A PROTOTYPE ON-BOARD SHIP-DETECTION SYSTEM

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Abstract

The DLR is currently exploring the feasibility of an on-board ship detection system, prospectively installed on Earth observation satellites. The applications are manifold: illegal activities like piracy, unauthorized fishery, refugee shipment, illegal cleaning and ocean dumping are daily occurrences. Furthermore, such a system can support live saving by detecting dangerous situations like sinking ships and facilitate fast reaction in case of oil spills or other sea pollution.
The key value for all these applications is the topicality of information. By now, near-realtime services offered by data processing centers on ground can provide information in the range of 15 minutes measured from on-ground data reception. Obviously, the bottleneck in this process is the time delay occurring between data acquisition and reception on ground. To react as fast as possible, product data like position, velocity, heading and condition of maritime objects are of interest, while high-quality image data in full spatial and spectral resolution is not obligatory in the first instance.
The on-board system introduced hereafter is intended to provide the mentioned product data in real-time and independent of a direct contact to a ground station. The aim is to completely overcome the usual delay emanating from the process of data acquisition, on-board storing and downlink. Furthermore, the product data can be received on any smart device on ground independent of its locality.

A prototype system will be tested in the flight experiment AMARO (Autonomous real-time detection of moving maritime objects), scheduled for 2018.

Keywords:
on-board computing, on-board image processing, ship detection, flight experiment

1 INTRODUCTION

The monitoring of the worldwide ship traffic is important for the maritime sector. To know the position of ships and their current condition at any time is a great benefit for shipping operators, maritime monitoring agencies, the water police and for many other stakeholders in this field.

For navigation on the sea, nowadays, radar and the automatic identification system (AIS) are used. With AIS, ships are actively identifying themselves by sending periodically a message on the very high frequency (VHF) band, containing amongst other information their identity, position, heading, and speed over ground.

A drawback of AIS is that it is a cooperative system. Maritime objects that are not sending an AIS signal or a faked one cannot be detected correctly. Examples are emergency situations, piracy, illegal shipment and refugee transportation. Also illegal activities like ocean dumping or oil spillage cannot be detected via AIS.

In such cases, additional satellite images are a useful information source for situational awareness, where the most crucial factor is the topicality of the derived information. By now, near-realtime services offered by data processing centers on ground can provide information in the range of 15 minutes measured from on-ground data reception. But, a significant time delay occurs between data acquisition on board and data reception on ground, since image data is comparatively huge and their downlink requires a direct contact to a ground station. This delay can amount to hours or even days.

Our aim is to design a system, which completely overcomes this time delay and provides product data like position, heading and velocity of ships within 3 minutes after sighting. Furthermore, this product data can be received via email on any smart device on ground independent of its locality.
In this paper, we want to present a prototype of our on-board ship detection system. This prototype will be tested in the flight experiment AMARO (Autonomous real-time detection of moving MAritime Objects.)

2 FEATURES AND CONCEPT

The on-board segment of our ship detection system consists of one or more Earth observing platforms carrying a camera, a GPS receiver, an on-board computer and a modem for real-time communication (e.g. Iridium). Optionally, an AIS-receiver can be mounted on board and its signals be synchronised with the image data. Ships, which send no signal - possibly on purpose - can such be identified.
On board, ships are detected from the image data by means of remote sensing algorithms. Product data like position, heading, velocity, type and status of the ship are extracted. This data - some kilobytes in size - will be sent from the Earth observing satellite to the network of communication satellites, which forwards the message until it can be downlinked. A small quick-look of the detected object can be included for visual inspection. At most, this procedure will take some minutes.
The product data can be received via email on any device connected to the internet or a smart device for satellite communication. Hence, the receiving person can be located practically everywhere on Earth.

Evaluating various usecase scenarios, the following requirements of the on-board ship detection system were identified:

1. The user shall be able to post user-defined requests.
2. The user shall be able to define events, where he gets informed immediately.
3. The information available shall include the object's position, classification, shape attributes (e.g size, perimeter), trajectory and estimated heading and velocity, and a small preview image of the object.
4. The communication to the user shall be location-independent (e.g open sea).
5. The data shall be of high accuracy.
6. A high amount of data shall be available.
7. The user shall be able to get information with a topicality of at least 3 minutes.

On operation, sensor data shall be acquired continuously by the camera system. The sensor data shall immediately be evaluated on-board the satellite and the product data shall be stored in a database on the satellite. The user shall be able to access this database by using the real time communication service. An example usecase scenario is demonstrated in fig 2. Furthermore, the user shall be able to define events, where he gets informed about immediately.

3 PROTOTYPE

We are currently designing and developing a prototype of our on-board ship detection system. With this prototype the concept of an on-board ship detection system will be demonstrated within an aircraft campaign. In the following the hard- and software architecture of the prototype on-board ship detection system is presented.

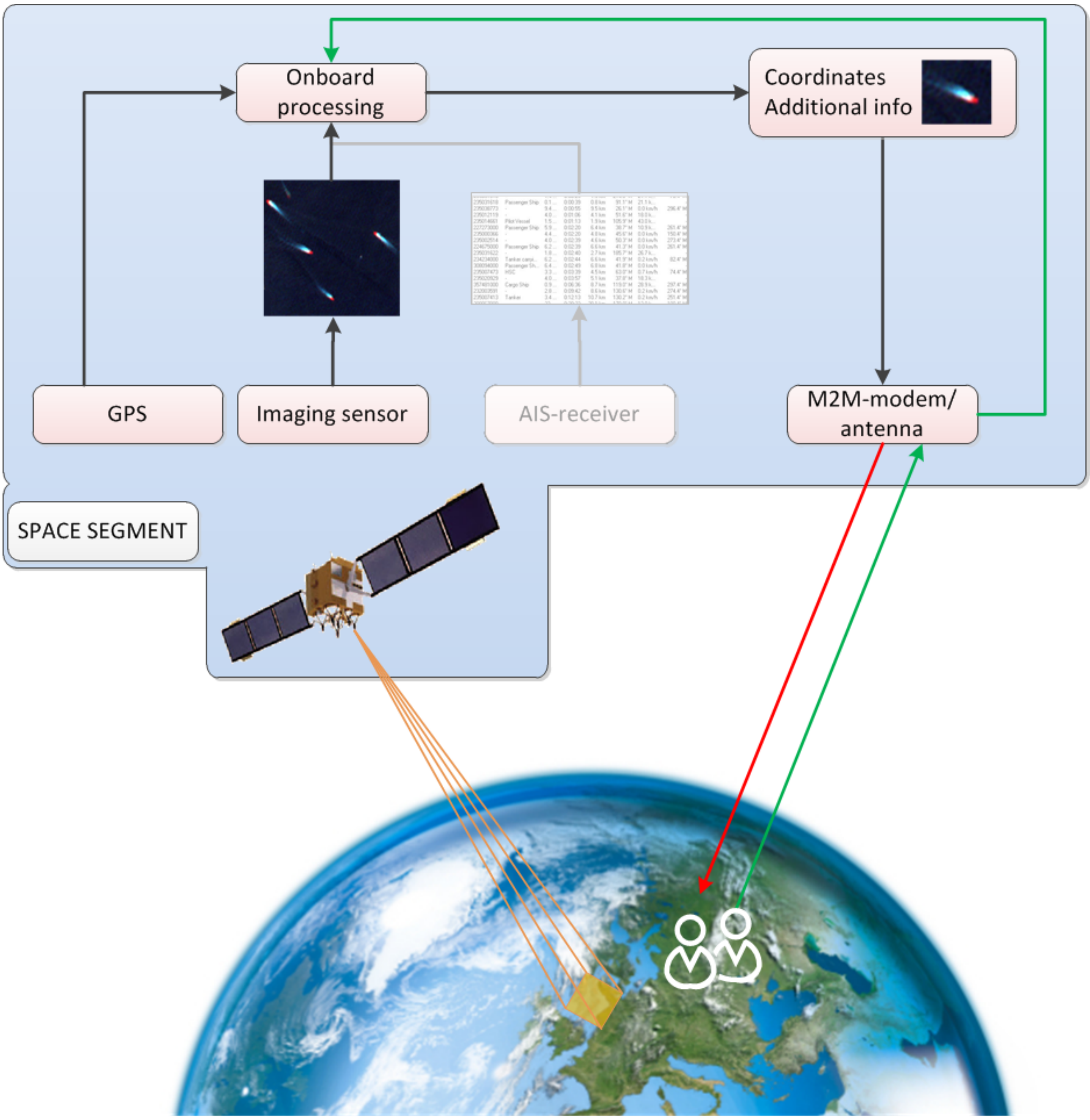

Figure 1: Concept of the space segment of the ship detection system

3.1 Hardware architecture

The prototype ship-detection system will be installed on a small science aircraft. In the following the subsystems of the ship-detection system are explained in detail.

3.1.1 Image sensor/GPS

For image acquisition, the Modular Airborne Camera System (MACS) is used[1]. It is a compact, adaptive multi-sensor system, which is especially made for maritime applications. For the AMARO experiment the configuration of the three sensors can be seen in table 1.

The MACS camera system has a built-in embedded desktop class camera computer, used for data recording and data processing. The AMARO on-board computer is connected via 1000MBit ethernet with the camera computer. One important feature of the MACS camera sys-

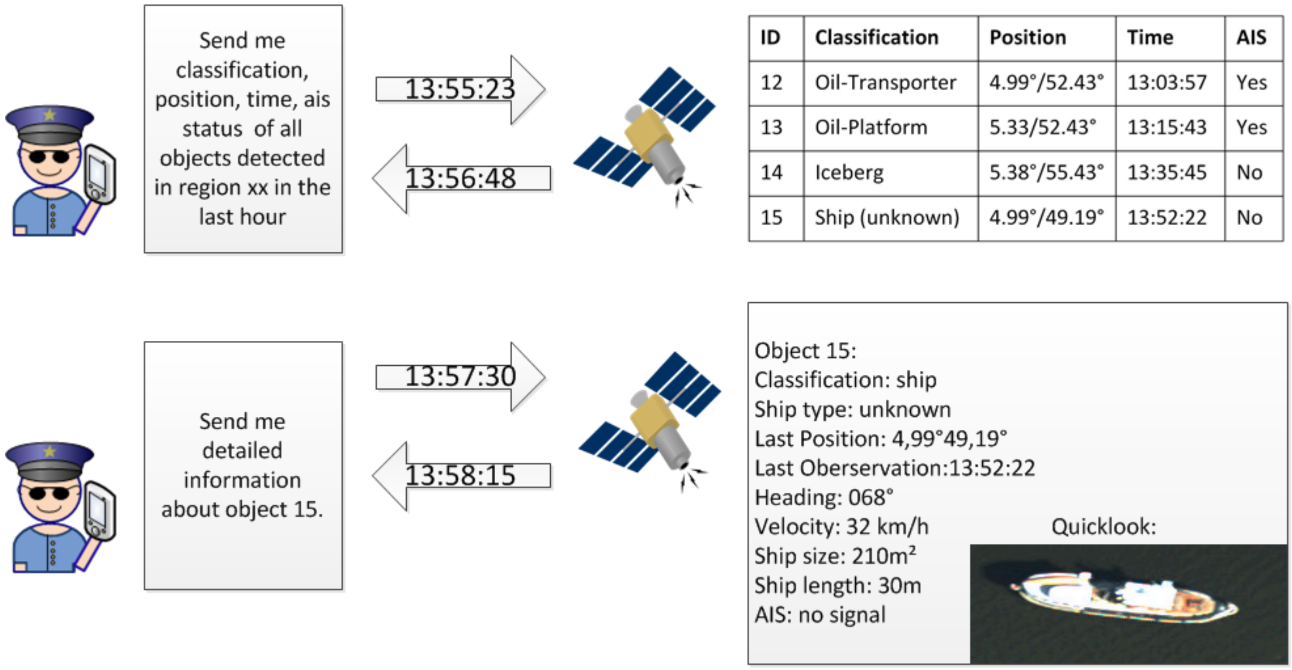

Figure 2: On-board ship detection usecase example

	RGB (Bayer color pattern)	**NIR**	**Thermal Infrared**
Spectral Bands (nm)	400 - 520 (blue) 500 - 590 (green) 590 - 680 (red)	700 - 900	7500 - 14000
Resolution (pixel)	4864 x 3232	4000 x 3000	1024 x 768
Image acquisition frequency (Hz)	1,0	1,0	2,0
GSD@3000m above ground/sea level (cm)	44.4	48.1	170.0
Filed of View across track(deg)	39.6	35.6	32.4

Table 1: MACS sensor configuration used for AMARO

tem is its built-in geo-referencing system. Each aerial image gets geo-tagged by using a Triple-Frequency GNSS receiver in combination with a tactical grade Inertial Measurement Unit (IMU). Sufficient accuracies are reached for attitude and position and allow the determination of geographical references for each pixel (time-stamp, ground position, position accuracies).

3.1.2 Communication system

After a careful elaboration of various options, we decided to use the Iridium short burst data (SBD) service. Iridium SBD is a simple and efficient network for transmitting short data messages between equipment and centralized host computer systems [2, 3]. Messages with a size around 300 bytes can be exchanged between the on-board device and the user at the ground. For sending and receiving messages from the device, standard email can be used. The latency for data exchange is specified as less than one minute worldwide [4]. The size of the transceiver device is comparable with a packet of cigarettes. The average power consumption is below 0.8W.

One big advantage of the Iridium system is that the antenna needs no exact pointing alignment to a determined direction. It is sufficient that the antenna points approximately to the sky. This is beneficial for reliability and for limiting the installation effort on a plane as well on a satellite platform. Regarding the limited data bandwidth,

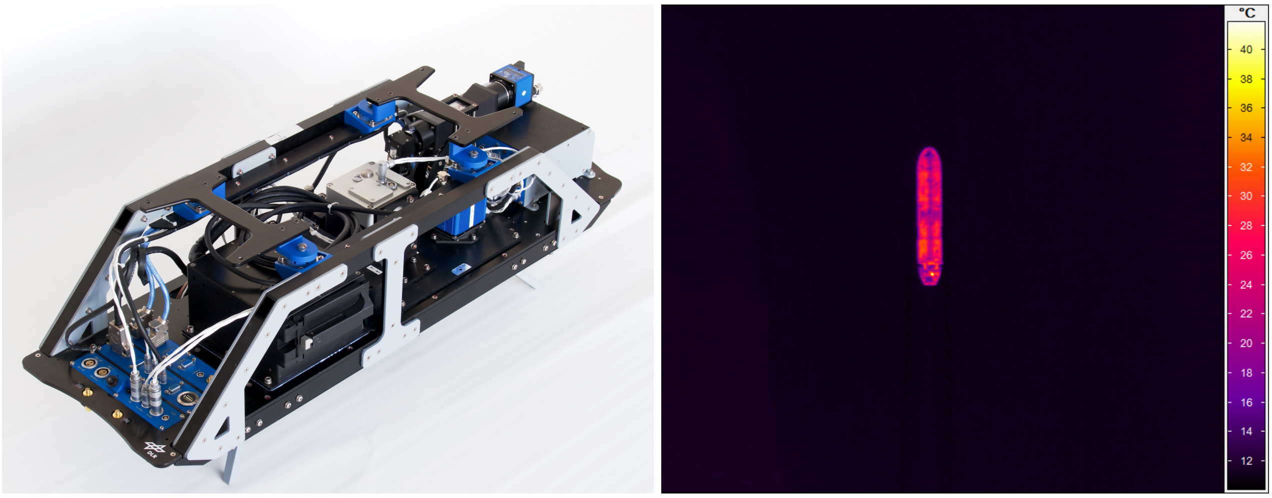

Figure 3: Macs camera, Thermal infra-red image from camera

we suppose that with an efficient data management, it should be sufficient for reasonable operation. Moreover, the demonstration that the Iridium SBD service can operate from space, has already been done [5]. Since they are available custom of the shelf, the purchase of the SBD transceiver and the antennas is uncomplicated.

3.1.3 On-board computer

The on-board computer is the core component of the on-board ship detection system. It obtains the camera data, controls the Iridium transceiver and the AIS receiver, performs data analysis and manages communication.
The on-board computer shall be small to fit in a 19” rack box together with the other components. The on-board computer shall also provide sufficient computing power for data processing. Moreover, it shall be physically and thermally robust for reliable operation on the aircraft (passenger cabin).
After studying the market is has been decided to buy a 1,3 litre slim standard personal computer (Shuttle DQ170), which is equipped with standard up-to-date desktop pc components[6]. The computer is robust enough to handle 24/7 operation and up to 50°C ambient air temperature. All interfaces needed for attaching the other components are present. Equipped with modern desktop PC components, that is Intel Core i7-6700, 16 GByte RAM and a 512 GByte SSD, the system is luxurious compared to todays or even next on-board computer solutions [7]. In contrast to space conditions, power usage, thermal output, space limitations and radiation impact are insignificant on an airplane. For the first proof of concept, we decided an artificial restriction in this regard to be unnecessary. Nevertheless and since we are also involved in building a next generation space computing platform [8], we assume that it is possible to integrate the software on a future satellite computing platform.

3.1.4 AIS Receiver

For deciding, whether an AIS receiver brings additional benefit for an aircraft (or a later spacecraft) mission, it is planned to integrate such a device in the system. At the current state of the project, is it planned to use the AIS receiver only for data logging.
We intend to examine the reliability of AIS signals received by a standard custom off the shelf receiver on-board the aircraft. The challenge is the limited time window, in which the AIS signals can be received on a moving airplane, since AIS is sent with time intervalls ranging form 2 seconds to 3 minutes [9] depending on classification and status. Furthermore, we plan to analyse the potential of fusing AIS data with optical data directly on-board and in real-time.

3.2 Software architecture

Within this section a high-level view of the AMARO software system is given. The software system is the most important and work intensive component of the AMARO system. Whereas most hardware components can be bought off the shelf, the software system has to be developed from scratch.

The main tasks of the software system are data analysis and communication. The data analysis process shall extract useful information from the image data. The system shall be capable to process as many data as possible to reach a high situation awareness. Due to the complexity of the ship detection algorithm and the high amount of image data, processing is computationally intensive. The AMARO communication system shall be readily responsive and the limited communication bandwidth shall be used efficiently. Since there are only limited maintenance options at runtime, the system has to be very reliable. Operation should never been interrupted and if an error occurs the system should be able to handle it and get back to operation without loss of information. Therefore we need a software system, that is high-performance, responsive and reliable.

To meet all this requirements a service based architecture has been chosen.
Starting the software design, we created a very simple processing chain: Getting data from the camera, extracting information, sending results down to earth. But during the designing phase we realized, that this approach is not versatile, it is not efficient in case of data communication and it is neither user-friendly nor powerful.
We thought of a system, where multiple users communicate directly with the on-board device and the user gets exactly that (high level) information he wants, at exact the time he wants. Finally, we took a database-like approach similar to internet services, like GoogleSearch, Alexa, Cortana or Siri. All this services are realized by using a big database and a lot of services that request and modify the database.

A top-level view of the service architecture can be seen in figure 4. Each task is carried out by a unique service operating independently of other services. This way, high computation performance, responsiveness and reliability are guaranteed. For data transfers between the services and for data storage, a SQL file based database (SQLite) is used [10].

In the following the services are explained shortly. The serviceSBD is a messaging service, responsible for sending and receiving messages over the Iridium SBD network.
The serviceQuery is responsible for dealing with user requests. A user can send a query message via email to the on-board device. For formulating the query, the SQL language is used.
The servicePush is a messaging service, sending messages automatically, if a predefined event occurs. An example of an event is the detection of oil near a ship (oil dumping). Events can be added and deleted during operation.
The serviceShipDetect is responsible for data analysis. It fetches the image data from the camera, analyses it and enters the results in a database table. For each detected ship a least the following information should been extracted: time stamp of the observations, location of each observation in geographic coordinates, shape attributes (size, perimeter, long axis, short axis, axes ratio), type of ship (coarsely), trajectory, estimated heading and velocity.

3.3 The AMARO experiment

The AMARO experiment is divided into the development phase including a first flight for the acquisition of image data, the final flight itself and the post-flight analysis.
We chose to conduct the experiment on a small Cesna airplane in an altitude of around 3000m above the Baltic Sea. The prototype described in detail above will be mounted on the small propeller airplane. Two scientists will be present, one for the supervision on board and the other one on ground. The latter will be equipped with a standard laptop or smartphone to exchange messages with the Iridium modem on-board.
Up to now, the hardware has been selected and the core functionalities of the software are implemented. The development of the ship detection algorithm is pending. To collect image data for the development of the ship detection algorithm, a first flight will be undertaken in the next weeks. Here, the MACS-MARE camera will acquire images from the Baltic Sea under preferably similar conditions compared to the final flight.

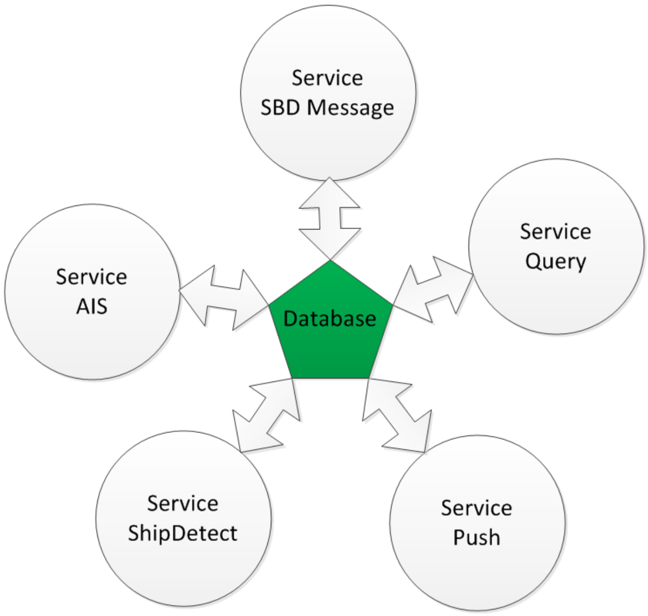

Figure 4: Top level overview of the AMARO software architecture

The experiment flight is scheduled for 2018.

4 PERSPECTIVE

Nowadays, more than 2/3 of the world's volume of cargo is transported seaborne. An enormous amount of money depends on reliable transportation routes. But, to safeguard the seaways is not only essential for the carriage of goods but especially for the integrity of humans' lives. Piracy, illegal fishery and illegal ocean dumping. Not least, the most controversial topic within the European Union regarding the monitoring of sea routes is refugee transportation over the Mediterranean Sea by human traffickers. Here, a system like the one we proposed, would bring a significant value to situation awareness.
Our ship detection system is not tied to a specific platform or a specific camera. It can be mounted on airplanes, satellites, drones or stratospheric platforms.
To monitor a defined geographic region as e.g. the Mediterranean Sea, stratospheric platforms or high-altitude drones would be a preferred option. The latter fly in an altitude of around 20km and can endure more than 2 days without human interaction. Equipped with a similar camera as we use for the AMARO experiment, they could monitor an area of around 140km^2 per second.

The ship detection system is applicable on satellites as well. Only satellites in the lower Earth orbits (LEO) can carry a camera payload with reasonable ground sample distance for ship detection. At the same time, LEO-satellites can have a repeat cycle of some days before returning to the same geographic region and hence, are not suitable for monitoring a small area steadily. But, since the ship detection system can also be encapsulated as black box, it could be mounted on various future LEO-satellites, which carry a appropriate camera payload. In such way, a monitoring network could be spanned around the world.
In any case, on-board processing of remotely sensed data bears a significant additional benefit for time-critical usecases.

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