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Creation of in-sky safety system using ADS-B radar receiver based on RTL-SDR device for SLR station Golosiiv

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The purpose of this work is to develop and assemble the real-time in-sky safety system for SLR (Satellite Laser Ranging) system. It is based on receiving ADS-B protocol aircraft data via RTL-SDR device. This solution represents an asynchronous service in the SLR laser control system. It instantly inhibits SLR laser pulses in order to prevent illumination of an aircraft. The service is ready at the SLR station 'Golosiiv' (Ukraine) (EUROLAS Data Center ID – 1824)[1].

Key words: space and satellite communication, geodesy

INTRODUCTION

Satellite Laser Ranging (SLR) is a method of determining the topocentric distance to a satellite, using laser pulses, by the principle station-satellite-station. The operational principle of the SLR station was completely described in [4]. In order to deal with atmospheric and ionospheric distortion and absorption laser pulses have the minimum threshold of the flow power and coil, which are significant compared to generated by 'non-astronomical' laser instruments. This defines the SLR station as an operator of a powerful laser device and requires to concern the safety of use the airspace. This responsibility is backed up by law in many countries around the world, and the methodology for implementing a security system for SLR stations is a topical issue for the International Laser Ranging Service[2] [2, 7].

The SLR station 'Golosiiv' (Ukraine) [1, 3] is equipped with a picosecond laser type Nd:YAN with a pulse energy up to 10 mJ at wavelength of 532 nm – maximum peak power of 200 MW. The impulses of this power cause a temporary threat to sight at distances up to 30 km [5]. According to the types of perception, the effects of beam penetration are divided into complete blindness, short blinding, flash, shine and distraction. Almost all SLR lasers have the highest class of hazard under the standardised classification[3]. As an example, statistics on laser illumination of aircrafts in USA[4] is shown in Figure 1.

The specifics of the station 'Golosiiv' (Ukraine) is its location near the two international civil airports — Zhulyany (IEV) and Boryspil (KBP). Also there are several flight schools nearby around Kyiv (Ukraine). Many aircrafts perform a take off and altitude gaining, and also perform long landing maneuvers in the area of visibility of the station. These circumstances create saturated and fast air traffic, which can prevent SLR station from continuous observations. Practically, the number of potentially dangerous cases (when, according to our definition, the location of a target satellite near the aircraft is at angular distance of less than 10°) is in average 12 per day.

MOTIVATION

There are several common methods and instruments of implementing in-sky safety at SLR station.

Most popular technique is visual aircraft detection. Often, it is a telescope-mounted camera, and an observer (human or computer vision service) monitoring the image from the camera in real time. This method is quite reliable, but if single observer maintains station, then his attention may not be enough to quickly analyse the image and perform necessary actions. In addition, there is no guarantee that a plane in the sky can be detected visually through

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[1]https://edc.dgfi.tum.de/en/stations/1824/
[2]https://cddis.nasa.gov/lw18/#safety
[3]http://www.lasersafetyfacts.com/laserclasses.html
[4]http://www.laserpointersafety.com/news/news/other-news_files/category-statistics.php

the camera.

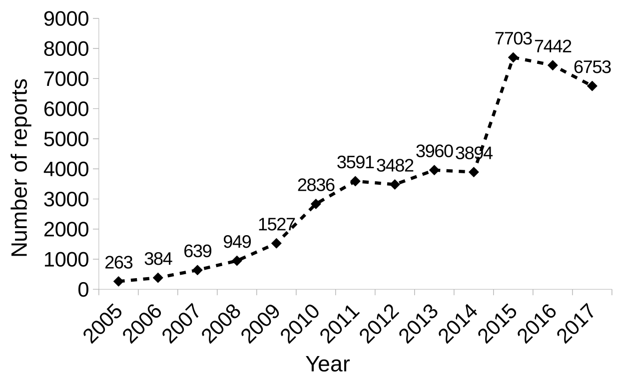

Fig. 1: Aircraft illumination by laser incidents annual total in USA.

Second technique based on LIDAR technology (Light Identification, Detection and Ranging). Such safety systems require high power and autonomy. A well-known example is the Laser Hazard Reduction System (LHRS) [8] — a commercial (proprietary) system developed by the Naval Research Laboratory of the United States. It combines visual and location detection, and also has the ability to use the laser interface for automatic control. Its main advantage is reliability at very high densities of air traffic. LHRS was developed in 2003, and by 2017 it costs approximately 550 000 USD. Of course, the system is not popular for such a price.

The use of a passive receiver is the third technique. It is based on the detection of specific signals directly from the aircraft. Nowadays it is the best option because aircrafts are required to report or broadcast their status and location using numerous data exchange protocols periodically. The most used protocol for such messages is ADS-B (Automatic Dependent Surveillance-Broadcast). According to EU legislation, this protocol is mandatory, therefore only it can be considered for our case. Designed to avoid collisions of planes during the flight, ADS-B provides the broadcast of geographic coordinates and barometric data (provided by GPS), direction of movement, course, condition and orientation of the aircraft. The data is transmitted by the encoded radio signal propagating the on-board transmitter at a constant frequencies of 1090 and 1030 MHz – for ground and air receivers respectively. The protocol is public, so the decryption of the signal can be done by any radio enthusiast. The broad community has developed many implementations of the protocol along with receivers. In this work, one of them is used.

ADS-B PROTOCOL AND DATA MODEL

A terrestrial receiver acquires transmitted data from aircrafts in the area of it's visibility. Receiver must accept modulated signal and recognise message by it's beginning and end. Data unit is message, a binary data packet. Table 1 shows the content of decoded data. This structure was used in the present paper as the final form of the ADS-B message. Its name is SBS–1[5]. Fields marked with bold text are sufficient for identification of an aircraft.

After data received, geographic coordinates of an aircraft (r_{geo}) must be transformed into local horizontal coordinates.

$$\vec{r}_{hor} = \mathbb{Q}(90^\circ - \phi_0)\mathbb{R}(\lambda_0)\vec{r}_{geo} - \vec{R}_{geo},$$

where $\mathbb{Q}$ and $\mathbb{R}$ – rotation operators for OY and OZ axes. R_{geo} refers to geograïňĄcal coodinates of the SLR station. We assume $\Delta\lambda = \lambda - \lambda_0$ (longitude difference) and $\Delta\phi = \phi - \phi_0$ (latitude difference) small and calculate radius-vector components in horizontal coordinates:

$$A = \tan\left(\frac{\Delta\lambda\cos\phi}{\Delta\phi + \frac{1}{2}(\Delta\lambda)^2\sin\phi_0\cos\phi}\right), \qquad (1)$$

$$\Delta^2 = (\Delta\phi)^2 + (\Delta\lambda)^2\cos^2\phi, \qquad (2)$$

$$H = \tan\left(\frac{(h-h_0) - \Delta^2(R+h)(h-h_0)}{\Delta^2(R+h)^2}\right), \qquad (3)$$

$$d = (R+h)\,\frac{\Delta\lambda\cos\phi\sqrt{(1+\tan^2 A)(1+\tan^2 H)}}{\tan A}.$$

So, we derived azimuth from Eq. (1), elevation from Eq. (2) and distance from Eq. (3). Next step is to calculate angular distance between an aircraft (ac) and the direction of the laser (lz):

$$\alpha = \arccos\left(\sin H_{lz}\sin H_{ac} + \cos H_{lz}\cos H_{ac}\cos\left(A_{lz} - A_{ac}\right)\right).$$

If $\alpha < 10^\circ$ for any visible aircraft then we inhibit laser pulses.

A single aircraft independently broadcasts ADS-B messages (up to 10 messages per second). So, a single receiver may acquire them simultaneously from different aircrafts. That is why receiver has limitations of airspace visibility, depending on it's bandwidth and message processing time. Fortunately, common air traffic in Kyiv never exceeds that limitation. Nevertheless, other components of the safety system have to operate with minimal delays.

Data about the direction of the laser beam can be obtained in several ways. Most often, these data are generated by the telescope itself, using the sensor of the angle of rotation of the servo drive. At the time of this work, there was no such interface at the station 'Golosiiv' (Ukraine), so another approach was

[5]http://woodair.net/sbs/Article/Barebones42_Socket_Data.htm

used. It is based on the practical assumption that only one satellite is observed continuously in a single observation session. Since well-known ephemeris are used to guide the satellite, calculated position of the target is considered to be the direction of the beam. This simplifies a task of obtaining data because it appears discretely and periodically. At the SLR station 'Golosiiv' (Ukraine), the position of a satellite is obtained every second. So, precision of 10° angular distance is quite safe.

SAFETY SYSTEM ELEMENTS AND STRUCTURE

Figure 2 shows the architectural design of the real-time safety system. Its elements include a receiver (USB-Dongle with antenna), a protocol decoder process (the open source implementation – 'dump1090'[6]) and the operating process of calculating, storing and visualising radar data called 'SafetyManager'. Service provides notification of the status and management of the telescope's shutter to prevent beam spreading.

The decoder process and the 'SafetyManager' form a network structure 'client-server'. It is based on asynchronous write to and read from a socket on computer's network card. Two processes are not blocked by read/write operations and work independently. This selected structure is the quickest.

We use a T-shaped antenna, a simple Hertz vibrator, or a dipole antenna. The ADS-B signal is polarised vertically, so antenna is mounted vertically. The antenna connects to the receiver with a coaxial cable. The digital receiver is a Digital Video Broadcast USB-dongle. The dongle is equipped with a demodulating chip RTL2832U. The chip is the implementation of a so-called software-defined radio (SDR) [6] – computer processing of the radio signal, known among broad community of radio enthusiasts as 'RTL-SDR'[7]. These devices' cost is nearly 15 USD in total.

FINAL RESULTS

The created safety system was verified by several simulations and in practice, on real objects in Kyiv's sky. Experimentally, a real radar reach ranges from 100 to 150 km, depending on the height, weather and quality of the survey. Figure 3 shows simplified patterns of flights, taken from 'FlightRadar24' service[8]. There are many altitude gaining flights in western direction. Their visibility time at the station (the height above the horizon is larger than 20°) is 15–20 seconds. This part of the traffic represents the most significant danger to the observations. Safety system may be a process of operating system Linux or Windows (XP and newer version).

CONCLUSIONS

The possibility of developing and installing a common and cheap system of aircraft safety for the SLR stations was explored. The result was a satisfactory system based on the receiving and processing of data from an aircraft by the ADS-B protocol. Its hardware base is SDR device that is available for studying, cheap and is distributed among radio enthusiasts.

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[6] https://github.com/MalcolmRobb/dump1090
[7] https://www.rtl-sdr.com/
[8] https://www.flightradar24.com/

Table 1: Content of a message from aircraft, SBS-1 format.

Name	Type	Detailed info
Message type	hex number	Message purpose (position, status, basic responce, etc.)
Session ID	hex number	Unique message id (locally generated by receiver)
AircraftID	hex number	Unique aircraft id (locally generated by receiver)
HexIdent	hex number	Aircraft Mode-S hexadecimal code (global)
FlightID	dec number	Flight record number (locally generated by receiver)
Date message generated	dd/mm/yyyy	Here and below, local time
Time message generated	hh:mm:ss.xxxxxx	
Date message logged	dd/mm/yyyy	
Time message logged	hh:mm:ss.xxxxxx	
Callsign	hex number	Flight record number (global)
Altitude	dec number	Altitude in feets. Barometrical height relative to 1013.2 mb.
GroundSpeed	dec number	In knots
Track	float number	Track of aircraft. Derived from the velocity E/W and velocity N/S
Latitude	float number	In degrees
Longitude	float number	In degrees
VerticalRate	dec number	Vertical speed component in knots
Squawk	dec number	Specific status code of an aircraft

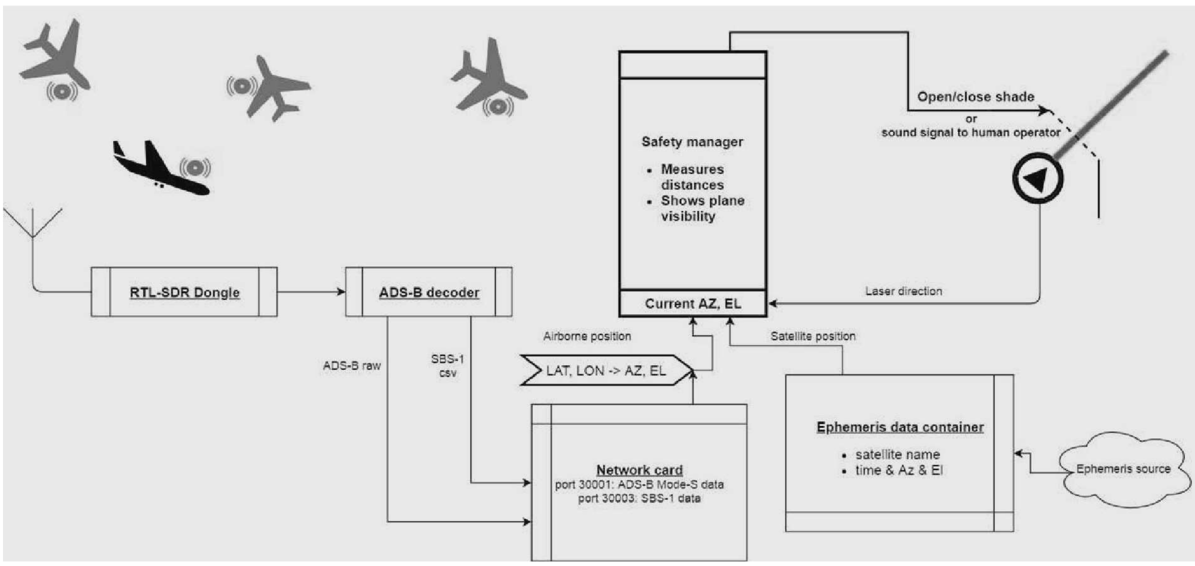

Fig. 2: Safety system principal scheme.

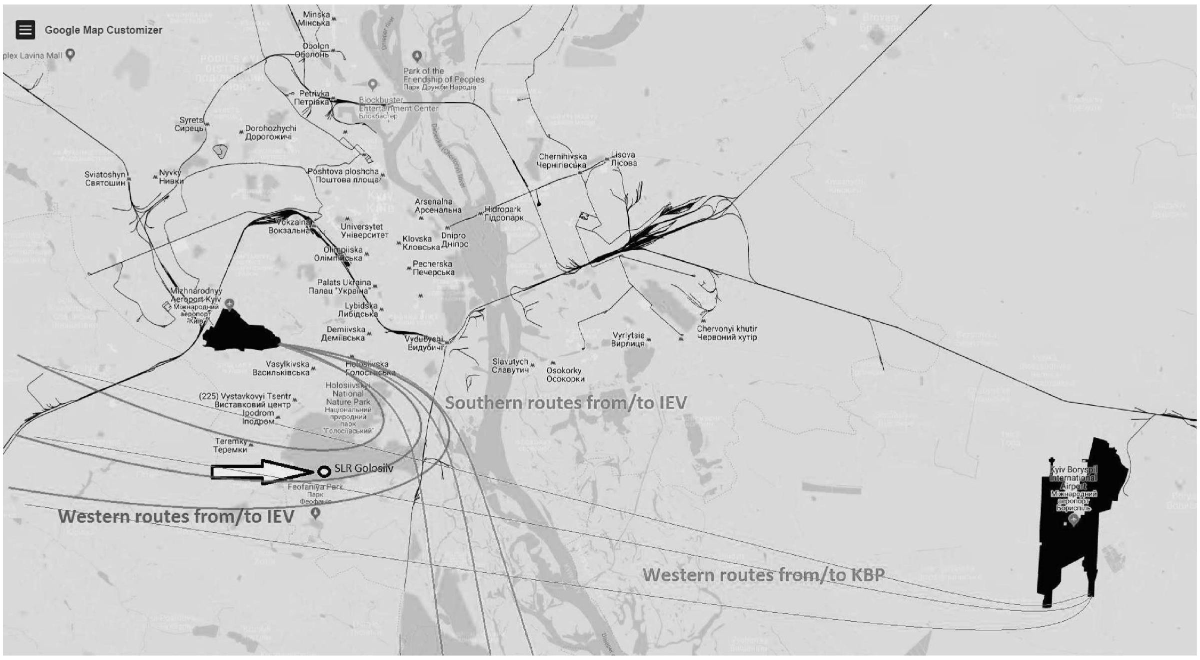

Fig. 3: Flights patterns across Kyiv and suburbs.