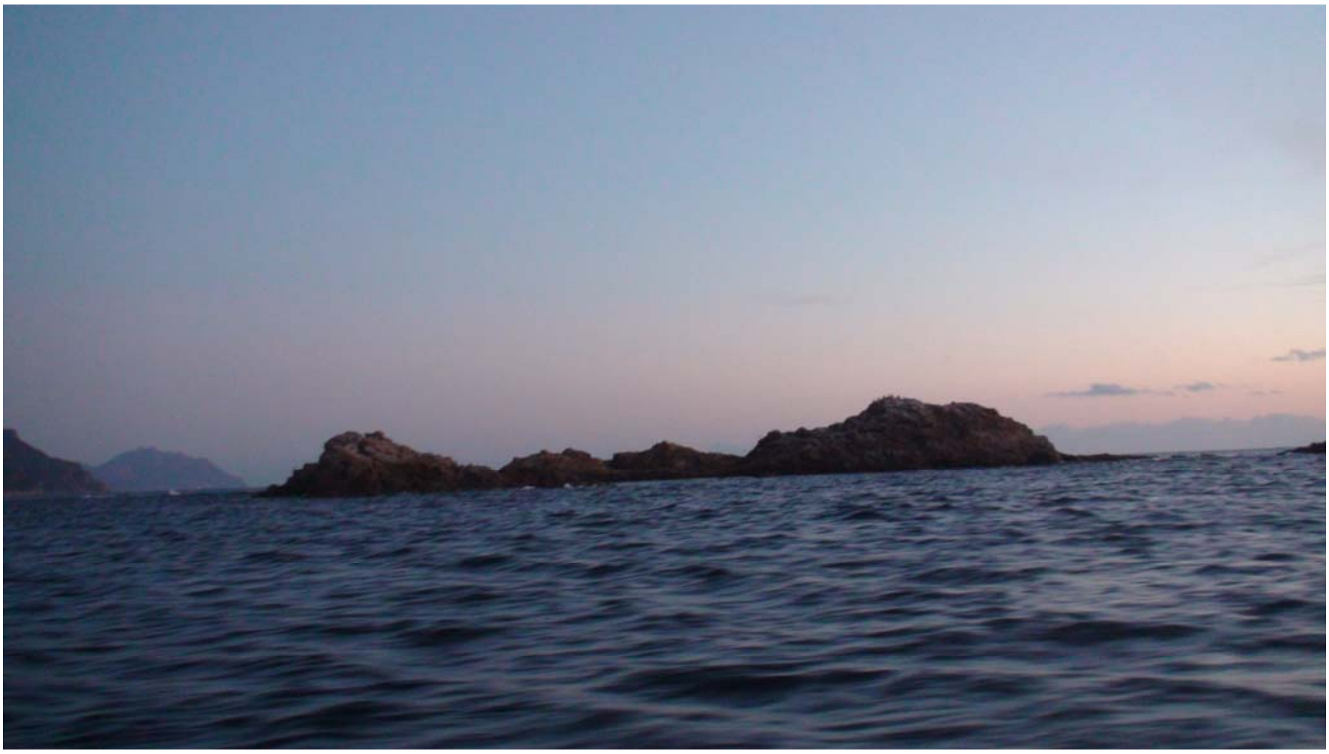

Figure 11 – Photo of the Sea taken from the 8-meter rubber boat by 5:28 UTC (7:28AM LT) on 29 Oct. 2010. The GPS coordinates of the photo are Latitude: 39° 31’ 21.0” N, Longitude 09° 39’ 27.8” E.

5.4 – Verification of the Results

This section briefly describes the verification of the targets detected in the spaceborne SAR image and in the SKY-Y UAS using the ground truth data collected during the experiment.

5.4.1 – Targets Detected in the TerraSAR-X-Spotlight Image

Figure 12 gives the positions of the 2 boats used as targets in the experiment at the approximate time of the SAR Satellite pass by 5:28 UTC. The Green pin shows the position of the 8-meter rubber boat (N 39° 31’ 21.2”, E 09° 39’ 31.7”) and the yellow pin gives the position of the 16-meter fishing boat (N 39°30'39.84", E 09°39'6.48").

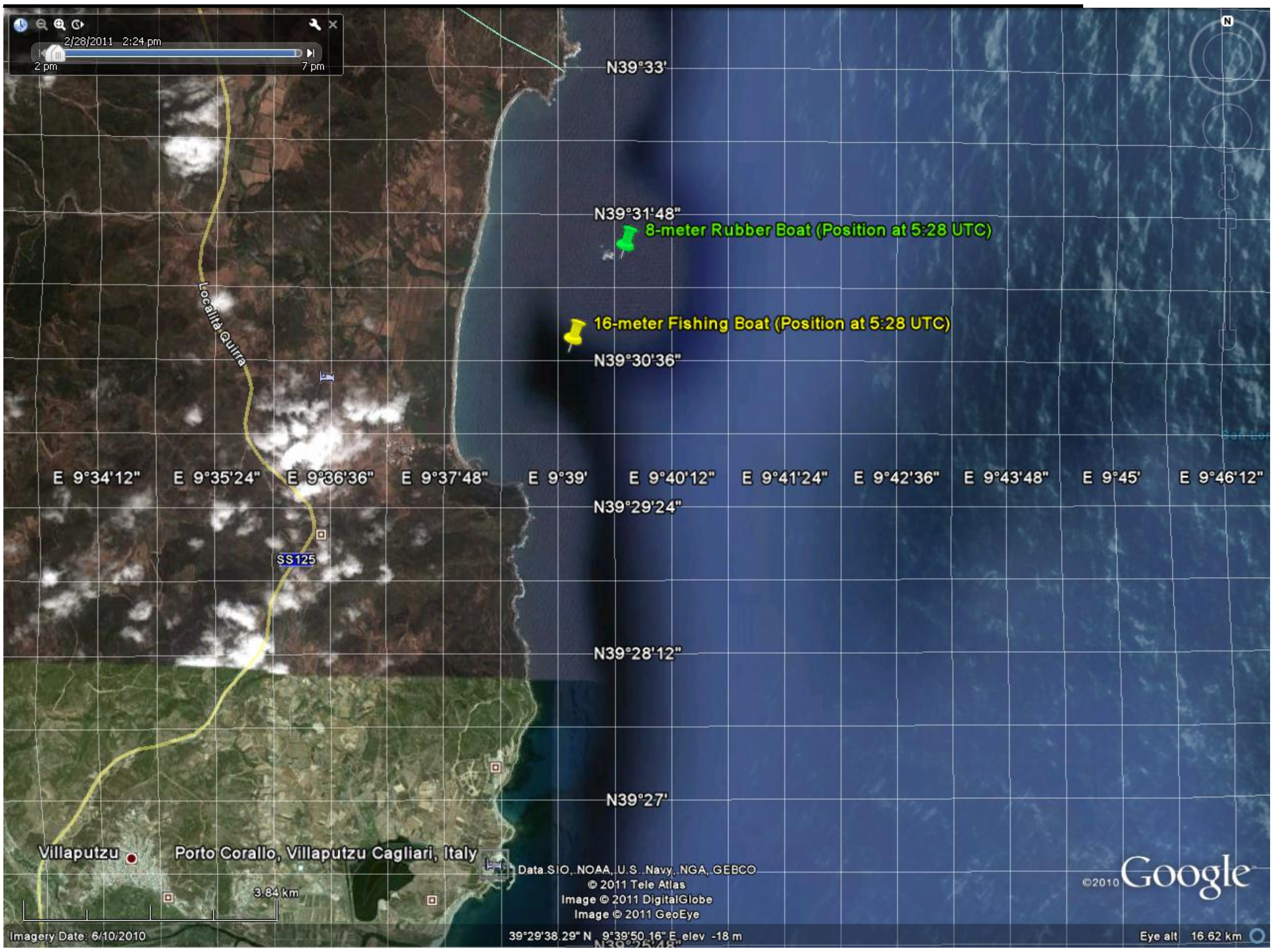

Figure 12 – Google Earth positions of the 2 boats at the approximate time of the SAR Satellite pass by 5:28 UTC. The Green pin shows the position of the 8-meter rubber boat and the yellow pin gives the position of the 16-meter fishing boat.

Figure 13 consists of a background (figure 12) and an overlay of a subset of the TerraSAR-X image acquired on 29 Oct. 2010 with the positions of the 2 boats used as targets indicated. There is a slight mismatch between the background and the SAR image, most likely due to SAR geo-referencing errors. The mismatch can also be seen in the coastline. Due to the scale of the image it is hard to see the SAR signatures of the boats.

In order to check if the SAR signatures of the boats are noticeable in the SAR image, figure 13 was zoomed-in. Figure 14 shows the zoo-in of two subsets of figure 13, namely the area around the position of boat 1 and the area around the position of boat 2. As it can be seen, the SAR signature of target 1 (8-meter rubber boat) is not noticeable. However, the SAR signature of target 2 (16-meter fishing boat) can clearly be seen but it is not a strong SAR signature.

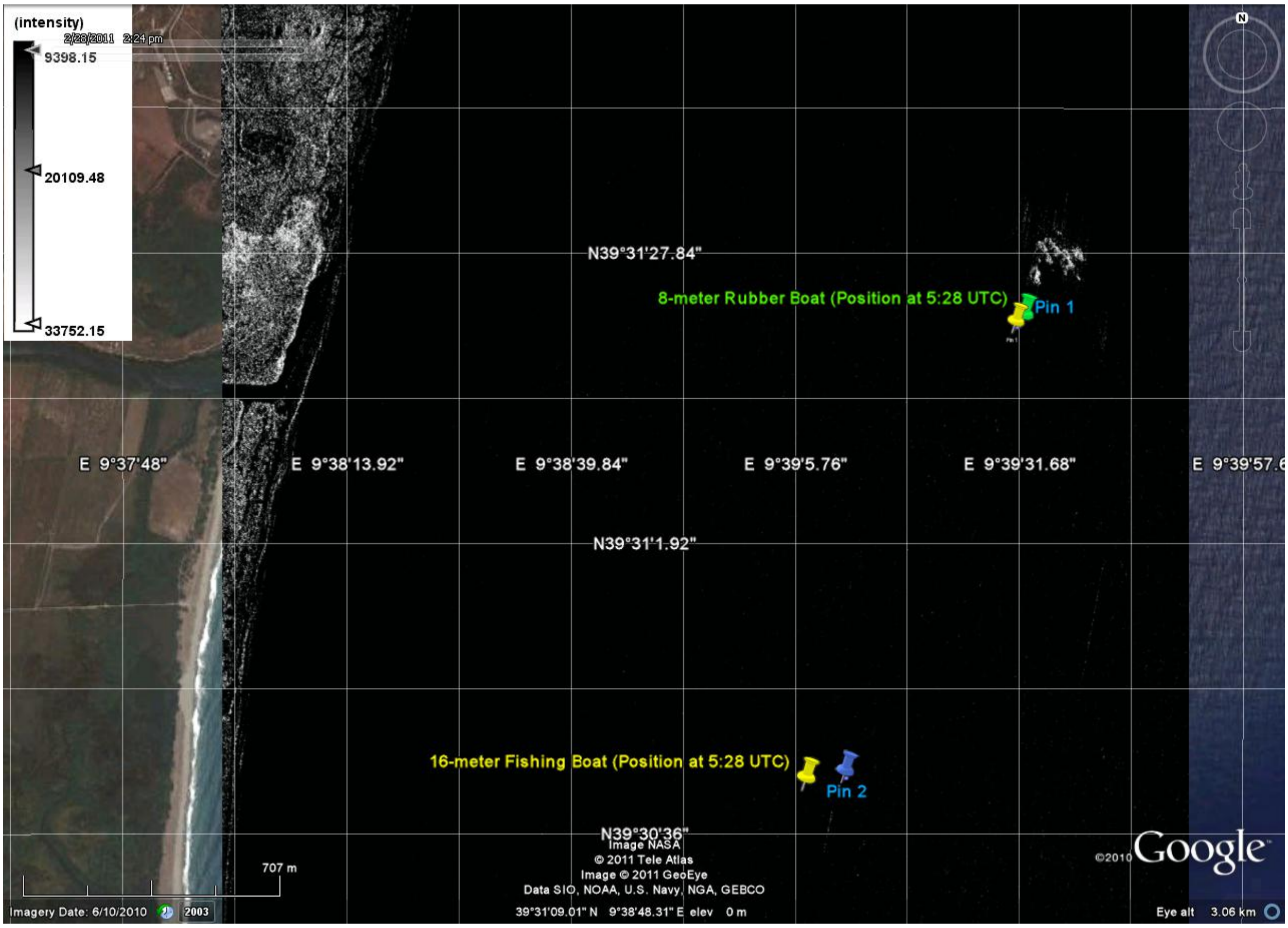

Figure 13 – On the background the Google Earth image from figure 12 with an overlay subset of the TerraSAR-X image with the positions of the 2 boats. As it can be seen there is a slight mismatch of the positions of the boats in the two images. The mismatch is due to geo-referencing errors of the SAR image. The mismatch between the coast lines confirms that error.

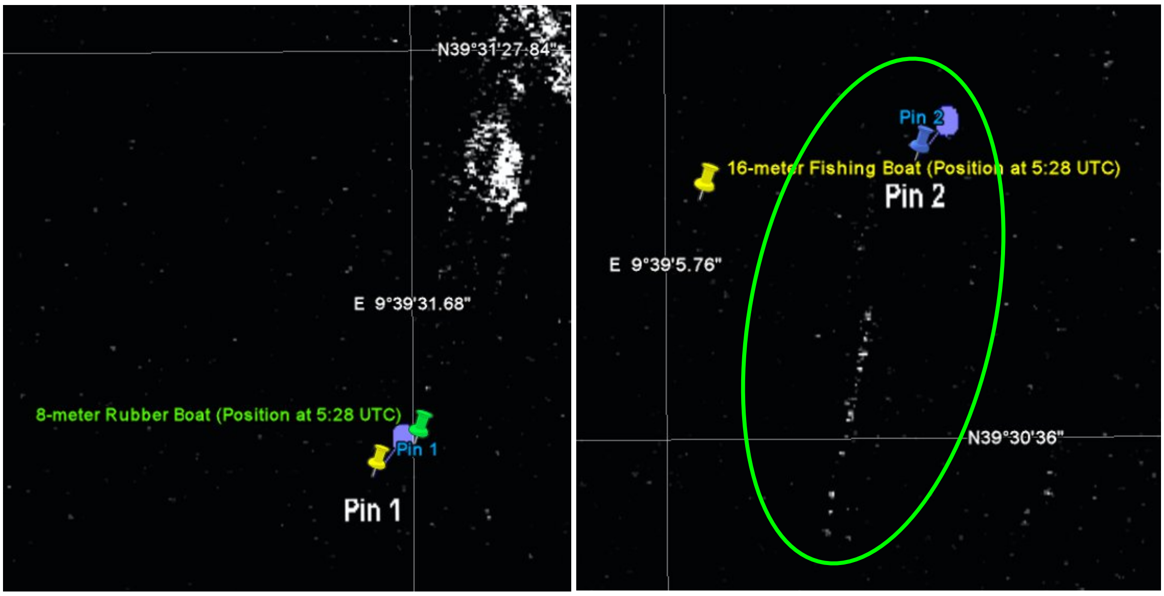

Figure 14 – Zoom-in of figure 13. On the left we have the zoom-in of the position of boat 1. No SAR signature of target 1 (8-meter rubber boat) can be seen. The figure on the right shows the SAR signature of boat 2 (16-meter fishing boat).

5.4.2 – Targets Detected and Tracked by the SKY-Y

The SKY-Y payload was able to detect, track and classify the two boats deployed as targets. The next figures show several images acquired by the SKY-Y payload during the experiment. Figure 15 and 16 show the 8-meter rubber boat .This shows the capability of the SKY-Y to detect small rubber boats from relatively high altitudes (e.g. >3,000 meters). The SKY-Y was able to detect the 8-meter rubber boat from relatively high altitudes, track it and classify the type of boat. The boat was steered at increasingly high speeds to test the UAS capability to automatically detect and track targets at high speeds. The detection and classification of the targets was successful. The direct identification of the target would have required a UAS flight at lower altitude. The images acquired by the different UAS sensors were acquired at relatively high altitude, well above 3,000m. Since the SKY-Y was not fitted with Satcom for BLOS navigation, the minimum UAS flight altitude allowed was about 3,000m to keep the Line of Sight with the Remote Control Station located at Decimomannu Airbase. Without that limitation the UAS would have been allowed to fly much lower than 3,000m and direct identification of the target.

Figure 15 – Boat Spotter, LRTV LIVE.

The SKY-Y information associated to the image in figure 15 is given next.

	Name	Note
(*)	FOM D/L	100%

On Board Computer Mission Data:

	Name	Note
(*)	Longitude WGS 84	09°38'027" E
(*)	Latitude WGS 84	39°29'946" N
(*)	Altitude WGS 84	0
(*)	Az Position report	-77,3493 (deg)
(*)	El Position Report	-25,7831 (deg)
(*)	Slant Range	6740 (m)
(*)	Distance On Ground	6001 (m)

Sensor Data:

	Name	Description			
(*)	Focus value	2000 (m)			
(*)	Video Out status	Spotter			
(*)	AZ position report	-77,6243 deg			
(*)	EL position report	-25,7831 deg			
(*)	Footprint Lat	39,49783 N	39,49816 N	39,50015 N	39,49984 N
(*)	Footprint Lon	9,63321 E	9,63475 E	9,63433 E	9,63285 E
(*)	Footprint Lat	39°29'869" N	39°29'889" N	39°30'009" N	39°29'990" N
(*)	Footprint Lon	9°37'992 E	9°38'085" E	9°38'059" E	9°37'971" E

A/C Data:

	Name	Note
(*)	Latitude	39°31'800" N
(*)	Longitude	09°44'400" E
(*)	Magnetic Heading	-2.22 (rad/s)
(*)	GPS Latitude	39°31'800" N
(*)	GPS Longitude	09°44'400" E
(*)	GPS Time	07:49:20

Figure 16 – Boat Spotter, LRTV LIVE.

The SKY-Y information associated to the image in figure 16 is given next.

	Name	Note
(*)	FOM D/L	100%

On Board Computer Mission Data:

	Name	Note
(*)	Longitude WGS 84	09°37'970" E
(*)	Latitude WGS 84	39°29'925" N
(*)	Altitude WGS 84	0
(*)	Az Position report	-105,5379 (deg)
(*)	El Position Report	-23,2862 (deg)
(*)	Slant Range	7035 (m)
(*)	Distance On Ground	6319 (m)

Sensor Data:

	Name	Description			
(*)	fov angle value	0.44°			
(*)	focal length value	460 mm			
(*)	Focus value	2000 (m)			
(*)	Video Out status	Spotter			
(*)	AZ position report	-105,4242 deg			
(*)	EL position report	-23,4913 deg			
(*)	Footprint Lat	39,49783 N	39,49816 N	39,50015 N	39,49984 N
(*)	Footprint Lon)	9,63321 E	9,63475 E	9,63433 E	9,63285 E
(*)	Footprint Lat	39°29'870" N	39°29'890 N	39°30'009" N	39°29'990" N
(*)	Footprint Lon)	9°37'992" E	9°38'085" E	9°38'060" E	9°37'971" E

A/C Data:

	Name	Note
(*)	Latitude	39,5498 (39°32'988" N)
(*)	Longitude	9,6651 (9°39'906" E)
(*)	Magnetic Heading	-2.352 (rad/s)
(*)	GPS Latitude	39,5496 (39°32'976" N)
(*)	GPS Longitude	9,6652 (09°39'712" E)
(*)	GPS Time	07:48:15

Figure 17 – Ship (Spotter), TVC LIVE.

The SKY-Y information associated to the image in figure 17 is given next.

	Name	Note
(*)	FOM D/L	100%

On Board Computer Mission Data:

	Name	Note
(*)	**Longitude WGS 84**	09°39'108" E
(*)	**Latitude WGS 84**	39°30'664" N
(*)	**Altitude WGS 84**	0 m
(*)	**Az Position report**	2.677166
(*)	**El Position Report**	-0.605653
(*)	**Slant Range**	4408,46 m
(*)	**Distance On Ground**	3126,06 m

Sensor Data:

	Name	Note			
(*)	**FOV Angle Value**	1.816379°			
(*)	**Focal Length Value**	113.498268 mm			
(*)	**Focus Value**	5011.957031 m			
(*)	**Video Out status**	EO (TVC)			
(*)	**AZ position report**	2.706888			
(*)	**EL position report**	-0.6255			
(*)	**Footprint Lat**	39,5109 N	39,51180 N	39,51109 N	39,51018 N
(*)	**Footprint Lon**	9,65307 E	9,65185 E	9,65045 E	9,65163 E
(*)	**Footprint Lat**	39°30'654" N	39°30'708" N	39°30'665" N	39°30'610" N
(*)	**Footprint Lon**	9°39'184" E	9°39'111" E	9°39'027" E	9°39'097" E

A/C Data:

	Name	Note
(*)	**Latitude**	39,50175 N (39°30'105" N)
(*)	**Longitude**	9,61734 E (09°37'040" E)
(*)	**Magnetic Heading**	-2,20684 (rad/s)
(*)	**GPS Latitude**	39,50194 N (39°30'116" N)
(*)	**GPS Longitude**	9,61813 E (09°37'088" E)
(*)	**GPS Time**	07:28:49

Figure 18 illustrates the potential of UAS for ship detection, classification and identification. The image was acquired from an altitude well above 3,000m because the UAS was not allowed to fly bellow 3,000 meters. A lower altitude flight would have allowed the acquisition of images with better quality and the possibility to identify the target, and eventually some of the crew members.

Figure 18 – Ship (Spotter), TVC LIVE.

The SKY-Y information associated to the image in figure 18 is given next.

	Name	Note
(*)	FOM D/L	100%

On Board Computer Mission Data:

	Name	Note
(*)	**Longitude WGS 84**	09°39'151" E
(*)	**Latitude WGS 84**	39°30'712" N
(*)	**Altitude WGS 84**	0 m
(*)	**Az Position report**	1.464325
(*)	**El Position Report**	-0.257141

(*)	**Slant Range**	5211,82 m
(*)	**Distance On Ground**	4183,20 m

Sensor Data:

	Name	Description			
(*)	FOV Angle Value	0.44°			
(*)	Focal Length Value	459.992981 mm			
(*)	Focus Value	2000 m			
(*)	Video Out status	Spotter (LRTV)			
(*)	AZ position report	1.500758			
(*)	EL position report	-0.247841			
(*)	Footprint Lat	39,51154 N	39,51190 N	39,51190 N	39,51154 N
(*)	Footprint Lon	9,65283 E	9,65289 E	9,65230 E	9,65224 E
(*)	Footprint Lat	39°30'692" N	39°30'714" N	39°30'714" N	39°30'692" N
(*)	Footprint Lon	9°39'169" E	9°39'173" E	9°39'138" E	9°39'134" E

A/C Data:

	Name	Note
(*)	Latitude	39,50944 N (39°30'566" N)
(*)	Longitude	9,60389 E (9°36'233" E)
(*)	Magnetic Heading	-2,34453 (rad/s)
(*)	GPS Latitude	39,50911 N (39°30'546" N)
(*)	GPS Longitude	9,60380 E (9°36'228" E)
(*)	GPS Time	07:29:21

Figure 19 – Refugees (Spotter), LRTV LIVE.

The SKY-Y information associated to the image in figure 19 is given next.

	Name	Note
(*)	FOM D/L	100%

On Board Computer Mission Data:

	Name	Note
(*)	**Longitude WGS 84**	09°37'878" E
(*)	**Latitude WGS 84**	39°30'043" N
(*)	**Altitude WGS 84**	2 m
(*)	**Az Position report**	-100,36 deg
(*)	**El Position Report**	-48,20 deg
(*)	**Slant Range**	4067,03 m
(*)	**Distance On Ground**	2661,57 m

Sensor Data:

	Name	Note			
(*)	**FOV Angle Value**	0.44°			
(*)	**Focal Length Value**	459.99 mm			
(*)	**Focus Value**	2327.07 m			
(*)	**Video Out status**	SPOTTER (LRTV)			
(*)	**AZ position report**	-100,36 deg			
(*)	**EL position report**	-48,20 deg			
(*)	**Footprint Lat**	39,50072 N	39,50049 N	39,50064 N	39,50087 N
(*)	**Footprint Lon**	9,63104 E	9,63124 E	9,63155 E	9,63135 E
(*)	**Footprint Lat**	39°30'043" N	39°30'029" N	39°30'038" N	39°30'052" N
(*)	**Footprint Lon**	9°37'862" E	9°37'874" E	9°37'893" E	9°37'881" E

A/C Data:

	Name	Note
(*)	**Latitude**	39,51229 N (39°30'737" N)
(*)	**Longitude**	9,65851 E (09°39'510" E)
(*)	**Magnetic Heading**	-2,40372 (rad/s)
(*)	**GPS Latitude**	39,51203 N (39°30'721" N)
(*)	**GPS Longitude**	9,65864 E (09°39'518" E)
(*)	**GPS Time**	07:53:32

Figures 19 and 20 illustrate the UAS capability to detect people from high altitudes (well above 3,000m). This is an important capability to mitigate maritime piracy because it allows the detection of the crew members and any weapons they may carry. It is also useful to mitigate illegal immigration, drugs trafficking and smuggling. It could also be useful for counter-terrorism operations since it allows the detection of people and weapons. It should be noted that a lower altitude flight would provide a much better quality image with the potential to identify the crew members.

Figure 20 – Refugees (Spotter), LRTV LIVE.

The SKY-Y information associated to the image in figure 20 is given next.

	Name	Note
(*)	FOM D/L	100%

On Board Computer Mission Data:

	Name	Note
	Mode Selected	
(*)	**Longitude WGS 84**	09°37'755" E
(*)	**Latitude WGS 84**	39°30'369" N
(*)	**Altitude WGS 84**	2 m
(*)	**Az Position report**	-100,36 deg
(*)	**El Position Report**	-48,20 deg

(*)	**Slant Range**	4068,45 m
(*)	**Distance On Ground**	2672,45 m

Sensor Data:

	Name	Description			
(*)	**FOV Angle Value**	0.44°			
(*)	**Focal Length Value**	459.99 mm			
(*)	**Focus Value**	2327.07 m			
(*)	**Video Out status**	SPOTTER (LRTV)			
(*)	**AZ position report**	-100,36 deg			
(*)	**EL position report**	-48,20 deg			
(*)	**Footprint Lat**	39,50595 N	39,50578 N	39,50600 N	39,50617 N
(*)	**Footprint Lon**	9,62903 E	9,62932 E	9,62954 E	9,62926 E

A/C Data:

	Name	Note
(*)	**Latitude**	39,52402 N (39°31'441" N)
(*)	**Longitude**	9,64998 E (09°38'998" E)
(*)	**Magnetic Heading**	-2,39452 (rad/s)
(*)	**GPS Latitude**	39,52349 N (39°31'409" N)
(*)	**GPS Longitude**	9,65061 E (09°39'036" E)
(*)	**GPS Time**	07:54:02

5.4.3 – SKY-Y Operational Limitations

It should be noted that all the SKY-Y images presented in this report were acquired from a relatively high altitude between 3km and 5km due to the topography (e.g. high mountains) of Sardinia. The area between Decimomannu military airbase and Porto Corallo is a mountainous area as illustrated in figure 21. The Remote Control Station of the SKY-Y was based at Decimomannu airbase. In order to avoid any loss of communications between the SKY-Y Control Station and the SKY-Y, the SKY-Y was not allowed to fly bellow 3km. Most of the images presented in this report were acquired from an altitude well above 3km. In most operational missions, this kind of limitation does not exist. If the SKY-Y were allowed to fly at lower altitudes the resolution and quality of the images acquired would be significantly better. Flying at lower altitudes would allow better classification and even the identification of some targets.

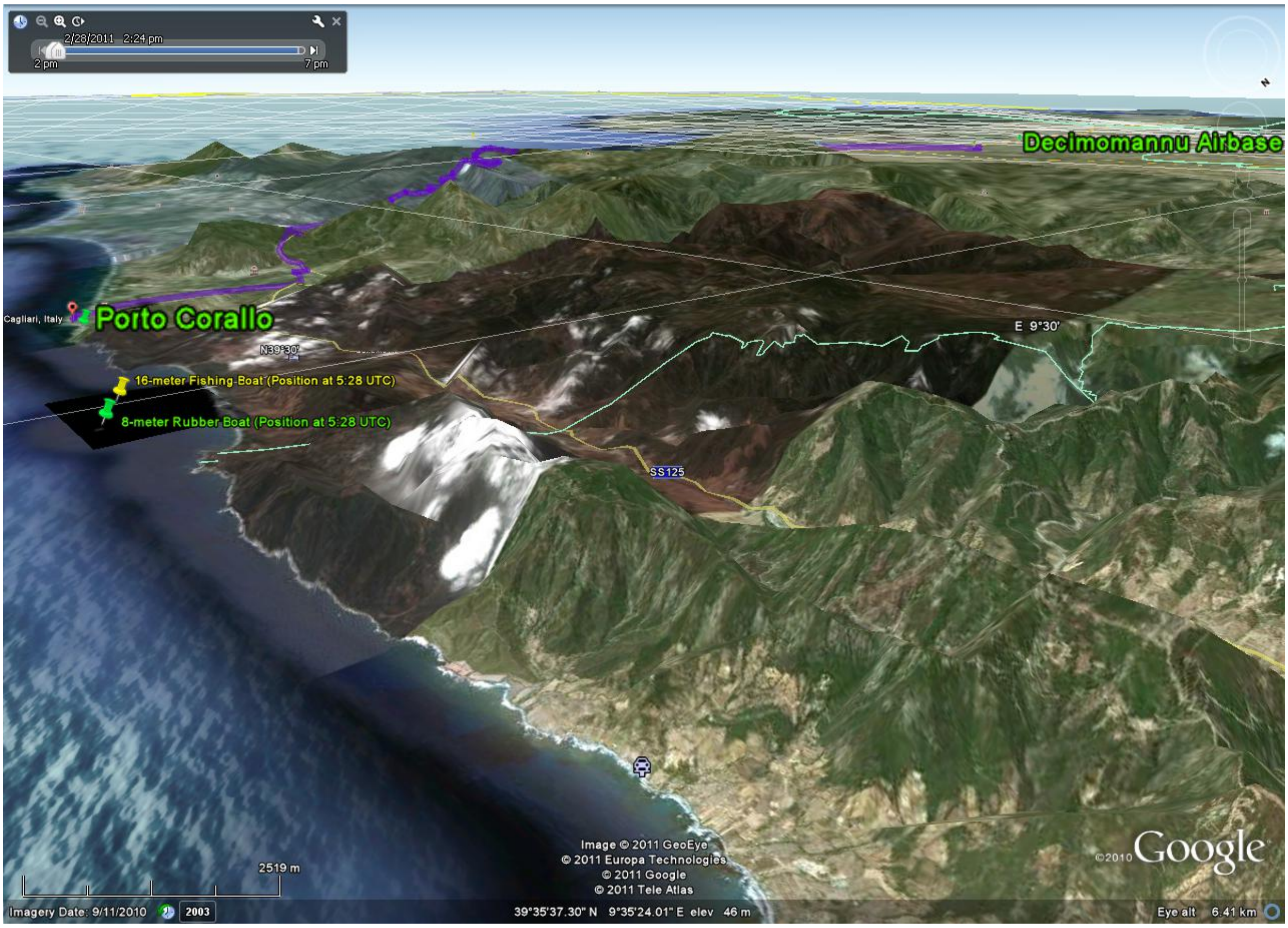

Figure 21 – Mountainous area between Decimomannu airbase and Porto Corallo. Since the SKY-Y Remote Control Station was based at Decimomannu airbase the SKY-Y was not allowed to fly bellow 3km.

5.5 – Quantitative Analysis of the Spaceborne SAR Image

In order to allow a quantitative analysis of the data, the spaceborne SAR image was calibrated using ESA's NEST software package, version 4B. The input was the SAR image acquired and the output was the Radiometric Calibration (Sigma Naught (σ°)) expressed in terms of intensity and in decibel (dB), the Radar Brightness (β°) and the Radiometric Normalisation (gamma naught (γ°)).

5.5.1 – TerraSAR-X-Spotlight, 29Oct.2010 (5:28 UTC), Porto Corallo, Sardinia-Italy.

Figure 22 illustrates the Intensity band of a subset of the TerraSAR-X-Spotlgiht image (29Oct.2010).

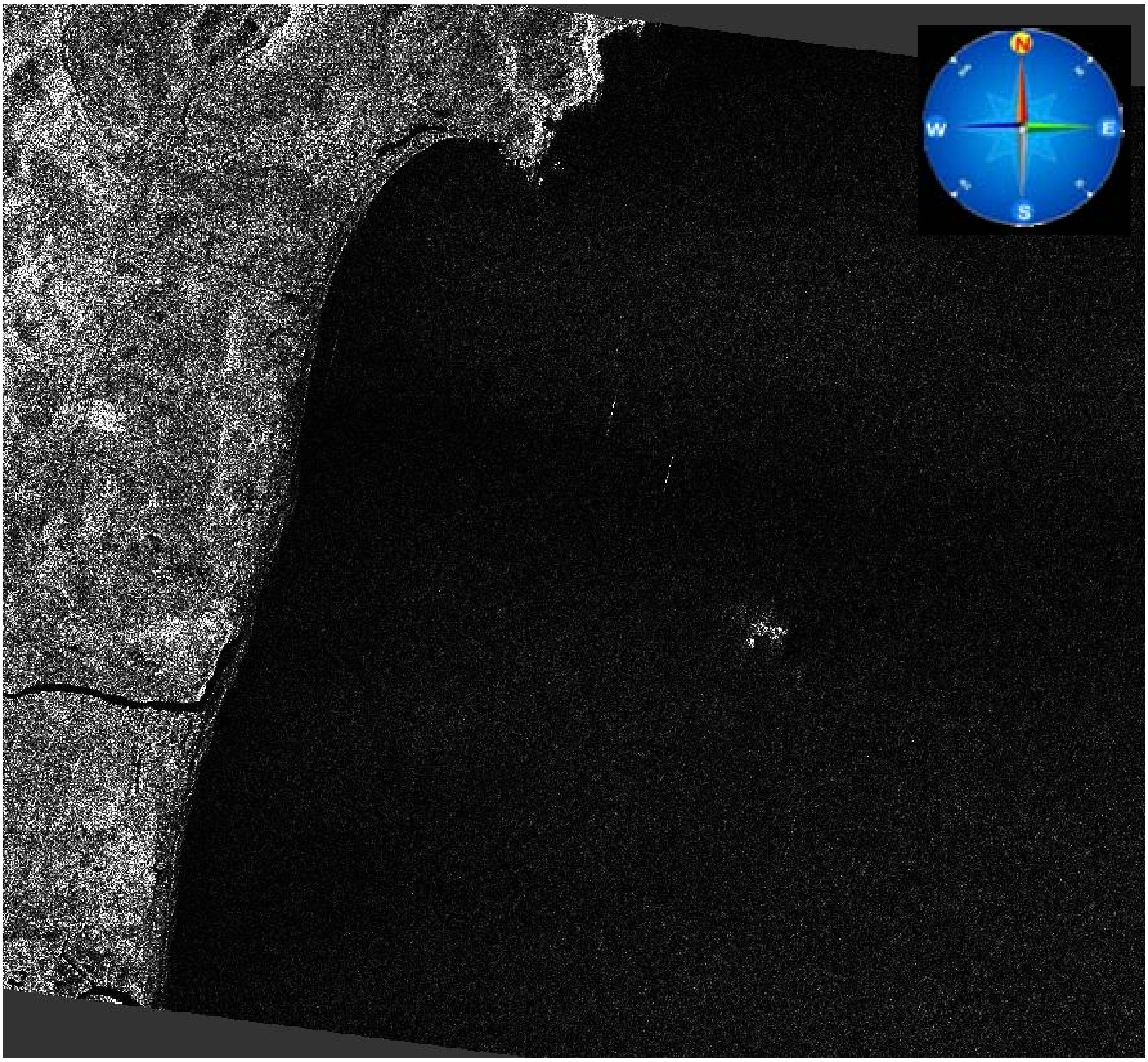

Figure 22 – TerraSAR-X-Spotlgiht image (29Oct.2010) - Intensity band.

Figure 23 illustrates the Sigma Naught Coefficient of the TerraSAR-X-Spotlgiht image (29Oct.2010) expressed in terms of intensity and decibel (dB).

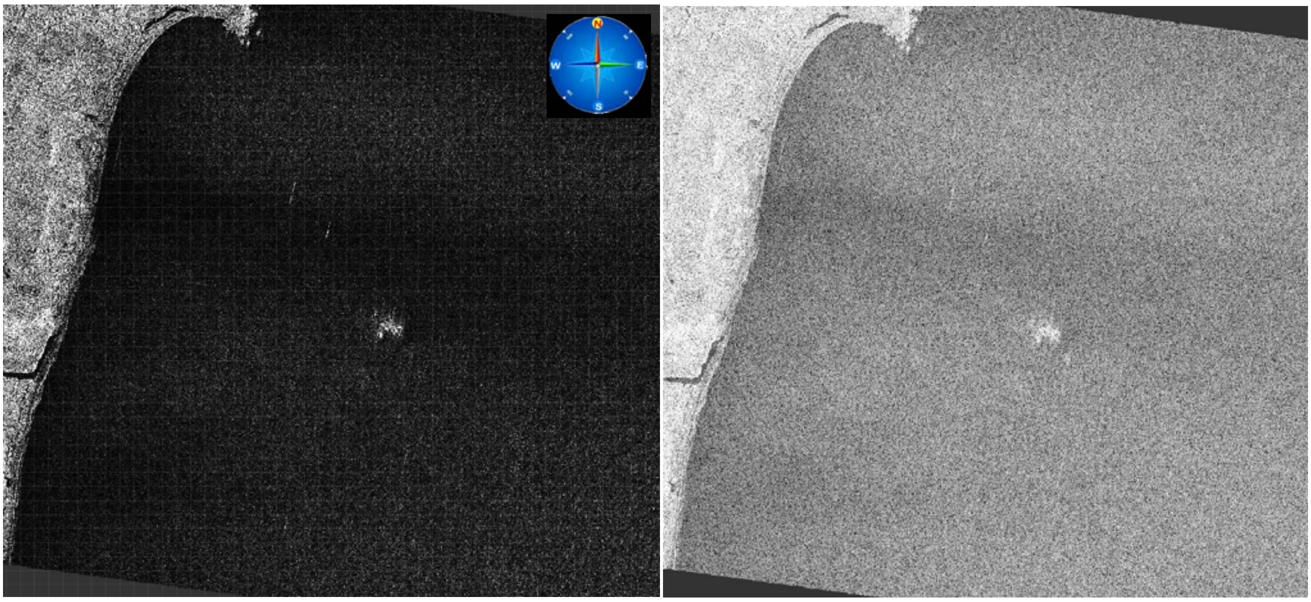

Figure 23 – TerraSAR-X-Spotlgiht image (29Oct.2010) - On the left, the Sigma Naught (σ°) (intensity) and on the right, the Sigma Naught (σ°) (dB).

Figure 24 illustrates the Radar Brightness (Beta Naught (β°)), and the radiometric normalisation (Gamma Naught (γ°)) of the TerraSAR-X-Spotlgiht image (29Oct.2010) expressed in dB.

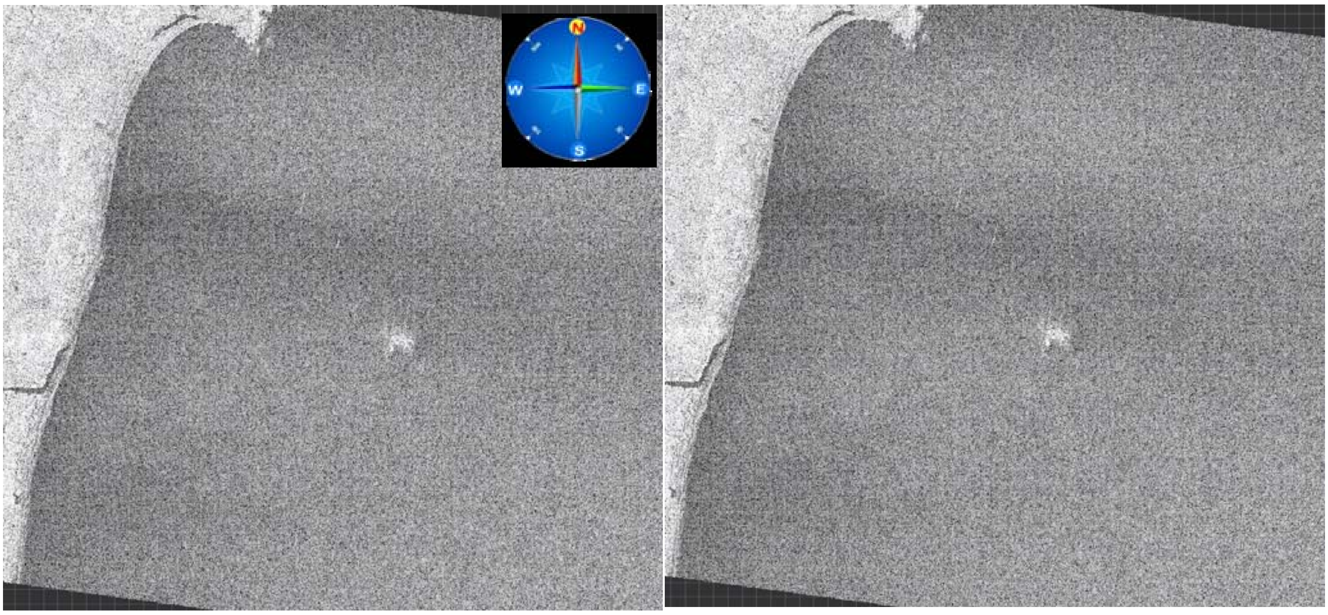

Figure 24 – TerraSAR-X-Spotlgiht image (29Oct.2010) - On the left, the Beta Naught (β°) and on the right, the Gamma Naught (γ°) (dB).

Figure 25 shows the Sigma Naught (σ°) in dB after some colour manipulation and the histogram of the Sigma Naught (σ°) image.

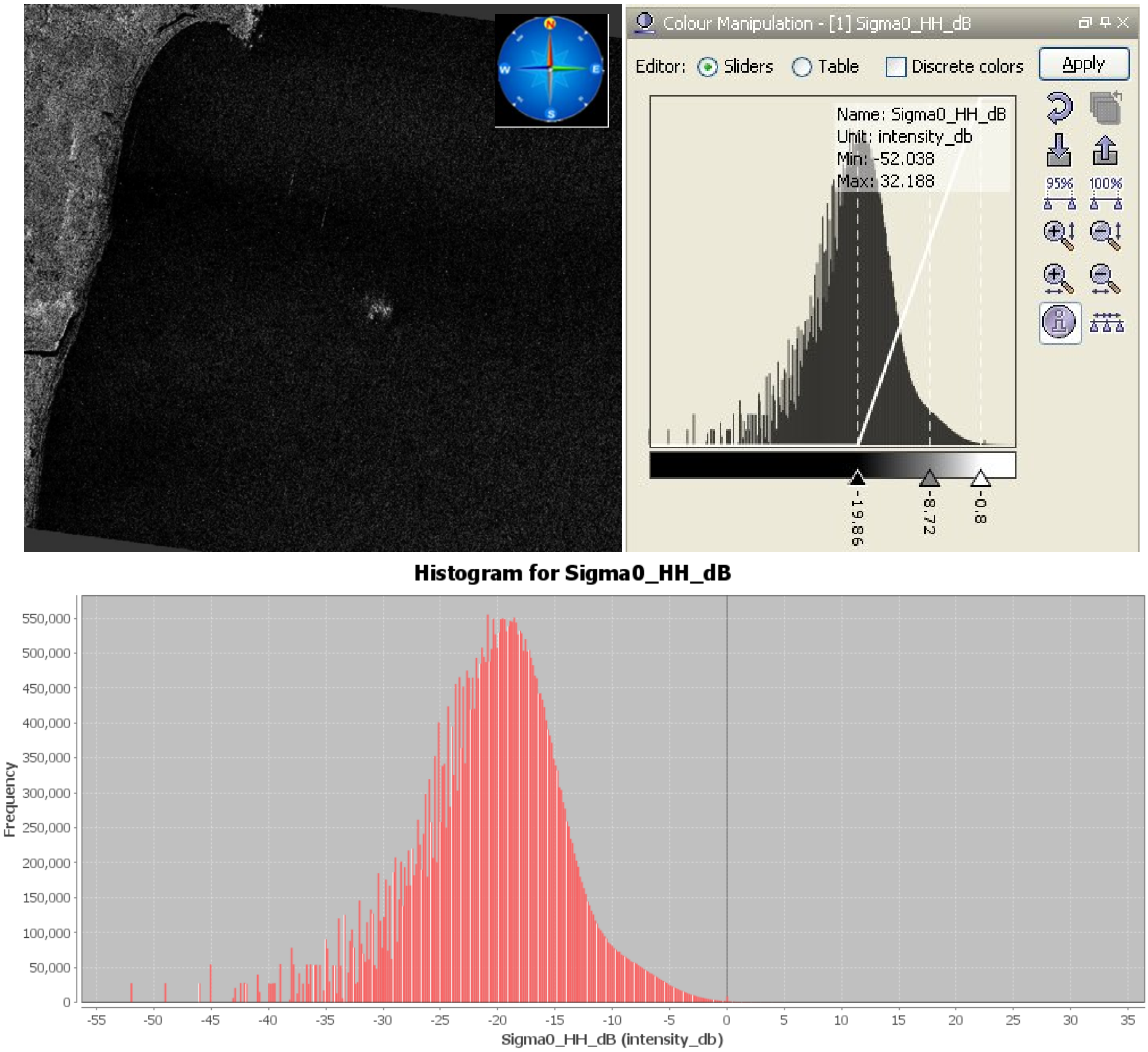

Figure 25 – TerraSAR-X-Spotlgiht image (29Oct.2010) - On the top left the Sigma Naught (σ°) after colour manipulation to enhance the targets and on the top right, the corresponding histogram. On the bottom, we can see the histogram of the image.

Table 8 gives the statistics of the Sigma Naught (σ°) TerraSAR-X-Spotlgiht image (29Oct.2010). The Sigma Naught (σ°) range from -52.0 dB up to 32.2 dB. The Mean value is -20.5 dB, the Median is -20.0 dB and the standard deviation is 6.4 dB.

Table 8 – Statistics of the TerraSAR-X-Spotlgiht image (17May2010) (05:27 UTC)

Statistics	Values	Unit
Only ROI-Mask pixels considered:	No	
Number of pixels total:	62373200	
Number of considered pixels:	44679677	
Ratio of considered pixels:	71.63%	
Minimum:	-52.037662506103516	intensity_db
Maximum:	32.18838119506836	intensity_db
Mean:	-20.526217424764447	intensity_db
Median:	-20.050240460889945	intensity_db
Std-Dev:	6.422167829350328	intensity_db
Coefficient of Variation:	-0.3128763388130881	intensity_db

Checking the radar backscattering coefficient of the targets (small boats) detected in section 1 (Fig. 25), we get values ranging from -9.1 dB up to -5.0 dB. The analysis of the Sigma Naught values (σ°) of the targets and the area around the targets shows a significant contrast.

5.6 – Summary of the Preliminary Analysis of the Spaceborne SAR Image

This experiment involved one spaceborne SAR image TerraSAR-X-Spotlight. One of the 2 boats deployed as targets was detected in the image. Table 9 summarises the characteristics of the SAR image acquired and the targets detected.

Table 9 – List of SAR Satellite Images acquired during the experiment and detected boats.

Date / Time	Place	Satellite / Mode	Ground Truth Data	Detected Boats
ITALY (Porto Corallo - Sardinia)				
29.Oct.2010 (AM)	Sardinia - Italy	TerraSAR-X / Spotlight	GPS/Photos/Movies	1 out of 2

Table 10 gives the minimum and maximum Sigma Naught (σ°) of the targets detected in each SAR image.

Table 10 – **M**inimum and maximum Sigma Naught (σ°) of the targets detected in each SAR image.

Date /Time UTC (LT)/Pass	Satellite / Image Mode / Polarisation	Sigma Naught (σ°) Min / Max
29.Oct.2010/5:28UTC(7:28AM LT)/ DES	TerraSAR-X / Spotlight / HH	-9.1dB / -5.0dB

The SAR signatures of the boats deployed were very weak. Some possible reasons to explain such weak signatures are the sea state, the wind speed, the incidence angle and the type and materials. Another possible reason is the processing at DLR.

6. – Preliminary Conclusions

The analysis of the results of this coupled UAS/Spaceborne SAR experiment shows a promising potential for the use of UAS for maritime surveillance. UAS can be integrated into the airborne building block of maritime surveillance systems to complement the existing assets, increase system performance and improve the overall maritime domain awareness. The main perceived maritime security and safety threats comprise piracy, terrorist and military threats, weapons proliferation/smuggling, drugs trafficking, illegal immigration, unlawful use of containers, attacks to critical infrastructures and illegal fishing. The main maritime security and safety gaps include a lack of technologies with the capability of detecting small targets (e.g. small boats), a lack of wide area and persistent maritime surveillance, a lack of coordination and information sharing, limited interoperability, a lack of containers security, a lack of persistent surveillance of critical infrastructures and early warning systems. Unmanned Aircraft Systems (UAS) are an emerging technology with strong potential to mitigate the above mentioned threats by filing in the main maritime security and safety gaps listed earlier. For instance, the wide range of potential applications of UAS to maritime surveillance includes, but is not limited to:

- — detection, classification and identification of small boats,
- — persistent maritime surveillance,
- — use as communications relays,
- — persistent surveillance of critical infrastructures,
- — early warning systems,
- — COMINT and ELINT collection, etc..

Table 11 illustrates the mapping of maritime security/safety threats vs gaps and summarises the main potential applications of UAS to maritime surveillance.

The above mentioned potential applications of UAS to the Maritime Domain will be addressed in turn in more detail next.

- — Detection, classification and identification of small boats – The capability of detecting, classifying and identifying small targets (e.g. small boats) is among the key technologies required to improve maritime domain awareness. This capability is critical to mitigate piracy, illegal immigration, drugs trafficking, weapons smuggling, illegal fishing, terrorism and critical infrastructure. Unmanned Aircraft Systems (UAS) provide this capability more efficiently and at a lower cost than any other existing technology.

- — Persistent maritime surveillance – With the continuous improvements of UAS technologies, such as platforms, sensors, collision avoidance systems, command and control systems, telecommunications, etc., UAS are increasing their autonomy, endurance and flexibility. These characteristics are very important for persistent maritime surveillance. UAS can be launched from land, ships, aircraft and technologies to launch UAS from submarines are currently under development. UAS have distinct advantages over other existing technologies for persistent maritime surveillance in terms of autonomy/endurance (the Global Surveyor has an autonomy of 1 week), cost (e.g. as the autonomy of UAS increases, the number of staff required to operate UAS decreases), risk (e.g. if the UAS crashes the crew is not at risk), flexibility (e.g. they can be launched from a ship reducing the time to reach potential threats), etc..

• – Communications relays – UAS are being used as communication relays, mainly in military context, but have the potential to play a similar role in Civil context in several situations, such as to replace satellite communications or as a redundant system over any location on Earth. The main advantages of using UAS as communication relays is that airborne communication relays mitigate kinetic and noise jamming threats to satellite communications uplinks by providing an alternative set of links either directly to surface-based terminals or to satellites beyond the range of threats. They are less susceptible to noise jamming threats than satellites because an adversary has to detect, geolocate and track the airborne asset and operate within line of sight of the receive antenna main beam.

• – Persistent surveillance of critical infrastructures – The security of critical infrastructures, such as nuclear power plants, refineries, ports, etc. requires persistent surveillance. UAS can play an important role in providing persistent surveillance over critical infrastructures and over a wide area around the critical infrastructure. Some advantages of UAS over other existing technologies, such as ground-based assets (e.g. video cameras, alarm systems, manned aircraft, etc.), comprise the security of the UAS (e.g. hardly can be damaged or switched off as any ground-based asset), the area covered by a UAS (e.g. it is larger than the area covered by any ground-based asset), the cost (e.g. UAS is cheaper than manned aircraft with similar capability), etc..

• – Early warning systems – UAS have the potential to be used as part of an integrated system of systems for early warning. A UAS can provide information about a given area at a fraction of the cost of alternative means. Formation flying of UAS can cover a wide maritime area. It is reasonable to assume that in a foreseeable future with the advent of UAS with increased autonomy, the operations cost of UAS will likely decrease, making them increasingly more attractive.

• – COMINT and ELINT collection – SIGNal INTelligence (SIGNINT) can be divided into two categories, namely COMINT and ELINT. COMINT stands for Communication Intelligence and ELINT for Electronic Intelligence. Collection of COMINT is passive. Exploitation of COMINT requires a human operator, which implies COMINT UAS are suitable for COMINT and ELINT collection in different scenarios,

The relatively reduced amount of data collected and analysed during this experiment and the lessons learned do not allow drawing final conclusions about the feasibility of using Unmanned Aerial Systems (UAS) for maritime surveillance. However, this experiment allowed hands-on experience with UAS technologies and significantly improved the awareness for its applications to maritime surveillance and related issues involved, including its potential, the feasibility, as well as the limiting and enabling factors. These different aspects will now be analysed in turn in the next sections.

Table 11 illustrates the mapping of the main maritime security threats and gaps, as well as the main priorities in terms of the different technologies involved in maritime surveillance. For each maritime threat, the technologies required to fill in each gap is indicated and its priority is expressed in a range of numbers (1 to 3, 1 = Maximum Priority, 2 = Medium Priority, 3 = Low Priority) and colours (Red = Maximum Priority, Orange = Medium Priority, Green = Low Priority). The main technologies involved in maritime surveillance are listed on the bottom of figure 4 and are reproduced here for convenience of the reader: 1.- Reporting Systems, 2.- Sensors, 3.- Platforms, 4.- Communications, 5.- Data Fusion & Sharing, 6.- Intelligence and 7.- Databases. For example, the mitigation of the main threat Piracy requires filling in several maritime security gaps (e.g. lack of persistent surveillance, lack of wide-are maritime surveillance, lack of small boat detection, lack of Early Warning Systems, and lack of Information Sharing with maximum priority (1- Red) and among the required technologies listed are UAS, LTAAV, GEO-HR, etc. Concerning the remaining two gaps (Limited Interoperability and Containers Security) they are less relevant to mitigate Piracy, hence the priority for Limited Interoperability is 2-Orange and for Containers Security is 3- Green.

Table 11 – The Main Maritime Security and Safety Threats vs Gaps and the technologies that can be used to mitigate them.

Maritime Security Main Threats / Gaps

Gaps→ / ↓ Threats	Lack of Risk Assessment Capability	Lack of Persistent Surveillance	Lack of Wide-Area surveillance	Lack of Small Boat Detection	Lack of Early Warning Systems	Lack of Information Sharing	Limited Interoperability	Lack of Containers Security
• Piracy	UAS, LTAV,GEO-HR + ...	UAS, LTAV,GEO-HR + ...	SAR, GEO-HR + ...	UAS, USV, LTAV + ...	UAS, LTAV, + ...	Coordination & Sharing + ...	Interoperabilty Optimisation + ...	
	1, 2, 3, 5, 6, 7	1, 2, 3, 5, 6, 7	1, 2, 3, 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	1,2,3,4,5,6,7
• Terrorism	UAS, LTAV,GEO-HR + ...	UAS, LTAV, GEO-HR + ...	SAR, AIS GEO-HR + ...	UAS, USV, LTAV + ...	Intelligence + ...	Inteligence + ...	Interoperabilty Optimisation + ...	Intelligence + ...
	1, 2, 3, 5, 6, 7	1, 2, 3, 5, 6	1, 2, 3, 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	1,2,3,4,5,6,7
• Weapons of Mass Destruction Smuggling	UAS, LTAV,GEO-HR + ...	UAS, LTAV,GEO-HR + ...	SAR, AIS + ...	UAS, USV, LTAV + ...	Intelligence + ...	Inteligence + ...	Intelligence + ...	Intelligence + ...
	1, 2, 3, 5, 6, 7	1, 2, 3, 5, 6	1, 2, 3, 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	1,2,3,4,5,6,7
• Drugs Trafficking	UAS, LTAV,GEO-HR + ...	UAS, LTAV,GEO-HR + ...	SAR, AIS + ...	UAS, USV, LTAV + ...	Intelligence + ...	Inteligence + ...	Intelligence + ...	Intelligence + ...
	1, 2, 3, 5, 6, 7	1, 2, 3, 5, 6	1, 2, 3, 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	1,2,3,4,5,6,7
• Illegal Immigration	UAS, LTAV,GEO-HR + ...	UAS, LTAV,GEO-HR + ...	SAR, AIS + ...	UAS, USV, LTAV + ...	Intelligence + ...	Inteligence + ...	Intelligence + ...	Intelligence + ...
	1, 2, 3, 5, 6, 7	1, 2, 3, 5, 6	1, 2, 3, 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	1,2,3,4,5,6,7
• Critical Infrastructure Security	UAS, LTAV,GEO-HR + ...	UAS, LTAV,GEO-HR + ...	SAR, AIS + ...	UAS, USV, LTAV + ...	+ ...	Inteligence + ...	Intelligence + ...	Intelligence + ...
	1, 2, 3, 5, 6, 7	1,2, 3, 6	1, 2, 3, 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	1,2,3,4,5,6,7
• Illegal Fishing	UAS, LTAV,GEO-HR + ...	AIS+SAR, UAS,LTAV+ ...	SAR,AIS, GEO-HR+ ...	UAS, USV, LTAV + ...	Intelligence + ...	Inteligence + ...	Intelligence + ...	
	1, 2, 3, 5, 6, 7	1, 2, 3, 5, 7	1, 2, 3, 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	
• Unlawful Use of Containers (Security)	UAS, LTAV,GEO-HR + ...	GPS Tracking + ...			Intelligence + ...	Inteligence + ...		GPS, Intrusion Detection, Seal
	1, 2, 3, 5, 6, 7	4, 6, 7	1, 2, 3, 5, 6	1, 2,3	1,2,3,4,5,6	4,5,6,7	1,2,3,4,5,6,7	1,2,3,4,5,6,7

(-)	Priority	(+)	Not Relevant

SURVEILLANCE TECHNOLOGIES	1- Reporting Systems	2.-Sensors	3.-Platforms	4.- Communications	5.- Data Fusion & Sharing	6.-Intelligence	7.-Databases

6.1 – Hands-on experience with UAS technologies and its applications to maritime surveillance

This coupled UAS/Spaceborne SAR campaign was a unique opportunity to acquire hands–on experience with UAS technologies and learn about the main issues related to its applications to maritime surveillance. From the planning phase up to the execution of the UAS flight and landing there are several factors that need to be carefully analysed and taken into account. A summary of the main issues identified in this experiment is given next.

1.- Selection of the Experiment Area /Authorisation to Fly – For the time being UAS can only be flown in restricted areas usually under control of national authorities, often the military. This is due to the risks that a UAS can pose to human life and property. In the present case, an area under the authority of the Italian Air Force in Porto Corallo, Sardinia-Italy, was used. The authorisation to fly was easy to obtain because the selected area is under the authority of the Italian Air Force and Alenia Aeronautica cooperates with the Italian Airforce in several UAS projects. Also the Italian Air Force already knows the main characteristics of the SKY-Y. For areas under the jurisdiction of the civilian authorities the authorisation to fly would have required a lengthy bureaucratic process and would have taken a lot longer to obtain. Figure 26 indicates the area of the experiment (in Green), as well as the Decimomannu airbase and the UAS flight plan.

2.- UAS Communications Issues – The SKY-Y used in the experiment was not equipped with a Satcom antenna. Hence, it required Line-Of-Sight (LOS) operation. Since the military airbase from where the SKY-Y took-off (Decimomannu airbase) is located about 80km from Porto Corallo where the experiment took place and the two locations are separated by mountains, in order to keep LOS communications with the Remote Control Station the UAS was not allowed to fly bellow an altitude of 3km. Figure 21 illustrates the mountains between Decimomannu and Porto Corallo. The LOS communications also limit the range of operation of the UAS. Satcom communications is essential for maritime surveillance. LOS implies limited range of operation and often also limit the minimum altitude of flight.

3.- Synthetic Aperture Radar (SAR) – The SKY-Y used in the experiment had no SAR sensor. However, the installation of a SAR sensor was already planned. A SAR sensor is essential for maritime surveillance since it allows 24/7 operations regardless of the weather conditions. The main limiting factor that can prevent the UAS from flying is the wind speed.

4.- Automatic Identification System (AIS) Receiver – The SKY-Y used in the experiment was not equipped with an AIS receiver. For maritime surveillance operations an AIS receiver is a very important tool since it allows the automatic identification of most ships allowing the UAS to concentrate on non-identified ships. Alenia Aeronautic has plans to install an AIS receiver on their UAS for maritime surveillance.

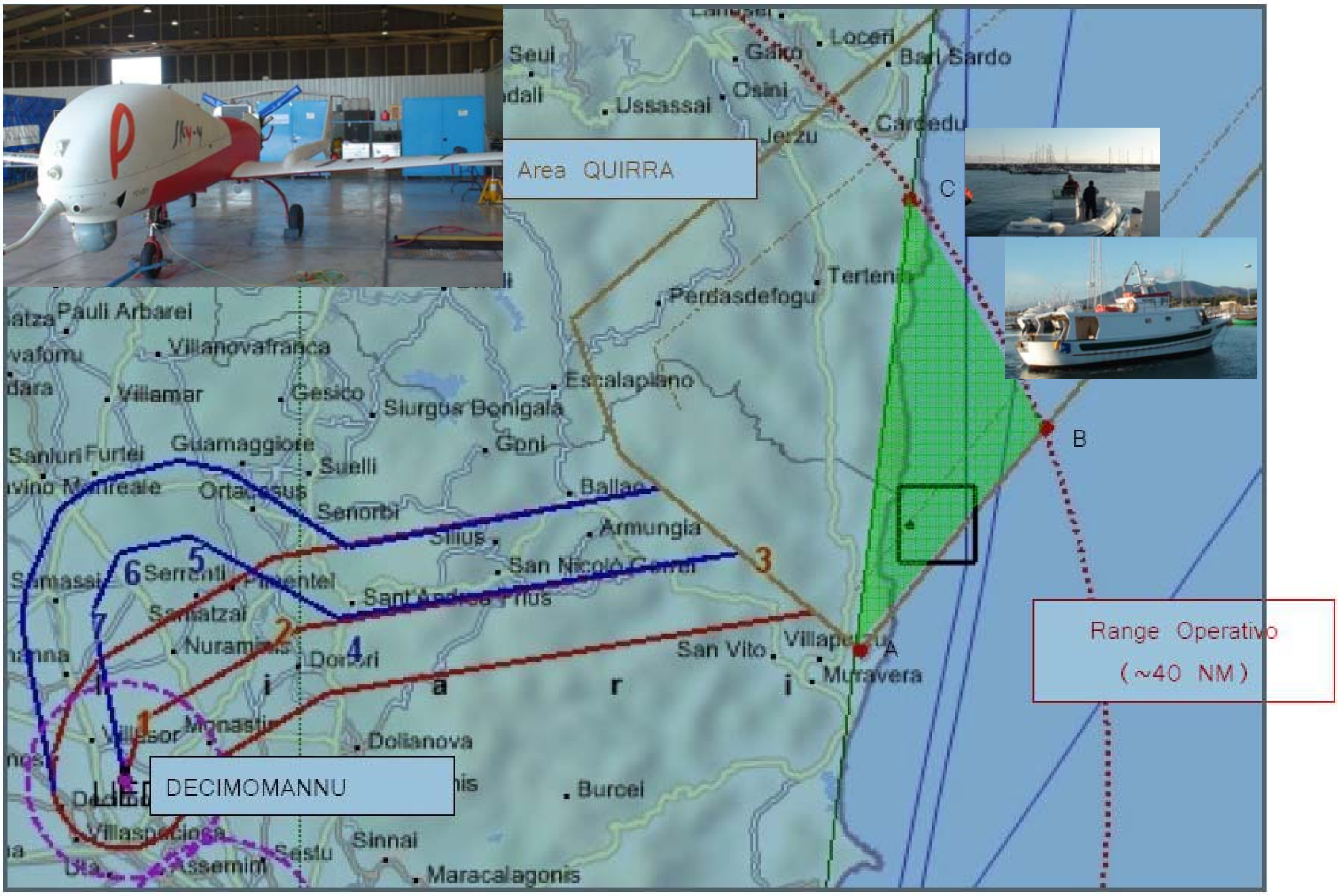

Figure 26 – Area of the experiment in Green. Decimomannu militaUAS flight plan are also indicated.

6.2 – Potential of UAS for Maritime Surveillance

UAS technologies are relatively recent and involve a wide range of fields spanning from aeronautics and sensors technologies to satellite communications and other engineering disciplines. Innovations in each of the fields involved are emerging by the day. UAS still have a long way to go before they become mature and their use fully operational. For the time being UAS are mainly used for military applications. However, a large number of non-military UAS applications have been identified by stakeholders and there are several studies and demonstration flights foreseen for the near future.

Maritime surveillance is one of the most challenging and promising fields of application of UAS. The challenges are due to the very demanding conditions under which the UAS must operate over sea and the requirements for safe operation.

The present UAS experiment has unveiled some of the potential of UAS for maritime surveillance. The UAS tests performed during this experiment include:

1 – Detection of a Small rubber Boat and a Fishing Ship,
2 – Tracking of a Small Boat and a Fishing Ship,
3 – Classification of a Small Boat and a Fishing Ship,
4 – Identification of a Small Boat and a Fishing Ship,
5 – Detection and Tracking of People on the Beach,

Despite the operational requirement that prevented the UAS from flying bellow 3km, the experiment has confirmed the capability of UAS for small boat detection, tracking and classification, as well as the capability for people detection and tracking. Concerning the identification of the targets, the characteristics of the images acquired during this mission suggest that flying at lower altitudes the UAS images would allow the identification of the targets. The UAS images can be seen from Figure 15 to 20.

6.2.1 – Advantages of UAS for maritime Surveillance

Some of the advantages of using UAS for maritime surveillance have been described in the literature and are summarized bellow.

- 1.- One potential benefit of UAS is that they could fill in a gap in current maritime surveillance by improving coverage.
- 2.- The range of UAS is a significant asset when compared to border agents on patrol or stationary surveillance equipment.
- 3.- Eletro-Optical InfraRed (EOIR) sensors (cameras) can identify small size objects from very high altitudes (high resolution).
- 4.- UAS can provide precise and near-real-time imagery to a ground control operator, who would then disseminate that information so that informed decisions regarding the deployment of border patrol agents can be made quickly.
- 5.- Long endurance UAS used along the border can fly for more than 30 hours up to several days without having to refuel, compared with manned helicopter’s average flight time of just over 2 hours.
- 6.- The ability of UAS to loiter for prolonged periods of time has important operational advantages over manned aircraft.
- 7.- The longer flight times of UAS means that sustained coverage over a previously exposed area may improve maritime security.
- 8.- The range of UAVs is a significant asset when compared to border agents on patrol or stationary surveillance equipment. Nevertheless, the extended range and endurance of UAVs may lessen the burdens on human resources at the borders.
- 9.- UAS accidents do not risk the lives of pilots, as do the helicopters and aircraft currently used by Coast Guards for border patrolling.

6.2.2 – Possible Drawbacks of using UAS for maritime Surveillance

UAS also have disadvantages; some of them are briefly described next.

● 1.- There have been concerns regarding the high accident rate of UAS, which can be multiple times higher than that of manned aircraft. Because UAS technology is still evolving, there is less redundancy built into the operating system of UAS than of manned aircraft and until redundant systems are perfected mishap rates are expected to remain high.

● 2.- If control systems fail in a manned aircraft, a well-trained pilot is better positioned to find the source of the problem because of his/her physical proximity. If a UAS encountered a similar system failure, or if a UAS landing was attempted during difficult weather conditions, the ground control pilot would be at a disadvantage because he or she is removed from the event. Unlike a manned pilot, the remote pilot would not be able to assess important sensory information such as wind speed.

● 3.- Inclement weather conditions can also impinge on a UAS surveillance capability, especially UAS equipped with only an EO camera and Forward Looking Infrared Radar (FLIR), because cloudy conditions and high humidity climates can distort the imagery produced by EO and FLIR equipment. The effects of extreme climatic or atmospheric conditions on sensors reportedly can be mitigated with the outfit of one synthetic aperture radar (SAR) system and a moving target indicator (MTI) radar. However, adding SAR and MTI to a UAS platform would increase the costs associated with using UAS.

● 4.- Depending on the type of UAS, the costs of operating a UAS can be higher than the costs of operating a manned aircraft. This is because some types of UAS require a significant amount of logistical support and specialized operator and maintenance training. Operating one UAS may require a crew of up to 20 support personnel. The high comparative costs of operating some sophisticated types of UAS may be offset somewhat by their comparatively lower unit costs.

6.3 – Main Limiting Factors Preventing the Use of UAS

Several pre-requisites must be satisfied to render the UAS a viable, cost-effective and regulated alternative to existing resources. Major civil and commercial market barriers include:

- — Single European Sky
- — Sense and Avoid technologies
- — Command and Control Technologies Reliability
- — Communications (Bandwidth, LOS, BLOS)
- — Lack of airspace regulation that covers all types of UAV systems (encompassing ‘sense and avoid’, airspace integration and airworthiness issues)
- — Affordability - price and customization issues (e.g. commercial off-the-shelf, open modular architecture)
- — Lack of efforts to establish joint customer requirements (although this is gradually changing)
- — Liability for civil operation
- — Capacity for payload flexibility
- — Lack of sufficient secure non-military frequencies for civil operation
- — Perceived reliability (e.g. vehicle attrition rate vs. manned aircraft)
- — Operator training issues
- — Recognition/customer perception of the UAV market
- — Technology developments for multi-mission capability

6.4 – UAS Key Enabling Technologies

Figure 27 illustrates the components of a typical UAV System, showing some of the capabilities needed and the enabling technologies required for performing a given mission. Any UAV mission involves many capabilities and technologies. Due to the depicted system complexity the main key players, such as the US Department of Defense (DoD) and other agencies have started to use the term Unmanned Aerial System (UAS) in place of UAV.

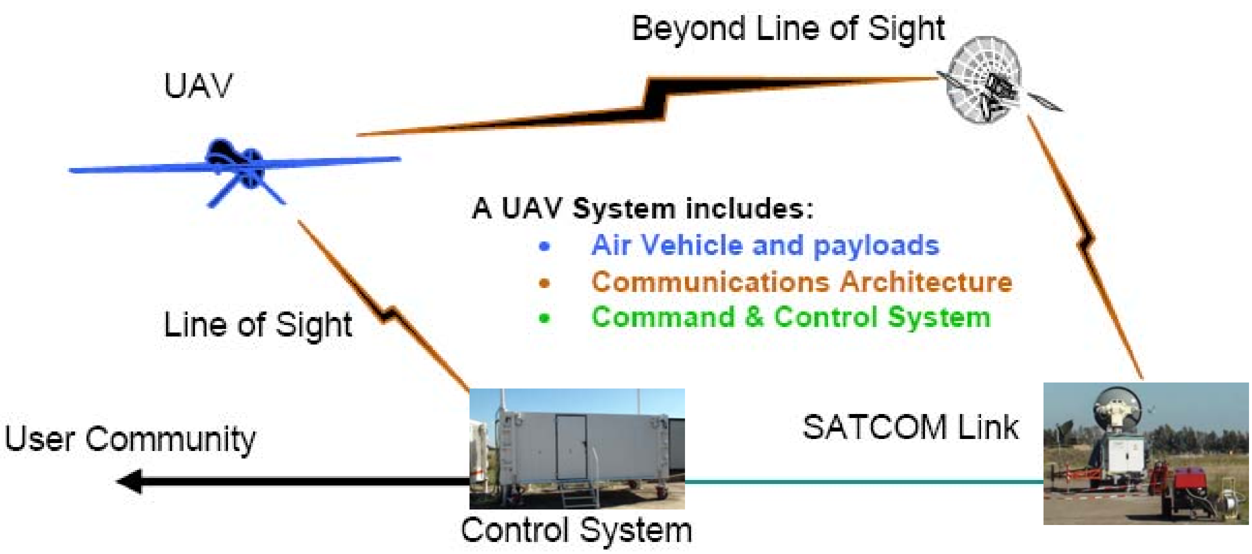

Figure 27 – Unmanned Aerial Vehicle System. Enabled by: Autonomous Mission Management, Reliable Flight Systems, Navigation Accurate Systems, Terrain Avoidance, Power and Propulsion

Some UAS key enabling technologies are listed below.

- — Autonomous Mission Management
- — Collision Avoidance
- — Intelligent System Health Monitoring
- — Reliable Flight Systems
- — Sophisticated Contingency Management
- — Intelligent Data Handling and Processing
- — Over-the-Horizon Communication
- — Network-Centric Communication
- — Open Architecture
- — Power and Propulsion
- — Navigation Accurate System Technology
- — Enhanced Structures

Table 12 gives a more detailed description of other critical technologies for emerging autonomous UAV systems both civil and military. Most of the technologies mentioned in Table 12 apply both to civil and military UAV systems.

Table 12 – Key Enabling Technologies (from SG/75 study on autonomous systems).

Critical Technologies	
Decision Making Software: • Fuzzy-based decision making • Knowledge-based system • Case-based reasoning • Self-learning techniques • Decision tree evaluation • Reasoning/Inferring • Probabilistic/stochastic reasoning Prediction Algorithms: • Predictive path/intent algorithms • Short reaction algorithm • Effectiveness evaluation Status Assessment Software: • Internal status analysis • Self-orientation Situation Analysis Software: • Situation analysis • Environmental analysis • External status analysis Modelling Software: • Air vehicle modelling algorithms • Sensor modelling algorithms • Scenario generation • Threat system modeling • Attack simulation • Mission success optimisation model • Simulation	Sensor Processing Software: • Sensor fusion • Area of interest identification • Automatic target recognition Adaptive and Self-learning Systems: • Failure self-compensation Attack Planning Software: • Attack plans and tactical alternatives • Plan change impact identification Weapon Engagement Procedure Software: • Weapon engagement algorithms Mission Plan Update Software: • Route planning system • Payload plan management system • Mission Success Optimisation model Path Optimisation Software: • Optimal trajectory planning • Path Optimisation System Targeting Software: • Target tracking • Target prioritisation Platform Technologies: • Obstacle detection and avoidance (airborne) • Obstacle detection and avoidance (ground) • Improved autopilot • Speech recognition

Figure 28 summarises system element designs needed to transition from current to next-generation autonomous UAV systems for civilian and military UAS.

Platforms	• Unreliable	• Safe, reliable
	• Short duration	• Long endurance
	• Vulnerable	• Survivable
	• Restricted airspace	• Controlled airspace
	• Single mission	• Multi-mission
Payloads	• Sensors only	• Weapons and sensors
Onboard Processing	• Vehicle and payload management	• Mission and contingency management
	• Signal processing	• Data Fusion; ATR
Communications	• Stovepipe	• Interoperable, net capable
	• Jam resistant	• Robust; secure; anti-jam
Mission Control	• Operator intensive	• Autonomous; intuitive HSI
	• Pre-planned	• Adaptive
	• Single vehicle	• Coordinated multi-vehicle
Support and Training	• Unique	• Common autonomic logistics

Figure 28 – System Element Designs Needed to Transition from Current to Next-Generation Autonomous UAV Systems.

These new paradigms are a combination of system attributes and technological capabilities. For instance, the data fusion, secure anti-jam, and coordinated multi-vehicle control require technological development as well as specific system development to bring full maturity to unmanned systems.

Finally, very small Micro UAVs (MAVs) and relatively large, sophisticated UCAV systems are examples of the range of UAVs that are applying the new platforms, payloads, onboard processing, communications, etc. to create next generation automated UAVs. It is with these new platforms, payloads, etc. that both UCAVs and MAV will be able to address similar operational challenges including:

- — **Mixed operation with other assets**:
  - Deconfliction, collision avoidance, C4I integration.
- — **Operation over populated areas**:
  - Safety issues.
- — **Need to reduce reliance on communications**:
  - UCAV – countermeasures.
  - MAV – limited size and power.
  - Limited line of sight environment.
- — **Need a fully integrated system**:
  - MAV propulsion/power generation still critical.
  - Operator machine interface critical.
  - All weather operations.
  - Survivability.

6.5 – Mission Readiness

6.5.1 – Mission Readiness Summary

This section summarises civil UAV mission readiness. The purpose of Mission Readiness is to assess the readiness status of the different technologies involved in UAS. In the present case this civil UAV mission readiness based on technology maturation forecasts that meet or exceed the desired, or required, capabilities identified by the user community.

Figure 29 summarises the mission readiness time forecasts for the different technologies. The technologies annotated with an asterisk (*) are shown within the figure with maturation forecasts based on development targets expressed in the US Department of Defences' UAV Roadmap document.

The purpose of the chart is to be able to identify when the capability to fly a particular mission can be expected as a function of time. The left-most end is the least probable and the right end the most probable timeframe.

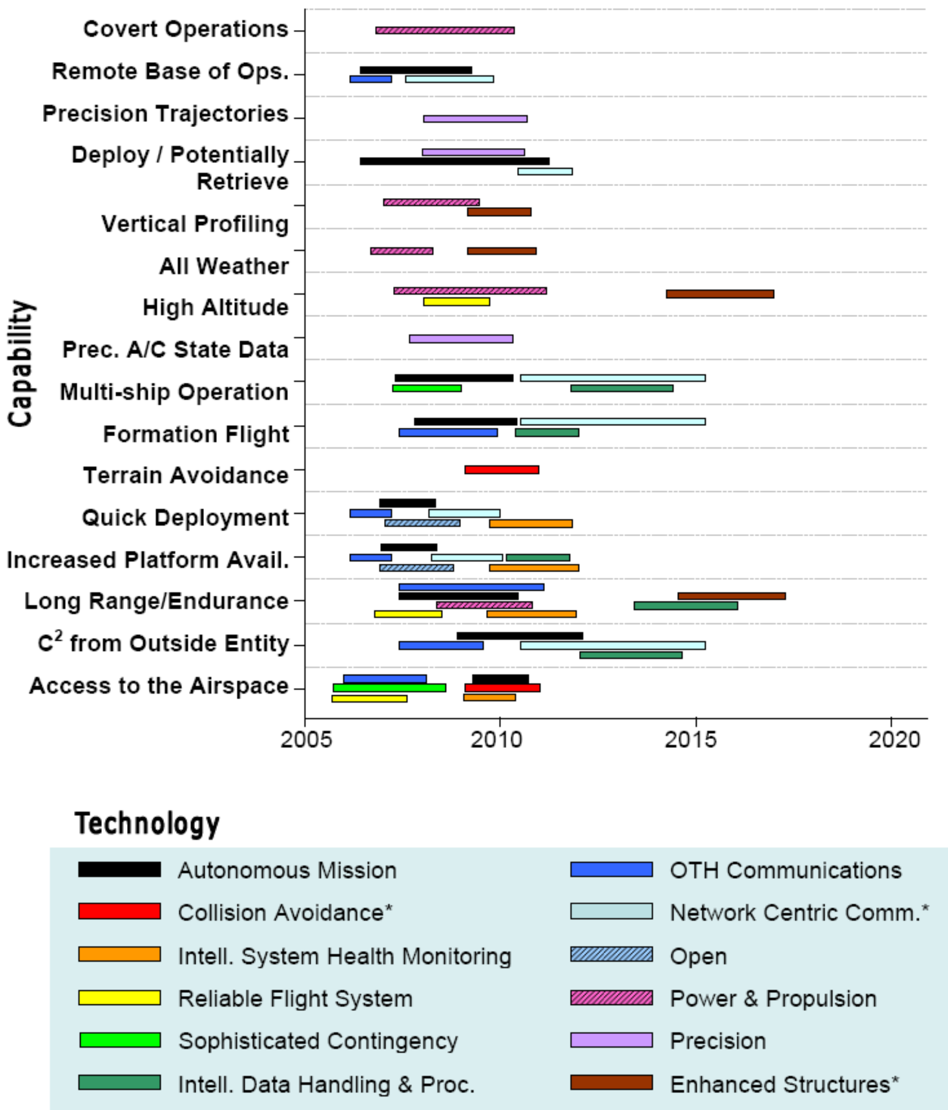

Figure 29 - Technology Maturation Summaries in Terms of Mission-Derived Capabilities.

6.6 – Small Boat Detection in SAR Satellite Imagery

The use of spaceborne SAR imagery for small boat detection requires additional small boat detection experiments under different conditions using different methods. It is not possible to draw final conclusions based on a limited number of small boat detection experiments, which are not representative of the multiple possible scenarios.

6.7 – Limitations of current State-of-the-Art SAR Satellite technology

The main limitations of current State-of-the-Art spaceborne SAR imagery for maritime surveillance, in particular aimed at small boat detection, are:

1. - SAR satellites repeat cycles do not allow the coverage of the same area at the required time intervals. Constellations of SAR satellites could be a solution.

2. - The conflict between resolution and image swath. High resolution is required to detect small boats. However, the high resolution images have small swaths. Maritime surveillance with high resolution images would require a large number of images to cover wide maritime areas, which is very expensive and for the time being technically not feasible. Intelligence data can play an important role by indicating an approximate position of suspicious non cooperative targets, therefore reducing the surveillance area, which can then be imaged using high resolution images.

3.- Spaceborne high resolution SAR imagery acquisition times are long enough to allow significant motion of the target during the acquisition time degrading the quality of the image. Further research efforts are needed to develop new sensors and platforms. As far as sensors are concerned, shorter integration times are needed to prevent the blurring effect caused by the motion of the targets. Regarding the platforms, more platforms are needed to allow lower repeat cycles and improved coverage.

7. – Plans for Future Work

The controlled experiments carried out by the EC-JRC together with Alenia Aeronautica in Sardinia-Italy comprised the deployment of a UAS (SKY-Y), one small 8-meter rubber boat and a 16-meter fishing vessel. A TerraSAR-X-Spotlight image was acquired and several EOIR images collected by the SKY-Y. The experiment unveiled the potential of UAS for maritime surveillance, in particular for detection, tracking, classification and possible identification of small targets. The UAS was able to detect, track and classify small targets, such as small boats and people. For low UAS altitude flights identification may be possible in some cases. The small 8-meter rubber boat was not detected in the spaceborne SAR image.

The small boat detection trials carried out by the JRC were very successful since most small boats deployed during the experiments were detected in different sea states, wind speeds and geographical locations. The several small boat detection campaigns conducted by the EC-JRC seem to suggest that the probability of detection of small boats in spaceborne SAR images strongly depends on factors, such as the sea state, the wind speed, the type of boat (shape and materials), the weather conditions, etc.. The results of the experiments conducted thus far are no enough to draw final conclusions about the feasibility of using spaceborne SAR imagery for small boat detection. However, the experiments have an overall positive outcome because they indicate that under suitable sea state and wind speed conditions it is possible to detect small boats using spaceborne SAR. The estimation of the probability of detection of small boats in spaceborne SAR images requires a large number of experiments under different circumstances (e.g. sea state, wind speed, characteristics of the targets, image type and mode, etc.).

Future plans include additional UAS experiments to asses its potential for maritime surveillance.

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REFERENCES

[1] Alenia Aeronautica: "UAV: Alenia FFP Proposal for Unmanned Aerial Vehicle (UAV) flight to collect Ground Truth data during a Maritime Surveillance Campaign and demonstrate UAV capabilities for Maritime Surveillance.", 2010.

[2] – Cheryl Yuhas, Suborbital Science Program Manager NASA Science Mission Directorate, "Earth Observations and the Role of UAVs: A Capabilities Assessment, Version 1.1", Civil UAV Assessment Team, http://www.nasa.gov/centers/dryden/research/civuav/index.html, August 2006.

[3] – Document NIAG (SG/75) NATO Industrial Advisory Group, Study Group 75 Pre-Feasibility Study on UAV Autonomous Operations, 2004.

[4] – United States Department of Defence (DoD) Directive 5000.1, "The Defense Acquisition System" and DoD Instruction 5000.2, "Operation of the Defense Acquisition System".

[5] – Mr. James Ramage ; Mr. Massimo Avalle ; Dr. Erik Berglund ; Dr. Luigi Crovella ; Mr. Robert Frampton ; Dr. Uwe Krogmann ; Mr. Christian Ravat ; Mr. Mike Robinson ; Dr. Axel Schulte ; Dr. Scott Wood, "RTO-TR-SCI-118 - Automation Technologies and Application Considerations for Highly Integrated Mission Systems", RTO-TR-SCI-118 AC/323(SCI-118)TP/204, January 2009.

[6] Victor M.G. Silva, Gilles Jurquet, Gabriel Marchalot, Maria T.G. Calzado, Txema Soroa, Juan Sancho, Adam Koubek, Harm Greidanus and Claudio Savarino, "Wide Maritime Area Airborne Surveillance (WIMA^{2}S) WP5 Final Report", WIMAAS WP5, FP7 Project, 2008-2011, - ISBN-978-92-79-22801-8 (print), 978-92-79-22802-5 (PDF), ISSN-1018-5593 (print), 1831-9424 (online), EC-JRC Scientific Report, JRC 70093, 2012.

[7] Victor M.G. Silva and Harm Greidanus, "Spaceborne SAR Small Boat Detection Campaign in Portugal and Spain", EUR 25281 EN, ISBN 978-92-79-22553-6, ISSN 1831-9424 (online), EC-JRC Scientific Report, JRC68160, 2012.

[8] Goncalves Da Silva V, Van Wimersma Greidanus H, Hejmanowska B, Loudjani P.: "UAS Applications With Societal Benefits – JRC's UAS-Related Activities", 2011-2012 UAS Yearbook - UAS Unmanned Aircraft Systems - The Global Perspective 9 (9); 2011. p. 127-129. JRC66600

[9] Goncalves Da Silva V, Van Wimersma Greidanus H.: "Small boat detection using TerraSAR-X and Radarsat2 satellite imagery.", 4th TerraSAR-X Science Team Meeting; 14 February 2011; DLR Oberpfaffenhofen (Germany); German Aerospace Center (DLR) (Organiser). 2011. JRC63663

[10] V. Silva, Harm Greidanus: "JRC - SAR Satellite Small Boat Detection Campaign - Portoroz – Slovenia" - ISBN-13: 978-92-79-21476-9, ISSN (online): 1831-9424, EC-JRC Scientific Report, JRC66835, 2011.

[11] V. Silva, Harm Greidanus: "JRC - SAR satellite small boat detection campaign - Algarve, Portugal" - ISBN-13: 978-92-79-21265-9, ISSN (online): 1831-9424, ISSN (print): 1018-5593, EC-JRC Scientific Report, JRC66631, 2011.

[12] – Goncalves Da Silva V., Van Wimersma Greidanus H.: "JRC-Frontex Spaceborne SAR Small Boat Detection Campaign – Italy & Spain", - ISBN-13: 978-92-79-22213-9, ISSN (online): 1831-9424, EC-JRC Scientific Report, JRC67517, 2011.

[13] - P.W. Vachon, S.J. Thomas, J. Cranton, H.R. Edel, and M.D. Henschel. Validation of ship detection by the RADARSAT synthetic aperture radar and the Ocean Monitoring Workstation. Canadian Journal of Remote Sensing, 26(3):200–212, 2000.

[14] - Crisp, D. (2004): The state-of-the-art in ship detection in Synthetic Aperture Radar imagery, DSTO Information Sciences Laboratory, Australia.

[15] - Joint Research Centre (JRC) of the European Community — IMPAST and DECLIMS web site, http://intelligence.jrc.cec.eu.int/marine/fish/index.htm.

[16] - McCandless, S.W., Jackson, C.R. (2004): Principles of Synthetic Aperture Radar. Synthetic Aperture Radar, Marine User's Manual, NOAA, Washington, pp 1-23.

[17] - Greidanus, H. (2008): Satellite Imaging for Maritime Surveillance of the European Seas. Remote Sensing of the European Seas. 343-358.

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Abstract
The European maritime area is one of Europe's most important assets with regard to resources, security and ultimately prosperity of the Member States. A significant part of Europe's economy relies directly or indirectly on it. It is not just the shipping or fisheries industries and their related activities. It is also shipbuilding and ports, marine equipment and offshore energy, maritime and coastal tourism, aquaculture, submarine telecommunications, blue biotech and the protection of the marine environment. The European maritime area faces several risks and threats posed by unlawful activities, such as drugs trafficking, smuggling, illegal immigration, organised crime and terrorism. Piracy in international waters also constitutes a threat to Europe since it can disrupt the maritime transport chain. These risks and threats can endanger human lives, marine resources and the environment, as well as significantly disrupt the transport chain and global and local security. It is anticipated that these risks and threats will endure in the mid and long run. In order to keep Europe as a world leader in the global maritime economy, an effective integrated/interoperable, sustainable maritime surveillance system and situational awareness are needed.
A significant number of unlawful maritime activities, such as illegal immigration, drugs trafficking, smuggling, piracy and terrorism involve mainly small boats, because small boats are faster and more difficult to detect using conventional means. Hence, it is very important to find out the feasibility of using Unmanned Aerial Systems (UAS) for small boat detection, tracking, classification and identification, as well as to study the potential of UAS for maritime surveillance. Since 2010 the EC-JRC has carried out a number of UAS maritime surveillance campaigns to study the potential of UAS for maritime surveillance, in particular for small boat detection. This report presents the results and conclusions of the JRC - Alenia Aeronautica Coupled UAS and Spaceborne SAR campaign carried out in Oct. 2010 in Porto Corallo, Sardinia, Italy.

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