MACS-Mar – A Real-Time Capable Multisensor Remote Sensing System for Maritime Applications

Current State of Development

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***Abstract*—This article describes a new version of the Modular Airborne Camera System (MACS) [1], which has been made especially for maritime applications. The system is a successor to a High Altitude Long Endurance (HALE) MACS system which was operated in the Himalayas in 2014 [2]. Scenarios in the maritime environment require a different constellation of sensor heads, as shown in this paper. Furthermore, a method of supplying real-time capabilities to ensure flexibility in operation, as well as photogrammetric evaluation, is described. An overview of current and planned results will give an idea of the camera system's potential. The scene to be monitored is an unchanging surface; in general, nothing but water can be seen. Every change of this condition needs to be detected and classified automatically and in real-time. To ensure this, it is necessary to have more than just a camera capturing visible light, so a thermal infrared capturing camera and a hyperspectral sensor are also used. The classification results derived onboard are sent to a ground station by radio downlink. An operator in the command and control facility is then able to use this georeferenced semantic information to decide on the next steps.**

Keywords—MACS; real-time; data fusion; aerial camera; hyperspectral; remote sensing; maritime security; thermal infrared

I. INTRODUCTION

Maritime safety and security are relevant topics from many perspectives. Barge traffic grew by 60% between 1992 and 2002 [3]. From 2002 to 2012, this traffic doubled in size. Such growth results in an increase in the side effects of maritime traffic. More ships lead to more pollution and a higher probability of accidents. Dumping and illegal cleaning of ships in international waters are hard to detect and affect the oceans more and more. Furthermore, the risk of piracy or terrorism endangers maritime traffic. The vast area of the seas combined with a low number of permanent installations make remote sensing a preferred method for monitoring the maritime environment.

Satellite-based passive optical instruments and active synthetic aperture radar systems are studied for ship detection and tracking [4][5], for example. Specialized satellites with receivers for the Automatic Identification System (AIS) are also in experimental use [6]. However, satellite-based operation remains a small market for specialized applications [6][7]. The focus of satellite-based maritime applications are large scale ecological issues like coral reef studies, thermal plume of warm water discharge caused by power plants or sediment transport in estuaries [8]. Space-based and airborne remote sensing in maritime regions is particularly important specifically for oil spill detection [9][10][11]. Hyperspectral- and thermal infrared-spectra imagers, or a combination of them, are well known sensors for remote sensing. Space-based they are mostly used for large scale environmental monitoring or airborne for terrestrial applications like geological analysis [12][13].

Airborne monitoring is quite common in coastal regions, but usually with a focus on military or border patrol tasks and for scientific projects. Small-scale missions like search and rescue or criminal investigation can rely on platforms such as helicopters. Large-scale missions are operated using aircrafts like P-3C Orion. Besides watching out of the window, the operator in several applications is assisted by optical surveillance equipment, e.g. for the identification of objects and to increase the observation radius.

All the methods, platforms and installations mentioned above have in common that they are expensive to implement and operate. Also, most of the aforementioned systems were either not originally developed for maritime operations or specifically designed for high value sectors such as the armed forces.

Fig. 1. Preliminary version of MACS-Mar mounted in a underwing pod of a Stemme S10 VTX motorglider

To tackle the problem from a civil security point of view, a joint project with the title 'Real-Time Services for Maritime Security' (EMSec) has been funded by the German Ministry of Education and Research (BMBF). One module of the proposed integrated approach is an airborne remote sensing system for the monitoring of maritime environments.

Based on discussions and interviews with responsible end-users of a maritime monitoring solution, a set of requirements has been derived. Leaving operational envelopes aside, the main task required of an optical payload can be summarized in two points:

1. Create a real-time (sub-minute), high-resolution and accurate georeferenced visual map of an area at short notice and for an extended time period.
2. Support the responsible authorities by delivering automatically generated information about objects at the scene.

While the first point seems trivial and easy to achieve using existing hardware, the second point requires robust and reliable automatic classification, which is not a given factor yet. On further analysis it becomes evident that the first point is, in fact, not trivial. Existing commercial mapping systems are built for post-processing applications and produce an amount of data that is not suited for real-time processing and streaming respectively. Existing surveillance systems are optimized for delivering a video stream to a ground station. Although they often claim to have mapping functions, these maps lack the accuracy of dedicated mapping systems.

For the automatic registration of objects described in the second point, restriction to a certain set of maritime objects was necessary. Using inputs from responsible authorities, the main focus will be on two different classes. On one hand, there are small-scale objects like boats, rafts, bigger items of flotsam and persons in life vests that should be registered and annotated. On the other hand, unnatural changes in the surface water, e.g. pollution, should be automatically determined.

To achieve an efficient solution for these tasks, a small, integrated sensor system has been proposed and will be set up for a validation experiment. Based on existing work shown in several DLR-developed versions of Modular Airborne Camera Systems, a light and reasonably small sensor system called MACS-Mar will be described in this paper and the first glimpse of the results of some preliminary tests will be given.

II. MACS Aerial Camera Systems

A. System Description

The Modular Airborne Camera System enables the fast and easy development of novel aerial camera concepts for special applications. Multiple passive optical sensors can be combined to acquire the relevant information. The sensors and their field of vision can be adjusted to specific use-cases. All sensors and their optics need to be able to be calibrated geometrically and for radiometric correction. The mechanical design must be rigid to allow for a precise overlap of the images taken by all sensors of the respective configuration. For an efficient evaluation of such configurations, an approach for combined photogrammetric processing of multiple sensor heads has been developed [14].

Besides their mechanical stability, the camera systems are built to achieve a small footprint and low mass. This helps in the installation of MACS systems on smaller carriers and in external wing pods. Several experiments have been carried out in an underwing pod of a cost-efficient motorglider Stemme S10 VTX (Figure 1). Auxiliary sensors and a programmable microcontroller allow for the traceability of malfunctions and environmental effects.

Each aerial image gets a unique georeference 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 (timestamp, ground position, position accuracies).

Image processing and recording is done by a desktop class embedded computer. This computational power is necessary to allow the simultaneous recording of various sensor data, online georeferencing and map projection of those data and implementation of suitable real-time image classification algorithms. In this way, various higher level geoinformation can be generated automatically during operation.

MACS can be operated by a proprietary flight guidance system that can be controlled onboard or directly by a mission control center through a radio link. The operator is able to configure the camera system and can choose between different flight modes. In general, the current position of the aircraft and the footprints of the images taken are shown continuously on a scalable map. The guidance system shows areas covered and the operator can choose between predefined flight missions or different cruising modes. During a mission, the guidance system will assist the pilot, and during free flight mode the onboard operator is able to track the progress of the acquisition.

Besides radio transmission, all aerial images will be stored permanently and can be processed after landing using various geoinformation-specific approaches when necessary.

Fig. 2. Georeferenced real-time image mapping

It is possible to generate precise true-ortho image maps with multi-spectral and multi-temporal information as well as Digital Surface Models (DSM) of land surface. 3D models and thematic maps can also be derived.

B. Real-Time Ability

By using calibrated camera modules and the unique assignment of position and attitude at any time, all aerial images can be projected onto an existing digital elevation model. While a higher resolution model (e.g. Shuttle Radar Topography Mission SRTM-1 or SRTM-3) is applied in coastal regions, only a geoid, for example the earth gravitational model 1996 (EGM96), is used in offshore applications. This allows fast generation of an image map under consideration of the deviation between WGS84 reference ellipsoid and mean sea level.

Absolute position accuracy of the map is defined by the accuracies of the system's position and orientation measurements, as well as the accuracy of the digital elevation model. Using a digital data downlink, the projected images can be transferred to a ground station and visualized as a geo-rectified map in full geometric and radiometric resolution. This also applies to the data from sensors recording different spectral bands, e.g. thermal infrared. Figure 2 shows an example of the mapping of RGB data in real-time.

This simple functionality of real-time mapping will enable novel concepts for the detection and interpretation of significant abnormalities by experts in the command and control center. It could be used as a tool for mapping large-scale areas or monitoring special regions of interest. The swath width can be changed by using different optics or by grouping several cameras together. The acquired spectral range can be adapted to application requirements.

Another important real-time function is the automatic detection of abnormalities based on pixel-based, co-registered images. As any pixel of the maps created in the aforementioned process has a reliable coordinate and time designation, the same applies to any detected object. By sending only detected objects to a ground station, the amount of data to be transferred can be reduced and the amount of information to be examined by an operator decreases.

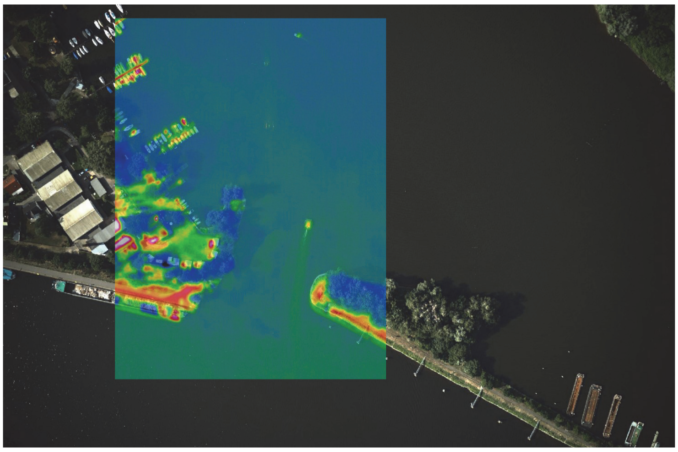

Fig. 3. RGB and thermal infrared data overlay

A telemetry data link with a data rate of 9,600 Bit per second would be enough under normal conditions, resulting in wider observation radii when transmitting the information directly to a ground station. If images, cropped due to the high overlap between two consecutives, are sent to a base station, the data link has to carry a payload of ca. 5 – 10 Megabit per second.

The visual information can be directly interpreted by humans. In addition, a broad range of object detection algorithms are applicable. Different sensors and lenses can be used and will allow task-specific footprints and ground resolutions. A ground sampling distance of up to 3 cm is achievable depending on the flight altitude and optical configuration. Within the map, distances and areas can be determined, e.g. the length of a vessel or the extent of oil contamination areas.

III. CURRENT CONFIGURATION

MACS-Mar was designed as a tool for detecting maritime abnormalities automatically by using a specific combination of optical sensors and algorithms. The following configuration has been chosen according to the requirements. Three optical sensor heads shown in Table 1 are arranged in a pod-mountable configuration, weighing a total mass of 23 kg including narrowband and broadband data downlink.

The average power consumption of about 200 W (including radios) is mainly due to the number of cameras and the embedded PC. The focal lengths of the sensor modules have been selected to achieve the desired ground sampling distances from an operational altitude of 2,500 ft above ground. Figure 4 shows a view of the complete system.

The sensor combination was selected to detect and describe maritime occurences based on the georeferenced multi-spectral image information. Objects in the water or polluted areas will be assigned with a suitable description of current time, position, category and signature. Additionally, an RGB real-time map with a ground pixel resolution of 12 cm will be generated automatically. By using a super high frequency (SHF) radio link, this information will be transmitted to a ground control center where it will serve as additional information for maritime decision-makers.

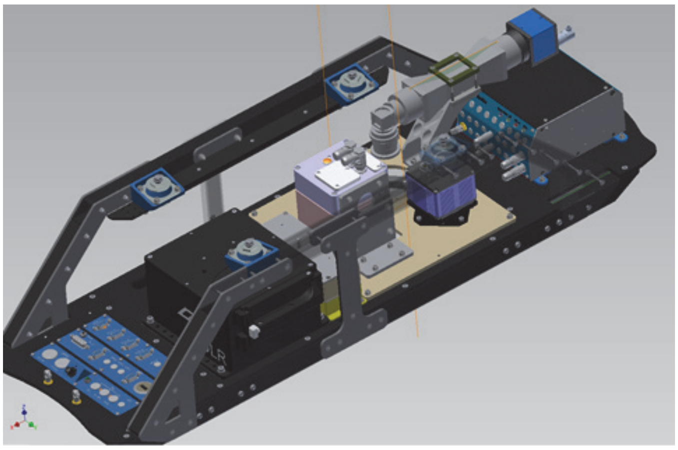

Fig. 4. Set-up of the MACS-Mar aerial camera system with vertically aligned thermal infrared, RGB and hyperspectral camera (illustration)

TABLE I. MACS-MAR CURRENT SENSOR CONFIGURATION

	RGB (Bayer color pattern)	Thermal Infrared	Hyperspectral
Spectral Bands (nm)	400 – 520 (blue) 500 – 590 (green) 590 – 680 (red)	7,500 – 14,000	450 – 950 (125 channels)
Resolution (pixels)	4,864 x 3,232	1,024 x 768	70 x 70
GSD @ 2,500 ft above ground / sea level (cm)	12	40	620
Field of View across track (deg)	40	32	34

As described in chapter I, two main classes of objects will be detected and annotated by the camera system. By using two vertically looking camera modules recording data in the visual and thermal infrared spectral range, small-scale objects (persons in rescue gear, boats, life rafts and flotsam) can be detected. Even objects not visible in RGB data can be recognized by their thermal signature, i.e. emitted body temperature or engine heat. Figure 3 visualizes the advantages of using precise assigned multi-spectral information. A vessel has been detected within the visual image and in the thermal information. Vessel detection also works at night when no visual data is available.

The assigned hyperspectral information is suitable for detecting water pollution and assessing water qualities [15]. The lower resolution of this instrument does not impede this task due to the larger extent of maritime pollution. Here, too, the combination of hyperspectral data and thermal infrared data should improve classification results, which will be verified in the course of the project.

Through on-board processing and classification, it is possible to generate semantic information which is significantly smaller than image data. As described above, an ultra-high frequency (UHF) data link with bandwidth of approximately 9,600 Bit per second has been integrated for such applications. It can also be used for telemetry and even for remotely commanding the camera system during operation.

IV. FIRST RESULTS

In a series of initial tests, the system delivered georeferenced and ortho-rectified aerial image maps with a typical delay of less than one second between image acquisition on board and visualization on the ground. Over open water or level terrain and from 2,500 ft altitude above ground, ground pixel position accuracies of less than 5 m CEP have been observed without image based photogrammetric processing.

In addition to the image data mapped in real-time, the system is able to carry out segmentation and classification of defined object classes in real-time. Classes can be open water, land, polluted water, small objects, boats or ships. Using all three sensor heads does not triple the amount of data to be processed because of the reduced geometrical resolution from both the thermal infrared and the hyperspectral sensor. Nonetheless, the requirements on the hardware and algorithms to compute the temporarily required data are increased. The first classification tests have been carried out in post-processing and not yet in real time, the run-time optimization of the algorithms is under development to transfer it to the flight hardware.

Object recognition has been proven to benefit significantly from the use of a combination of RGB imagery and thermal infrared data. Thermal infrared images, albeit showing a lower geometrical resolution, are quite resistant to sun glitter, cloud shadows and other visual effects that can compromise automatic object extraction from RGB images. Also, cross-checking between the different data sources reduces the amount of false positives. On first available data sets a success rate of ca. 95 % was accomplished for items covering a minimum of 2 x 2 pixels in thermal infrared images and 4 x 4 pixels in RGB images, respectively. Figure 5 shows exemplary results of an automatic object-based classification on a combined data set.

Photogrammetric evaluation of the RGB sensor data has been tested, too. This feature may not be relevant for open water areas but there might be applications for the inspection of coast protection installations or even 3D reconstruction of maritime objects – such as offshore oil rigs – during post-processing.

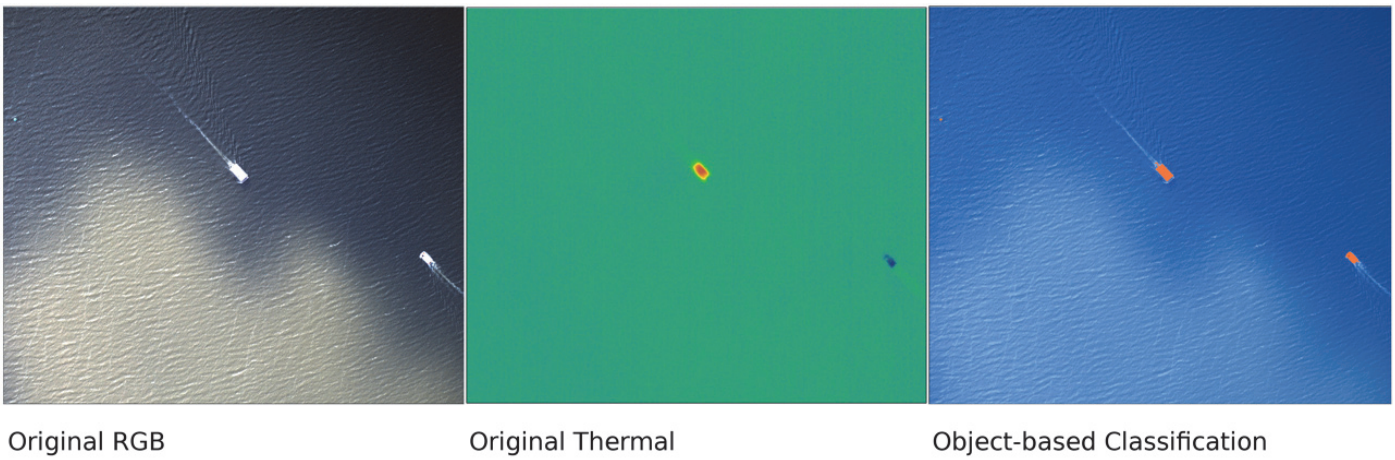

Fig. 5. Automatic object-based classification from the combination of RGB and thermal infrared imagery

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