FUEGO: A DEDICATED CONSTELLATION OF SMALL SATELLITES TO DETECT AND MONITOR FOREST FIRES

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ABSTRACT

The objective of FUEGO programme is the design and development of a space-based system for the early detection and monitoring of forest fires. The studies carried out lead to a LEO constellation of small satellites as the best solution to fulfil the user requirements. This solution allows the utilisation of small service buses as the ones like INTA MINISAT series, reducing the mission complexity and costs. The system consists on a Walker constellation 12/3/2 at 700 km altitude and 47.5 deg inclination orbit, which optimise parameters such as the revisit time and image resolution. The payload is based in a MIR camera to detect forest fires assisted by a VIS/NIR and TIR cameras to improve the resolution of the fire monitoring and to reject false alarms. The acquisition is made by means of a pushbroom technique, using a steerable mirror to point the sensor beam and pitch manoeuvres to increase the coverage.

1 INTRODUCTION

The forest fire phenomena in temperate latitudes represent a serious economical and ecological problem, especially in some areas as the Mediterranean ones in Europe. The current fire fighting systems are not efficient enough to manage this problem, as can be seen from the statistics of forest fires and area burnt every year.

Nowadays the forest fire fighting strategy is based on fixed towers with observers on the top, supported by mobile ground patrols or aerial means. There are also some new technologies as IR towers, but their operational results do not completely satisfy the users.

FUEGO is a space-based system designed to provide fire fighters with a powerful tool for early fire detection and monitoring of forest fires, as well as an efficient risk and damage assessment tool.

FUEGO has been conceived from the outset as a user driven system, it has been designed and developed in cooperation with final users (forest fire fighters, forest fire fighting organisations, civil protection organisations…) by means of users conferences, meetings, and questionnaires. Users have been involved in every stage of the design process and have been periodically informed about the evolution of the system, ensuring that the system is tailored to the forest fire-fighting services needs.

2 SYSTEM REQUIREMENTS

The most important user requirement is the early detection of small fire outbreaks, to allow a fast control of the fire when it has not reached an unmanageable size. The geo-location accuracy is another key requirement as well as the monitoring resolution and the reception of the data in real time. The main user requirements, fulfilled by the system, are:

- Data reception, processing, and dissemination in near real time at regional level.
- Continuous service in time, coverage of 100% of risk areas, easy to use by the ground staff, robust, reliable, and low cost.

• Detection phase

- Outbreaks time detection of less than 15 minutes in average, that is a revisit time in the order of 25 minutes.
- A minimum detection size of fire of 50 m^2, with automatic alarm generation and intensity classification.
- Geolocation of fire alarms within 300-500 m.
- The probability of false alarm should not exceed 5% of the cases.

• Monitoring phase

- Automatic monitoring information for on-going fires larger than 25 Ha, without previous request.

- The geo-location of monitoring products should have accuracy of the order of magnitude of the pixel (35-50 m), as well as the resolution of the images.

The areas of surveillance are located in the temperate forest latitudes (37 deg – 46 deg) in both hemispheres. The main areas are located in the Mediterranean area of Europe (30 MHa), the rest of the areas are located in the west coast of USA, Florida, Canada, Chile, and Australia.

3 MISSION DESCRIPTION

The main constraint of the system is the detection time, and several solutions have been studied to minimize it. The revisit time requirement leads to a LEO constellation of twelve satellites as can be seen hereafter.

- **GEO**. It would be able to cover all the risk areas in Europe with only one satellite (three for a world wide coverage) in a continuous way. But the dimensions of the payload and specially of the optics to meet the image resolution requirements would be very high, for a monitoring resolution of 144 m, the corresponding focal length is 5.35 m. This makes unfeasible the utilization of a small platform, with small costs.
- **MEO**. It can be reached a good revisit time, lower than 10 minutes in some cases, with only eight satellites between 5000 km and 15000 km. However, in this case the main drawback is again the size of the telescope to provide a useful resolution for the detection phase, the monitoring is unaffordable for altitudes over 5000 km due to the mass and size requirements of the payload needed and imposed to the platform.
- **LEO**. A revisit time of less than 25 minutes can be reached with twelve small satellites at 600 to 900 km of altitude. The payload required is small enough to allow the utilization of small platforms, easy and cheap enough to make the system economically feasible.

Several studies have been carried out in order to select the optimal constellation to fulfil the user requirements. The constellation altitude, inclination and number of satellites have been optimised to reach an economical system, which is able to provide the forest fire fighters with a useful tool.

Taking into account the geometrical and radiometric resolution required by the users, the distribution of the areas of surveillance, the technological constrains of the sensors (detectors size, optic aberrations) and system cost, the trade offs carried out lead to a configuration with a swath of 2500 km, a field of view of 177 km at nadir, and a circular orbit of 47.5 deg inclination at 700 km altitude. This configuration provides a resolution up to 20 m at nadir.

In general, since a unique satellite placed in this orbit is able to observe the same region during around 5 consecutive passes (the orbital period is around 100 min so this takes 5 x 100 min ≅ 8 hours), at least three different planes are needed to provide continuous service during 24 hours per day. But 100 min revisit time is not enough frequency, therefore there is needed to insert more satellites into those planes. Constellations of N times three have been considered, yielding the results shown in Figure 1.

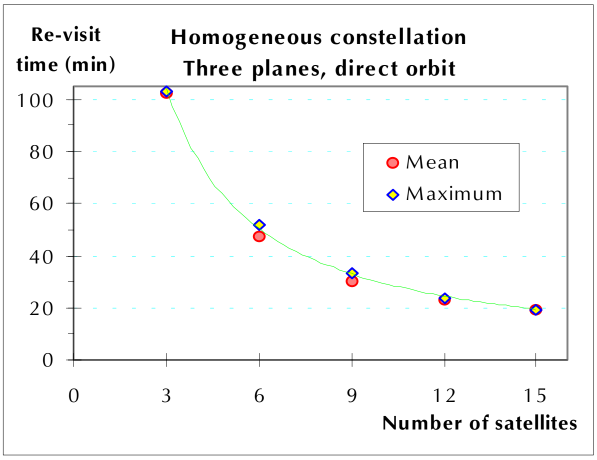

Figure 1: *Simulation result for latitude 40 deg*

Orbit Profile	
Altitude	700 Km
Orbital inclination	47.5 deg
Orbital period	98.8 min
Orbital geometry	Circular
Satellite constellation design	
Number of satellites	12
Configuration	Direct Walker (12/3/2)
Symmetry	Homogeneous
Revisit time	23.8 min medium & 25.8 min maximum
Service	Continuous (24 h a day)

Table 1: *Baseline mission parameters*

The twelve-satellite solution is a good compromise to provide 25 minutes re-visit time. In order to homogenize the observation pattern a direct Walker 12/3/2 constellation has been selected. The constellation parameters can be seen in Table 1.

The main products offered by the system will be fire outbreak detection and fire monitoring:

- Fire detection. Small fires (20 - 220 m^2) will be detected in less than 15 and 25 minutes of average and maximum time, respectively. Additional information could be included as meteorological information, GIS, …
- Fire monitoring. Fires larger than 25 ha in the areas of risk will be monitored in an automatic way, with a temporal resolution of 25 to 90 minutes and a image resolution of 20-80 m. Users can ask for the monitoring of the areas of interest when necessary.

Other products can be offered as post-fire phase products (identification fire hotspots with potential danger to restart a fire, burnt area assessment…) or other Earth studies (applications like vulcanology, hot events, meteorology, forestry, etc). For those products other areas of interest are defined apart from the ones mentioned above.

The system will be available 24 hours per day, 365 days per year. Both products will be offered by means of an easy to use graphical interface like the one shown in Figure 2.

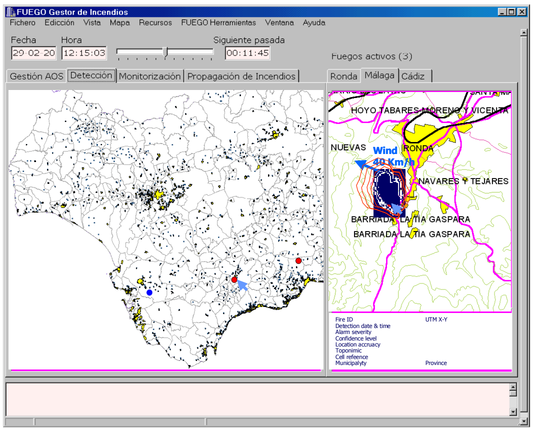

Figure 2: *FUEGO System Demonstrator*

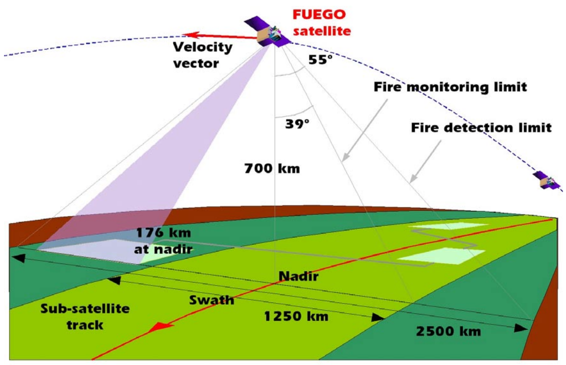

Figure 3*: Geometric Observation Sketch*

4 OPERATIONAL CONCEPT

In detection mode the data acquisition is made by means of a pushbroom technique using a steerable mirror to point to the areas of interest (Figure 3). One of the advantages of the FUEGO system is that the satellites are capable of concentrating the observation mostly on the interesting areas, being not necessary to cover the whole satellite swath. The satellite will be able to perform pitch manoeuvres in order to have more than one observation opportunity on certain track points in which the satellite is not able to observe the whole areas of interest with just one pass.

The areas of surveillance can be updated every day by the users. This information is sent to the Mission Control Centre from the Primary User Stations. With all of this information the MCC generates the ‘Plan of Observation’ by means of coverage simulations. This plan contains the tasks to be performed by the payload, as well as satellite pointing required, both referenced in time. After that, the MCC schedules all satellite operations and generates the proper telecommands to be transmitted to the satellite by the Primary Ground Station.

The payload data are directly transmitted to user ground stations in real time by means of a L-band communication subsystem. The data will be processed on ground at the local user stations, which will generate the final FUEGO product.

5 PAYLOAD DESCRIPTION

The payload required by the system has been designed to fulfil the user requirements with the minimum mass and power consumption as possible. This constrains make possible to fit the payload into a small satellite.

The payload mass has been reduced to 62 kg. The power consumption depends on the duty cycle of the satellite (time for observation, sun-pointing, stand by, calibration,..). The daily average of acquisition is 14 % of the time. The peak power consumption during these periods is 180 W, and the average 140 W. During the stand-by periods the payload power consumption remains below 75 W.

The FUEGO system is provided with four cameras:

- **MIR**: This medium infrared camera is the most appropriate to detect potential fires since it has the optimal spectral range in terms of maximum fire / background contrast for detection of hot spots. Staggered sensors are used to increase the image resolution.
- **VISNIR**: This visible and near infrared camera data is required to discriminate false alarms due to small sun glints. It is also used to provide high-resolution data for the fire geolocation and for monitoring images and for the NDVI calculation.
- **TIR**: This thermal infrared camera provides information on cloud presence and it also helps to reject false alarms due to warm surfaces.

A payload processor will be used to perform the payload data management (the data flow estimated is 3.2 Mbps) in order to free the OBDH of this task and reduce the data processing time. A scan mirror is used to point the sensor beam across track. Other payload elements are the calibration objects and the optical bench, a rigid structure to which all the instruments are attached.

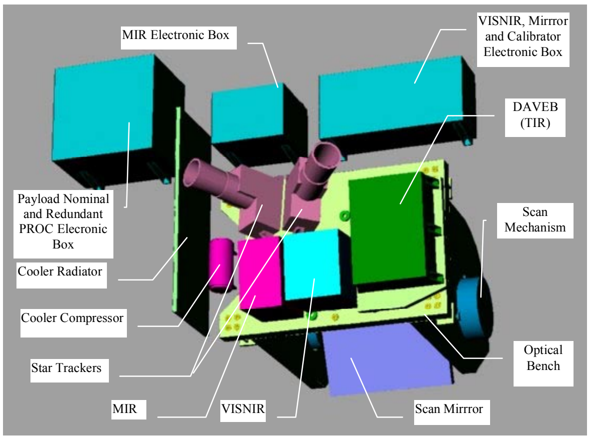

Figure 4: *FUEGO Instrument*

	MIR	TIR	VIS	NIR
Geometry				
Num elements per row	1100x2	240@45°	8800	8800
Num elements total	2200	480	8800	8800
Element footprint (m)	128	519	18	18
Spatial sampling (m)	80	367	20 (x4)	20 (x4)
Effective resolution (m)	101	436	80	80
Field of view (deg)	14.41	14.41	14.41	14.41
Radiometry				
Channel centre (µm)	3.80	10.0	0.63	0.83
Channel width (µm)	0.70	4.0	0.10	0.14
Sampling time (µs)	12.49	57.23	3.122	3.122

Table 2: *Summary of payload parameters*

6 SERVICE BUS DESCRIPTION

The reduced dimensions (volume, mass and power) of the FUEGO payload make it suitable to be fit in a small service bus. At present, an adaptation of the INTA-CESAR service bus and the FUEGO payload has been carried out in order to converge both elements into a feasible satellite.

The communications subsystem is based on a S-band system for service module and payload telemetry and telecommand, and a L-band for the payload data downlink.

The service module is able to provide the payload the power required as well as the pointing control [0.15 deg across track and 0.1 deg along track] and stability [6 arcsec (1σ) from 0.5 Hz to 2 Hz and 3 arcsec (1σ) from 2 Hz to 150 Hz] required for the data acquisition. The capability of the service module to perform pitch manoeuvres of 45 deg in 30 seconds is required to improve the observation strategy of the areas of surveillance. This agility is favoured by the service bus design, outstretched along the axis of rotation. The dimensions of the service bus are 750x750x1800 mm, without solar panels.

The baseline launcher is Rockot. The geometry and mass (less than 240 kg) of the satellite allow the launch of four satellites at the same time. Since there are four satellites per plane, this launching strategy is optimum requiring only three launches for the whole constellation, with the resulting cost saving for the system.

7 CONCLUSIONS

FUEGO is being developed under the EU 4th Framework Programme and the European Space Agency Observation Programmes, and plans to start full operational service in 2005. It is a good example of cooperation between private and public actors to set up a space operational system.

FUEGO will provide fire-fighting organisations with an innovative and powerful tool to manage the forest fire problem. FUEGO concept has been defined through interaction with the users and based on a design-to-cost approach.

FUEGO has demonstrated that user requirements can be fulfilled using small satellites in a LEO constellation. This solution is based mostly on COTS components, resulting a low-cost full operational system.

Coverage will be provided to 30 MHa in Europe and 30 MHa in the rest of the world, resulting in an estimated service cost of 0.7 EUR/Ha per year. The predicted cost of the system is estimated to 203 MEUR, while the income will be 265 MEUR for a lifetime of 7 years.