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Analysis and design of Cubesat constellation for the Mediterranean south costal monitoring against illegal immigration

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Abstract

Costal monitoring is focused on fast response to illegal immigration and illegal ship traffic. Especially, the illegal ship traffic has been present in media since April 2015, as the number of reported deaths of immigrants crossing the Mediterranean significantly increased. Satellite images provide a possibility to at least partially control both types of events. This paper defines the principal criteria to select the best satellite constellation architecture for maritime and coastal monitoring, filling the gaps of imagery techniques in term of real-time control. The primary purpose of a constellation is to obtain global measurement improving the temporal resolution. The small size and low-cost are the main factors, which make CubeSats ideal for use in constellations. We propose a constellation of 9 Cubesats distributed evenly in 3 different planes. This reduces the revisit time enhancing the coverage duration. In addition, it also allows observing fire, damage on building and similar disasters. In this analysis, the performance criteria were reported such as the revisit time, the vision duration and the area coverage.

Keywords: CubeSat; Constellation; Coverage; Revisit time

1. Introduction

Maritime surveillance has been receiving a growing interest during the recent years (Hassanin et al., 2015; Mazzarella et al., 2015). It has been performed mostly with information from vessel monitoring systems based on cooperative transmitting technologies, but in the last years other observation platforms are possible as well. A significant number of illegal immigrants cross the Mediterranean to Europe in overcrowded small boats inappropriate for a journey on the open sea. Immigrants, who in a hope for a better life try embarking on a dangerous journey to Europe, mostly originate from African countries. Unfortunately, many immigrants lose lives on the journey. Even if immigrants survive the dangerous journey, many do not get an asylum approved and can be deported back to where they came from Mbugua and Nganga (2012). In addition, the number of victims can increase due to the irregular departure to Europe in a repetitive manner. Although a significant number of victims were recorded already in 2014, the year 2015 represents the deadliest year. Particularly, many victims were recorded in April 2015, as nearly 1250 immigrants died. Among 828 immigrants, only 28 survived and were brought to Italy due to capsizing of the ship in the coast of Libya (NBC News, 2015).

Otherwise, in the framework of control and safety of fishing boats, Tunisia, as an African country with a long coast in the Mediterranean, has named a communication unit with the control centers (U3C), allowing to determine the location of the boat, its direction and its speed, besides

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the exchange information immediately. This is a project to monitor the activities of the boats, to the benefit of the Directorate General of Fisheries and Aquaculture and allows launching alerts in urgent cases such as accidents or natural disasters in the sea.

Real-time maritime monitoring requires using several techniques such as the air imaging, ground observations, and updated maps based on drone data collection. However, these data usually contain gaps in temporal or spatial coverage. Thus, imagery from satellites present promising advantages to accomplish this goal filling the missing requirements presented with the classical techniques. Various satellite systems have the capacity to quickly acquire images in different incidence angles. These include the push-broom Imaging IKONOS (Cook et al., 2001), Quickbird (Miers and Munro, 2001), the Multi-angle Imaging Spectro-Radiometer (MISR) Diner and Beckert, 1998, the Along Track Scanning Radiometers (ATSR-1, ATSR-2, AATSR) (Edwards and Llewellyn-Jones, 2002). However, all these systems can't respond to a continuous coverage and monitoring during the mission. In addition, these require big budgets in term of mission and construction.

Here, a CubeSat constellation method is proposed for a quasi-periodic coverage with the minimum revisit time and the lowest production cost. Ulybyshev (2009) modeled satellite constellation architecture on elliptical orbits of the Molniya type using critical inclination and putting the orbit apogee in the Earth's hemisphere, with an area of continuous coverage with periods of ~4, 12, and 24 h. Nicholas et al. (2013) proposed an Ad Hoc constellation to obtain global measurements with improved spatial and temporal resolution. Ad Hoc can decrease global satellite revisit time to 6 h and response time to 13 h.

CubeSat technology can provide the key technology to close this gap by introducing larger constellations of small satellites in Low Earth Orbit, thus increasing temporal and spatial coverage at reasonable cost. A CubeSat is a small satellite standard with strict standards for size, mass, power, and launch configurations. COTS (Commercial Off-the-Shelf) components are an integral part of CubeSat design, and there are companies that specifically target the CubeSat market (e.g. Pumpkin and Clyde Space). Due to this standardization and availability of COTS components, Cubesats are relatively cheap and simple to integrate when compared with larger satellites. Each unit (U) of a CubeSat is a 10 cm × 10 cm × 10 cm cube with a 1.33 kg upper mass limit (The CubeSat program, 2009). For this mission, a Cubesat which standardized 1 → 3 unit assembly, where each unit is a 10 × 10 × 10 cm box containing one or more subsystems.

To accomplish the goal of the real-time monitoring, a constellation of several units is necessary to meet requirements of different applications. A good option is a constellation of CubeSats flying in different orbital planes; each CubeSat acquires images of a chosen scene in different positions and time (Bernard and Decluseau, 2012).

2. Case of study overview

The main objective of the proposed mission is the continuous monitoring of sea with a focus on illegal immigration. Mediterranean Countries as Tunisia, Libya and Morocco are particularly vulnerable to this immigration activity (Fig. 1).

The proposed mission is a Tunisian project based evolved on the experiences of the German NetSat andUWE-3 mission (Busch et al., 2015) demonstrating in-orbit technologies for autonomous flight.

3. Mission and requirements

The two main mission drivers are the minimum revisit time and low-cost for every mission. These drivers constrain the mission as seen in Fig. 2, leading to the use of small satellite constellations.

The most suitable orbit for the proposed mission is a Low Earth Orbit (LEO). The operational orbit characteristics will be driven by the response to the specific user requirements.

To achieve the temporal coverage desired for earth observation, we seek to reduce the waiting time to observe the specific area and we need a revisit time that should not exceed 25 min. In this state, we look to have an interval duration of 5 min at least.

General parameters are shown in Table 1.

3.1. Description of entire system sensor

There are various tools for maritime monitoring. Larger and regular vessels are equipped with the Automatic Identification System (AIS), which transmits the location of the ship to the traffic control center via radio communication. However, irregular small vessels usually cancel its functionality.

Radar technology is widely used in maritime traffic control systems to detect and track ships. In general, it is very accurate technology, but interference in the radar signal coming from echoes of other targets such as ground, sea and other atmospheric effects makes detection more difficult and it needs high power, and the antennas tend to be large. In addition, small and non-metallic vessels are not detected. Alongside these technical difficulties, the application of radar technology is rather expensive.

Optical satellite imagery has recently been used for the detection of ships, as they can provide more detailed information for small target detection and ship recognition. In addition, the interpretation of an optical image is simpler than that of a radar technology. They can be very agile using different off-nadir angles. A disadvantage is that they depend heavily on the weather and they can only operate during the day. Optical satellites combined with SAR satellites can provide more frequent monitoring (M'attyus, 2013).