SPACEBORNE-AIRBORNE BISTATIC RADAR FOR UAS NAVIGATION PURPOSES: PRELIMINARY ANALYSIS AND STRAWMAN SYSTEM IDENTIFICATION

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1. INTRODUCTION

Navigation of Unmanned Airborne Systems (UAS) is mainly performed with satellite navigation systems (e.g. GPS, Galileo) which offer accurate and reliable navigation data, but no information about the surrounding environment. A vision-based navigation system can greatly improve UAS autonomy with an additional beneficial impact on obstacle avoidance capability. Synthetic Aperture Radars offer great capabilities and have been already experienced on-board aircrafts of different classes. Nevertheless, such sensors have been only used as experimental remote sensing payloads in side-looking geometry. For navigation purposes a forward looking geometry is preferable, but it has been rarely experienced due to major limitations (imaging geometry) [1] which can by only partially mitigated at the cost of strong complexities [2-4]. Bistatic Synthetic Aperture Radars have beneficial effect on an imaging radar for navigation purposes in reducing, forward-looking geometric limitations. In addition, the airborne receiver can be much more compact and lightweight, with a reduced power request. In the following, a navigation system based on bistatic SARs relying on spaceborne transmitters and airborne receivers is analyzed to obtain a preliminary feasibility assessment and a preliminary definition of a strawman system concept. The study herein reported was carried out under ESA contract 22449/09/F/MOS.

2. REQUIREMENT ANALYSIS

UASs can be categorized either accordingly to the type of the mission, or on the basis of altitude/endurance/range performance, or depending on maximum take-off weight (MTOW), on propulsion technology, etc. In the study herein described, a MTOW Class 1 vehicle is assumed as a reference UAS platform with the following characteristics: altitude <5000m; MTOW<500kg; endurance7 hours; range 60km; max velocity 70m/s; cruise velocity 52m/s. A typical flight profile for such vehicle accounts for take-off, climb, mission maneuvering/execution; descent; holding, diversion, landing. Depending on mission and UASs capabilities, mission phases can be totally or partially automated with complexities of relevant GNC algorithms depending on the a-priori knowledge of the operational environment. Such automation may typically require some operative needs, such as: sense and avoid (allows a safe cooperated or non-cooperated flight with the other scenario participants with utilization of sensors such as inertial sensors, with/without GPS, and radars); navigation aid (in case of totally or partially obscured communications); on air or on ground target tracking (sensors used are infrared/optical imaging sensors and tracking radars with limitations arising depending on weather conditions, stealth targets, etc.); identification of landing site and of ground obstacles. Results of requirement analysis for the selected UAS are summarized in Tab. 1 (R, θ and Ψ are range, azimuth, and elevation of the target wrt the UAS).

3. PERFORMANCE ANALYSIS

The adoption of a spacecraft constellation for providing future UASs with high-resolution forward-looking imaging capability to support autonomous navigation has been analyzed. According to the gradient method [4-6], the main limitations of monostatic forward-looking operation due to range/Doppler ambiguity can be overcome provided that specific requirements on the acquisition geometry are satisfied. For LEO transmitters greater and more complex constraints are established on allowed relative configurations, that is for any given illuminator position only a limited range of velocities are allowed. On the contrary, for GEO/MEO illuminators performance depends solely on position. Figure 1 shows this different behavior, whereas the effect of transmitter-target-receiver relative geometry on range/Doppler directions is highlighted in Fig. 2. Thus, it is possible to state that for keeping low the number of illuminators and for simplifying the design of a constellation of satellite illuminators, MEO altitude could be a good choice, since no constraints are established on the orientation of the illuminator velocity.

	Application	**SAR BASED Sensor Preliminary Requirements**			
		FOV / Image size	Resolution / Accuracy	Minimun Update Frequency	Maximum Latency Time
MTI Mode	On Air Target Detection	R: 500ft..5Nmi θ: [-10..10]deg Θ: [-60..60]deg	R, θ, Ψ: [10m, 1.3deg, 1.4deg] $\dot{R}$, $\dot{\theta}$, $\dot{\Theta}$: [3m/s, 0.2deg/s, 0.2deg/s]	10Hz (target) 1Hz (acceptable)	0.1s (target) 0.5s (Acceptable)
	On Ground Target Detection	R>3.8Nmi θ: [-15..15]deg Θ: [-60..60]deg		0.3Hz	0.1s
Image Mode	Map based Navigation	Minimum distance from UAV: Don't Care Size: as large as possible	Landing: Horiz. 1m Mid-Air Horiz. 10m, Vert. 15m	1Hz (landing) 10min (mid-air)	0.1s (landing) 5min (mid-air)
	On Ground Obstacle and Runway Detection	(runway always in view) R: 0..3.8km θ, Θ, : ±20deg	Resolutions: Transversal/Aligned to UAV motion: 2m/10m Obstacle size: 80cm	One shot is acceptable. Target : more than one shot	Latency shall be accurately known
	3D Synthetic Vision for RPV	(runway always in view) R: 0..3km θ : ±40deg Θ: ±50deg	Horiz. Accuracy Landing: 1m Mid-Air: 10m	10Hz	0.1s (normal) 0.3s (degraded)

Table 1 Summary of SAR Sensor Required Performance.

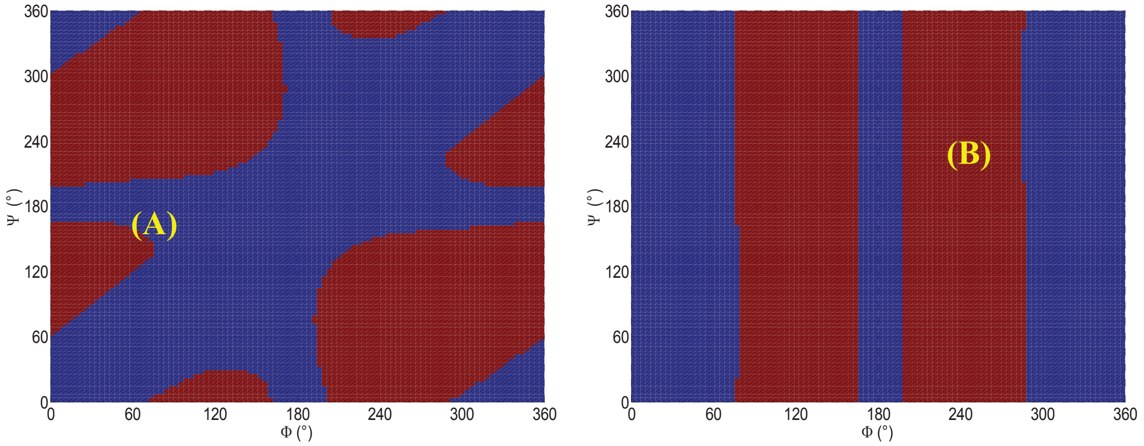

Figure 1 Allowed illuminator position and velocity (red) for an airborne receiver and LEO (A) or MEO (B) illuminators (assumed performance: 4 m^2 pixel area and $30° < \Omega < 150°$), with the varying transmitter out-of-plane angle, Φ, and transmitter velocity out-of-plane angle, Ψ

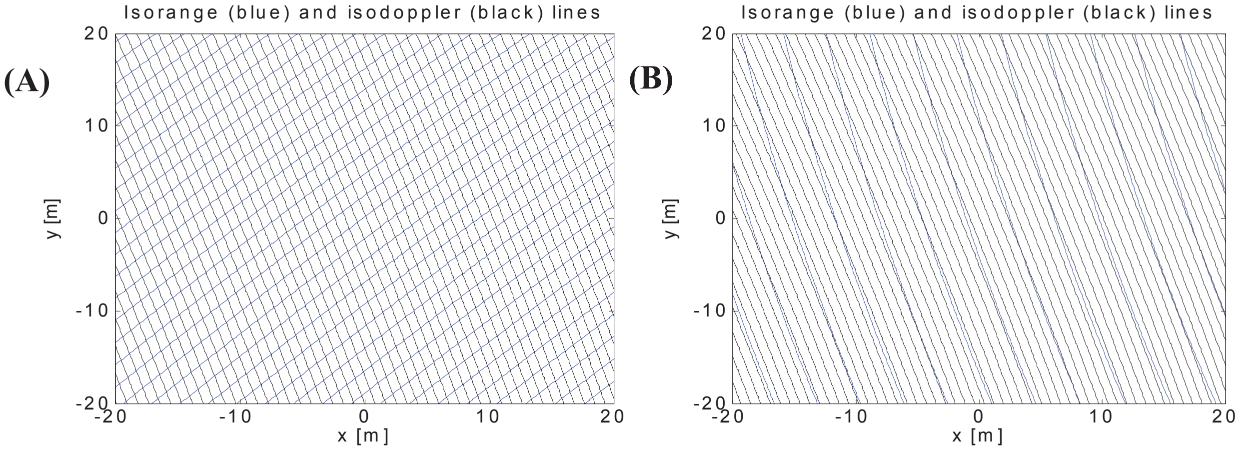

Figure 2 Performance of good (A) and poor (B) observation geometries. In the first (latter) case, transmitter out-of-plane angle is 220° (160°), velocity out-of-plane angle is 100° (90°), ground range and Doppler resolutions are 1.6m (3.5m) and 0.8m (0.75m), Ω is 105° (177°), pixel area is 1.5 m^2 (52m^2).

In such a case, satisfactory observation geometries can be resumed as follows: imaging mode – transmitter incidence angle ranging from 25 to 55 degrees, and transmitter out-of-plane angle ranging from 90 to 150 degrees or from 210 to 270 degrees; tracking mode – transmitter incidence angle lower than 60 degrees.

4. SYSTEM PRELIMINARY DEFINITION

On the basis of previous analysis, two preliminary strawman system configurations, characterized by different performance levels and complexities, can be envisaged, all building of an upgrade of Galileo constellation. In the first case, the additional payload to be embarked on Galileo satellites has a medium impact on the platform, whereas such impact is kept at a more reasonable level for the second option. For both options, the airborne receiver has the same parameters: altitude below 3000m, velocity up to 100m/s, antenna size 1m×0.5m, fixed antenna pointing, antenna dimension for direct signal reception <0.01m^2, quantization level from 5+5 to 8+8 bits. In the case of transmitter (altitude 23222km, velocity <3km/s), parameters are listed in Tab. 2.

Assuming that all 27 Galileo satellites are equipped with such payloads, imaging and MTI capability has been verified by a constellation simulation over Europe which shows that: (a) MTI capability is guaranteed at any time for any target with multiple satellites (at least 6); image capability is guaranteed at any time for any target over 78.6% of the routes towards any target.

	Configuration #1	**Configuration #2**
Antenna dimension (diameter)	10 m	2 m
Transmitted Power	2 kW	50 W
Radar Wavelength	L-Band	L-Band
Radar Bandwidth	250 MHz	50 MHz
Radar duty cycle	0.25	1
Area covered by a single spot beam	2500 km	6000 km
Number of simultaneous spot beams	2-4	1

Table 2 Transmitter constellation parameters for each selected system configuration.

5. CONCLUSIONS

A feasibility study was conducted of a novel navigation system for UAS based on a constellation of spaceborne radar transmitters and airborne receivers, which are mounted in a forward-looking geometry. The derived performance established the ground for the identification of two strawman system concepts, with different performance and system complications/challenges and based on the use of Galileo constellation with additional payloads with medium to low modifications of GALILEO satellites. The first system has to be considered only as an on-demand service provider, whereas the second, even if characterized by worse performance, could be developed to continuously illuminate a set of given, thousands of kilometers wide, target areas. Besides some limitations of achieved versus required performance, it is shown idea robustness, in fact several UAS navigation applications could be fulfilled at the required geo-radiometric accuracy and time schedule.

6. REFERENCES

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