Detecting Migrant Vessels in the Cyprus Region using Sentinel-1 SAR data

George Melillos*[ab], Kyriacos Themistocleous[ab], Chris Danezis[ab], Silas Michaelides[ab], Diofantos G. Hadjimitsis[ab] Sven Jacobsen[c], Björn Tings[c]

[a]Department of Civil Engineering and Geomatics, Faculty of Engineering and Technology, Cyprus University of Technology, Limassol, Archbishop 30 Arch. Kyprianos Str., 3036, Lemesos, Cyprus.
[b]ERATOSTHENES Centre of Excellence, 2-8 Saripolou,3036 Limassol, Cyprus
[c]German Aerospace Center, Remote Sensing Technology Institute, (DLR-IMF), Bremen, Germany

ABSTRACT

Remote sensing is considered as an increasingly important technology for maritime surveillance. The process of maritime surveillance for safety is critical for every country. The need for information on migrant movements by sea using different sizes and types of vessels is of paramount significance. Such information is essential for the search and rescue (SaR) operations of unauthorised migrants. The aim of this paper is to show how to detect migrant vessels in the Cyprus Region using freely available Sentinel-1 SAR data. The comparison was made using open source available migrant data and Sentinel-1 SAR acquisitions. Sentinel-1 SAR images were used to investigate three Areas of Interest (AoI). The main AoI is located at the Northwest coasts, whilst the second area includes the Southeast coasts of Cyprus. The results indicate that the Sentinel-1 SAR data can provide decision-makers with effective results and spatial information on migration routes.

Keywords: Remote Sensing, Sentinel-1 SAR, OSINT, Migrants, Maritime surveillance, Cyprus coasts

1. INTRODUCTION

People have always migrated from one place to another. The flow of migrants who travel for various reasons is a phenomenon that is repeated in modern and pre-modern societies. Although migration is not a new incident, the countries of the Southern and Eastern Mediterranean, namely the external European borders of Greece, Italy, Malta, Spain and Gibraltar, have been experiencing a dramatic increase in unauthorized migration by sea, in the last two decades [1]. Refugees often risk their lives and cross the Mediterranean Sea in illegal vessels and under poor conditions. The countries on the threshold of Europe are in most cases only transit areas for migrants [2], who mainly originate from Syria, Iraq, Afghanistan, Nigeria and Pakistan, i.e., countries with recent or ongoing military conflicts. These migrants are frequently on their way to northern European destinations, which have more established diverse ethnic communities, better legal provisions and more promising reception [3].

Maritime surveillance can be defined as the monitoring of human activities at sea [4]. The surveillance is intended to support efforts related to security (e.g. irregular sea border crossing, and smuggling of illegal goods or substances), safety (e.g., Search and Rescue (SaR) and shipping traffic), and environmental and sustainability aspects (e.g., fishing control, and pollution) [5].

In the first months of 2020, it was estimated that 77 migrants died while crossing the Mediterranean Sea [5]. In 2019, the number of deaths is estimated to 1,900. However, the accurate number of deaths recorded in the Mediterranean Sea cannot be ascertained. Between 2014 and 2018, for instance, about 12,000 people who drowned were never found [5].

Satellite observation is a key tool for the observation of the Earth, enabling, in particular, detection of migrant vessels in the Mediterranean Sea. The Mediterranean Sea has been the theatre of intense illegal immigration phenomena during the last decade [6]. Note that most of migrant boats do not broadcast their position via the Automatic Identification System (AIS).

Therefore, it is very difficult to detect their position using marine traffic websites, such as Marine Traffic or Vessel Finder. In this way, optical remote sensing plays an important role in vessel detection. Specifically, very high-resolution multispectral imagery is useful in detecting very small ships and estimating their shape and route [7].

Current methods to monitor migrants in the Mediterranean rely on ground-based information. Boats are located either visually, if they are in the vicinity of patrol or fishery vessels, or remotely, if they are identified by ground-based radars. To control a relatively small portion of sea, this approach requires deployment of a considerable amount of resources, which are limited by territorial waters [8].

The aim of this paper is to show how to detect migrant vessels in the Cyprus Region using freely available Sentinel-1 SAR data. The comparison was made between open source available migrant datasets and Sentinel-1 SAR data combining dates, time and locations.

Cyprus is only 100 kilometers (62 miles) from Lebanon and 80 kilometers from Turkey [9]. This close proximity is leading traffickers to offer the opportunity of a risky crossing to Syrians, who currently make up the largest group of refugees in Cyprus. Current migration flows mainly originate from Syria and terminate in the southernmost part of Cyprus. The number of Mediterranean Sea arrivals has been rising at an increasing rate over the recent years. Unfortunately, these journeys can end up in tragedies [6].

Using Open Source Intelligence (OSINT) we can collect and analyse information regarding migration flows that are gathered from public or open sources. The categories of open sources might usefully be categorised as follows [10]:

Media

- Radio, television satellite.
- Newspapers and magazines.
- Digital format accessible via the Internet – digital media.

Research & Dissemination

- Academic research, access to academic journals.
- Conferences, conventions and meetings.
- Public sector statistics and databases.
- Private sector market research and databases.

Commercial Product

- Commercial imagery – available remote sensing satellites images.
- Private sector market research and databases.

In this research, we demonstrate a vessel detection and classification algorithm that was developed based on several Sentinel-1 acquisitions of maritime areas around Cyprus' coasts, which have been the most affected by unauthorised entrances of refugees in the last years. The results show that the Sentinel-1 SAR data would give to decision-makers effective results and spatial information on migration routes.

2. METHODOLOGY

2.1 Study Area

Sentinel-1 SAR images of three Areas of Interest (AoI) were processed throughout this research. The AoI-1 is located in the Northwest coasts (Pomos Port), the AoI-2 in the Southeast coasts (Cape Greco) and the AoI-3 in the Southeast coasts (Larnaca port). Sentinel-1 data from the Copernicus Open Access Hub was used through the online interface.

All images mentioned in Table 1 were acquired during the period of year when most passages of migrants occur. Initially, the whole Sentinel-1 acquisitions were downloaded from Copernicus Open Access Hub. These were subsequently cropped to obtain smaller areas that cover the selected AoIs and speed-up the processing time.

Table 1. Images Acquisitions from Copernicus Open Access Hub.

Areas of Interest	Locations	Image Acquisition date/time
AoI-1	Cyprus Northwest	19 November 2019/15:50
AoI-2	Cyprus Southeast	26 November 2019 /15:41
AoI-3	Cyprus Southeast	02 December 2019 /03:51

To accelerate the immigrants' data collection process, Open Source Intelligence (OSINT) automation tools were used, such as search engines, Web services, social media resources etc. Table 2 lists the data regarding the arrivals of the immigrants at the Cyprus coasts.

Table 2. Data regarding the arrivals of the immigrants at the Cyprus Coasts.

Date/Time	From	To	Speed
19 November 2019/18:00	Mersina Port, Turkey	Pomos Port, Cyprus	~24km/hour
26 November 2019/16:15	Fishermen Port Jounieh, Lebanon	Cape Greco, Cyprus	~30km/hour
02 December 2019 /04:00	Tartus Port, Syria	Larnaca Port, Cyprus	~20km/hour

2.2 Methods

The methodology was formulated in order to be used within the Sentinel Application Platform (SNAP), a common architecture for all Sentinel satellite toolboxes. The processing graph in 'xml' format allows the processing of Sentinel-1 GRD, by means of the command line graph processing framework, which allows for batch processing of large datasets [11]. The proposed method defines an automatic, simple and robust workflow to detect moving vessels based on an object-oriented approach [12].

The overall methodology adopted in this study consists of ten (10) processing steps briefly described below (see Figure 1):

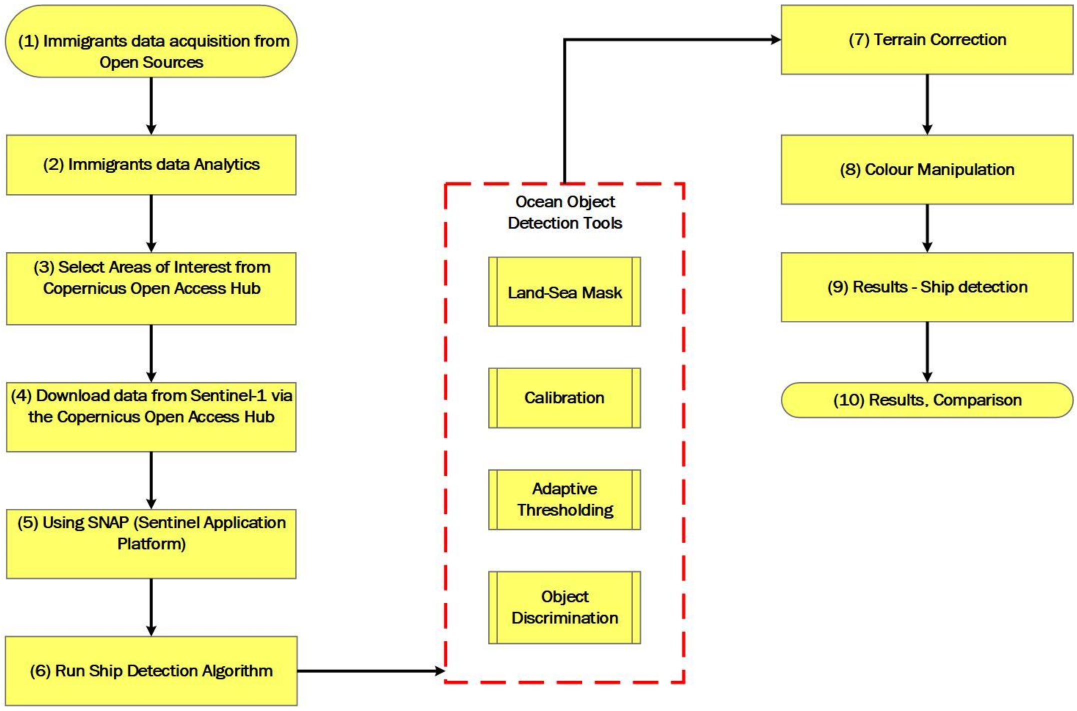

Figure 1. The overall methodology adopted in this study.

Step 1: Immigrants data acquisition from Open Sources. Data include the date and time of arrivals and departures, port of departure, port of arrival, ship size, type of ship, ship speed and migrant's routes.

Step 2: Immigrants data Analytics. Compare, combine and validate the data to check the accuracy and quality of sources before using, importing or otherwise processing data.

Step 3: Select Areas of Interest from Copernicus Open Access Hub (Figures 2 and 3).

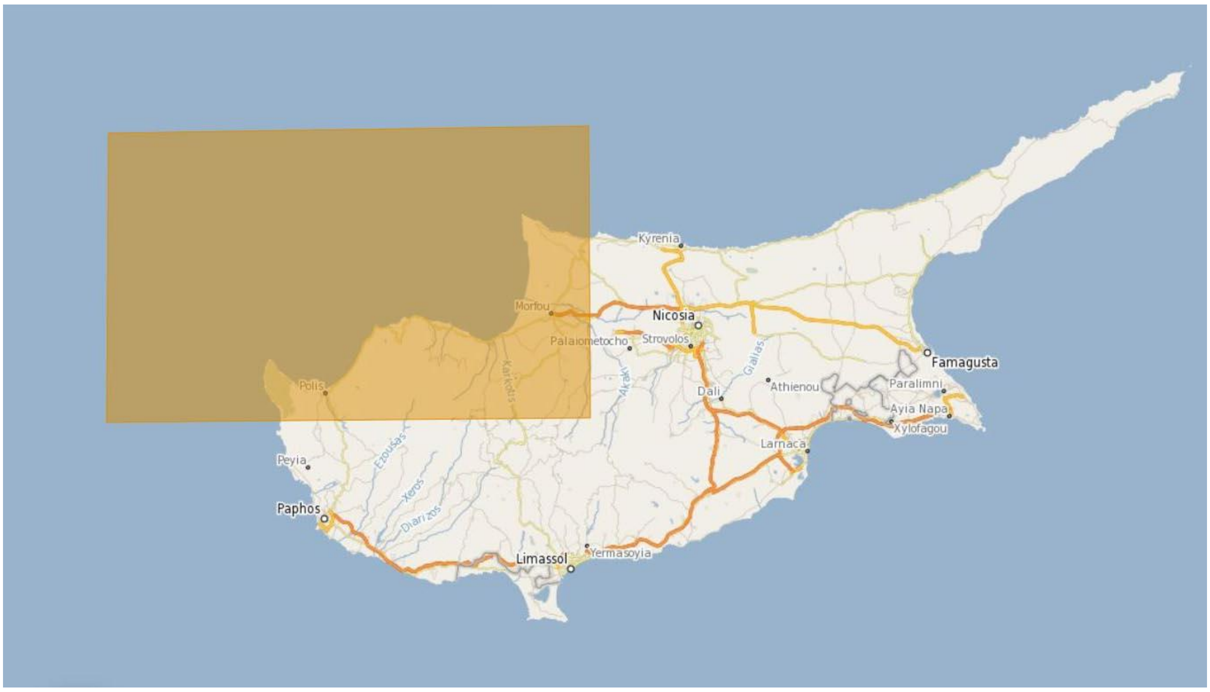

Figure 2. Selected Area of Interest (on 19 November 2019) from Copernicus Open Access Hub used in this study.

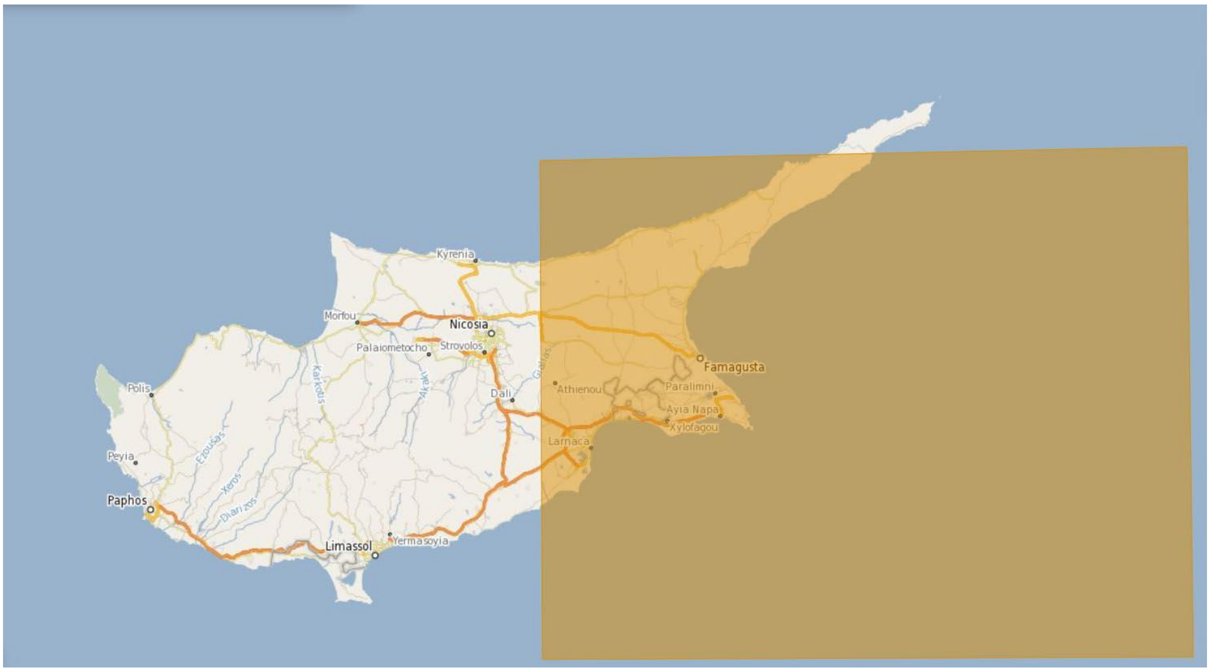

Figure 3. Selected Areas of Interest (on 26 November 2019 and 02 December 2019) from Copernicus Open Access Hub used in this study.

Step 4: Download data from Sentinel-1 via the Copernicus Open Access Hub using the online interface by specifying the following parameters:

Sensing periods (Date/Time): On 19 November 2019 at 15:50 – On 26 November 2019 at 15:41 - on 02 December 2019 /03:51.

Check Mission: Sentinel-1.
Satellite Platform: S1A*.
Product Type: GRD (Ground-range-detected product).

Step 5: Using SNAP (Sentinel Application Platform) software. Opening Amplitude_VH to visualize the band.

Step 6: Run ship detection algorithm. This step consists of four (4) stages briefly described below:

Land-Sea Mask: The first stage is masking the land areas to avoid false target detections on land [12].

Calibration: Calibration is the procedure that converts digital pixel values to radiometrically calibrated SAR backscatter [13].

Adaptive Thresholding: Adaptive thresholding is a frequently used method for target detection in SAR imagery. The underlying assumption is that targets appear bright on dark background. The adaptive thresholding algorithm is applied on a moving window. For each pixel under test (central pixel), a new threshold value is calculated based on the statistical characteristics of its local background: if the pixel value is above the threshold, the pixel is classified as target pixel [12].

Object Discrimination: This stage is used to filter out false targets based on minimum and maximum size limits [12]. In this study, 5 m and 30 m were determined for minimum and maximum target size. These values were selected based on fishing boats size estimation. Commonly, immigrants are transferred by means of fishing boats.

Step 7: Terrain correction: Terrain corrections are intended to compensate for the distortions arising due to the sensor's side looking geometry, so that the geometric representation of the image will be as close as possible to the real world [14].

Step 8: Colour Manipulation: The colour manipulation windows was used to modify colour appearance towards the bright targets (ships) within the red circles.

Step 9: Results - Ship detection: Open band using Sigma_VH and Sigma_VV [15]. The red circles highlight locations of detected candidate ship signatures.

Step 10: Comparison of results is performed by using the results from step 9 to the ground-truth information gathered in the first/second step (Immigrants data acquisition from Open Sources/ Immigrants data Analytics) the candidate ship signatures can be identified as immigrant boats. Immigrant's boat targets are highlighted with blue circles as shown in Table 3.

Table 3. Data regarding the arrivals of the immigrants at the Cyprus Coasts.

Areas of Interest	Latitude			Longitude			Acquisition date / time
AoI-1	35°	30'	17.00"N	32°	59'	48.00"E	19 November 2019 / 15:50
AoI-2	35°	1'	1.00"N	34°	10'	7.00"E	26 November 2019 / 15:41
AoI-3	34°	56'	9.00"N	33°	39'	11.00"E	02 December 2019 / 03:51

3. RESULTS

In the ship detection process, using the ocean object detection tool in SNAP, a ship is extracted from Sigma Nought VH [15]. The results show that the objects are detected in satellite images as follows: Area of Interest 1 (AoI-1) on 19 November 2019 at 15:50 (see Figure 4), AoI-2 on 26 November 2019 at 15:41 (see Figure 5) and AoI-3 on 02 December 2019 at 03:51 (see Figure 6). In SAR images using SNAP viewer, ships tend to appear as bright pixels in a darker local background [15]. We can see the bright targets (ships) shown within the blue circles [15] (see Figures 4, 5, 6) in the Areas of Interest. The confirmation of the immigrant boats was successful by crosschecking with the immigrant open source data. The position was accurately known from ground truth data during image acquisition time.

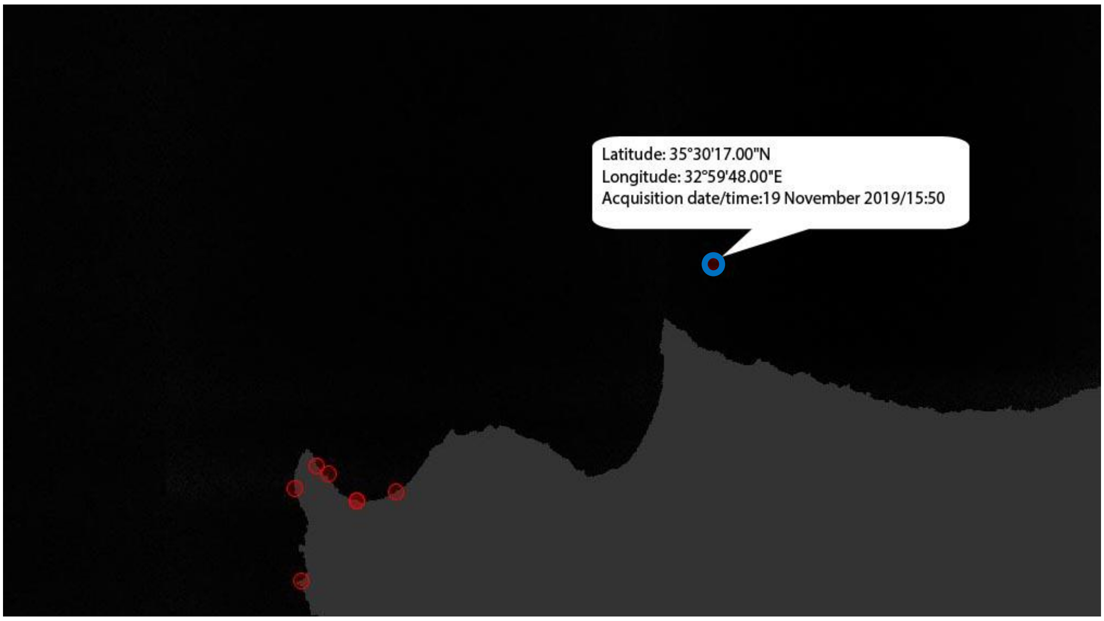

Figure 4. Ship detection results in SNAP viewer for AoI-1 (on 19 November 2019). Target (ship) within the blue circle.

Figure 5. Ship detection results in SNAP viewer for AoI-2 (on 26 November 2019). Target (ship) within the blue circle.

Figure 6. Ship detection results in SNAP viewer for AoI-3(on 02 December 2019). Target (ship) within the blue circle.

4. CONCLUSIONS

There is no doubt that migration has been established as a critical phenomenon of modern times. By analysing satellite imagery, it is possible to collect detailed data and offer up-to-date spatial information on migration routes to decision-makers (e.g., humanitarian organizations or national authorities that assist migrants). Predominantly, we can obtain valuable data which may otherwise be difficult to obtain due to political or geographical reasons [3].

Ship detection is part of maritime surveillance that is in the focus of this paper using Sentinel-1 acquisitions. Due to the free, full, and open nature of the Sentinel-1, SAR imagery enables access to unprecedented volumes of data [15]. This fact raises significant opportunities, which cannot be exploited unless the challenges that also come with the huge volume of data are confronted [1].

The surveillance is intended to support efforts related with safety and security [15]. In this research, the analysis of freely available Sentinel-1 SAR data shows that it is possible to detect migrant vessels in the Cyprus Region. The comparison of vessels detected by Sentinel-1 SAR acquisitions was made against available open source immigration data. Sentinel-1 data for ship detection was applied on SAR images in three Areas of Interest (AoI). The main Area of Interest is located in the Northwest coast (Figure 4) and the second area in the Southeast coast of Cyprus (Figure 5 and Figure 6). The results show that the Sentinel-1 SAR data could provide to decision-makers effective results and spatial information on migration routes.

Observations are planned in the near future to study different periods of time and different study areas in order to evaluate the above results, the satellites' sensitivity and perform time series analysis.

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