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The Testing of MLAT Method Application by means of Usage low-cost ADS-B Receivers

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Abstract— **The paper describes the process and results achieved during the measurement which was realized with the aim of identify an applicability of MLAT (Multilateration) method by means of using so-called "low-cost" ADS-B receivers. In terms of measurement, ADS-B receivers without GPS time synchronization module was utilized thus specific time synchronization method was required to implement.**

Keywords- Surveillance; Mode S; ADS-B; 1090ES; MLAT; Multilateration; transponder

I. Introduction

There is a wide range of so-called "low-cost" ADS-B receivers on today's market that are used for receiving 1090 ES (Extended Squitter) so as to decode and provide a position information obtained from these messages. This approach is suitable for tracking the commercial aircraft which are equipped with ADS-B technology. However, it is not sufficient for tracking the airplanes of General Aviation since only few of them are equipped 1090 ES technology. Nevertheless a majority of these aircraft are equipped by Mode S transponder nowadays. Hence, it is possible to employ a MLAT method in order to survey such traffic. This method enables to determine a position of the aircraft based on a measuring time difference in the signal reception on the several pairs of ground stations. Such kind of systems is already used in the field of commercial aviation. (An example of a producer that supplies alike system may be ERA, a.s.). Nonetheless, such systems are developed for ANSP (Air Navigation Service Providers) so that they are very efficient and expensive as well. Therefore, in terms of affordability, these systems are not applicable to the regional airports, for example.

Nowadays great effort is tend to improve safety in the area of General Aviation. Availability of suitable surveillance system could bring another evolution step in offer services in this area. Whilst the use of the surveillance information is crucial for operating Commercial Aviation nowadays, there is a complete lack of such technology in General Aviation.

The applications of multilateration method using low-cost ADS-B receivers could provide surveillance information for noncritical applications in aviation. It means the applications, whose primarily aren´t used for air traffic control, i.e. lives and health of people doesn't depends on such applications. For example it is applications for support of situation awareness of AFIS officers, or applications for FOC (Flight Operation Control) department within airline companies.

Application of MLAT method enables:

- Observation of an airplane based on receiving Mod S replies (Mod A/C replies). I.e. track the airplanes which aren´t equipped with ADS-B 1090ES technology.
- Possibility of verification of position information within ADS-B messages. False targets mitigation. There is possible to expect great problems with correctness of information within messages during the implementation 1090 ES technology in GA domain.
- Combination of ADS-B and MLAT method enable more frequent position information updates.
- MLAT method doesn't rely on navigation sensors on board. System is more robustness as far as local GPS jamming is concerned.

II. The Testing Platform

Within the scope of measurement there were used six ADS-B receivers AURORA from Eurotech Ltd. company. The receivers were lent by CS Soft a.s. company. The ADS-B receiver's deployment which simulated MLAT system is depicted in figure 1.

Since the position of every receiving station must be very precise located, the geodetic GNSS receiver Astech ProMark500 was used for positioning (figure 2). Data were being collected by FastSurvey software, which was operated on pocket PC Ashtech MobileMapper 10. Data were only collected in landscape. Afterwards obtained data were processed by ArcGIS 10.1. software. For positioning in every location around 600 points were measured out by means of GPS eventually GLONASS system. All measurements were improved by the aid of CZEPOS net of permanent references stations. (i.e. DGPS measurement was applied.)

During the measurement all points in the horizontal plane were positioning in S-JTSK Křovak coordinate system. Afterwards the transformation into WGS-84 coordination system was performed. The height is specified in the meters after ellipsoid WGS-84 (see Table 1). Actual multilateration calculation was executed in ECEF (Earth Centered Earth Fixed) coordinate system, or more precisely in ENU (East-North-Up) local topocentric coordinate system.

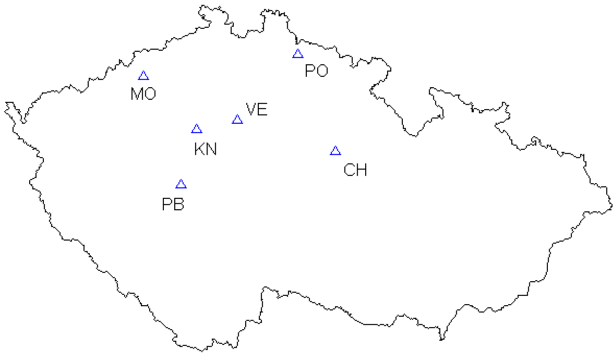

Figure 1. Positions of receiving stations

Figure 2. Ashtech ProMark500 (on the left side), Ahtech MobileMapper 10 (on the right side)

TABLE I. LOCATION OF RECEIVING STATIONS

ID	Location	Coordinates in WGS-84		High above ellipsoid WGS-84 [m]
		Latitude	Longitude	
MO	Most	50.495196 N	13.652872 E	366.4667
PB	Letiště Příbram	49.717652 N	14.097091 E	463.8876
KN	Kněževes	50.117934 N	14.258444 E	352.5686
VE	Nový Vestec	50.184171 N	14.723400 E	183.7791
PO	Rozhledna u Borovice	50.660266 N	15.401640 E	671.9303
CH	Chrudim	49.956316 N	15.814271 E	335.2384

TABLE II. ADS-B RECEIVERS LOCATION POSITIONING ERROR

Location	Date of measurement	Average number of satellites used for measurement	Average value			Estimation Horizontal error (RMS) [m]	Estimation vertical error(RMS) [m]	Error ellipse confidence intervals (95%)	
			HDOP	VDOP	PDOP			X [m]	Y [m]
KN	24.5.2013	14	0.8	1.0	1.3	0.469	0.580	0.49	0.16
VE	24.5.2013	14	0.7	1.3	1.5	0,146	0.212	0.23	0.8
CH	25.5.2013	13	0.7	1.0	1.2	0.430	0.590	0.17	0.1
MO	24.5.2013	12	0.8	1.5	1.7	0.344	0.577	0.16	0.10
PO	25.5.2013	13	0.7	1.0	1.2	0.357	0.470	0.25	0.04
PB	24.5.2013	14	0.8	1.0	1.3	0.183	0.178	0.24	0.7

III. RECEIVER'S CLOCK TIME SYNCHRONIZATION METHOD

Necessary assumption for correct system function is achievement of very precise time synchronization (around tens of nanoseconds) of all receiving stations. As was mentioned above AURORA receivers don't dispose of GPS time synchronization module. Due to that reason other method was necessary to be developed and applied in order to enable associate precise timestamps for every received message. Applied method is depicted on figure 3. Method is based on the presumption that at least one aircraft equipped with ADS-B technology is found within the coverage of the system. Thus such aircraft transmits messages containing actual position based on onboard GPS receiver. One of the set of receiving ADS-B station is taken as a reference station (for our example it is p_1 station) and its clock represents reference time t_1. When the aircraft transmit the message containing its position p_A, this message is received both p_1 and p_2 receivers in time t_1 and t_2 respectively. We know (are able to figure out) distances between p_1 and p_A, and between p_A and p_2, which represent the signal propagation trajectory. Thus we can recalculate the message time reception in receiver p_2 with respect to p_1

receiver's clock. Now we have t_2 (time of message reception at p_2 receiver according to p_2 clock) and t_{2_cor} (time of message reception at p_2 receiver according to p_1 clock). t_2-t_{2_cor} represents the correction which is consequently applied to each time message reception at p_2 receiver.

Unfortunately the value of the correction isn't constant in time but it suffers from some fluctuation which you can see on figure 4 and figure 5. From that reason it is desirable to recalculate the correction as frequently as possible on behalf of keeping the time synchronization as precise as possible.

Of course many other problems arise from above described method. For example there exist very small number of aircraft which report the height above the WGS-84 ellipsoid within the messages nowadays, and thus such height must be estimate from reported barometric height/altitude. It brings into calculation additional errors.

Above described method was applied to all receiving stations, in order to find receiver's clock corrections for our measurement. (As a reference station was set the Kněževes location).

Table III summarizes the errors in time stamps of received messages for particular locations. Two methods are compared in the table III. The first one is a method where for correct time stamps of receiving message the last known time correction is used (i.e. last known correction is added to receiver's clock time stamp). For the second one a correction at the time of reception of a message is calculated based on extrapolation from last *k* known corrections. The first one method gave so bad results that for our measurement were unusable.

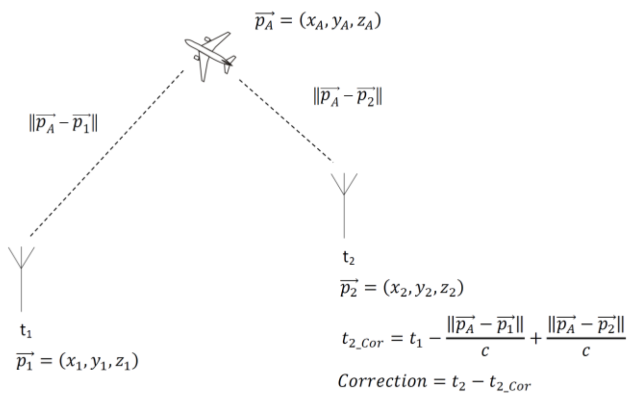

Figure 3. Applied receiver's clock synchronization method

TABLE III. APPLIED CORRECTION ERRORS

Location	Correction based on N-1 correction			Correction based on extrapolation from N-k corrections		
	MAE [m]	MSE [m]	RMSE [m]	MAE [m]	MSE [m]	RMSE [m]
KN	0	0	0	0	0	0
VE	6.878e-05	1.342e-08	1.158e-04	4.822e-07	9.583e-13	9.789e-007
CH	2.09e-03	1.147e-05	3.386e-03	3,534e-06	8.543e-11	9.242e-006
MO	8.894e-06	4.873e-10	2.207e-05	1.007e-06	3.073e-12	1.753e-006
PO	3.137e-04	3.382e-07	5.815e-04	1.978e-06	1.403e-11	3.746e-006
PB	1.891e-03	8.568e-06	2.927e-03	2.902e-06	6.180e-11	7.861e-006

MAE (Mean Absolute Error)
MSE (Mean Square Error)
RMSE (Root Mean Square Error)

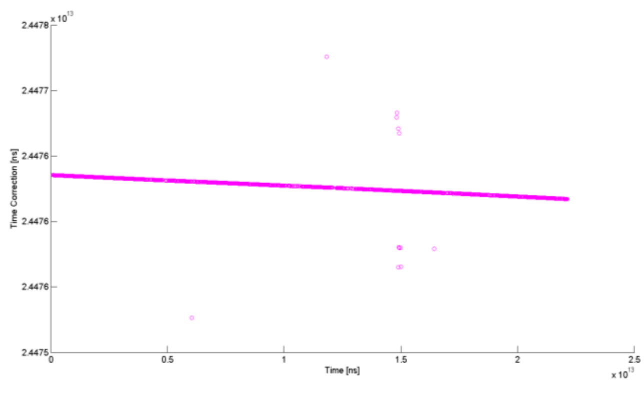

Figure 4. The time drift progression of VE with regard to KN during 6.13 h = 1.8228e+008 ns =0.1823 s

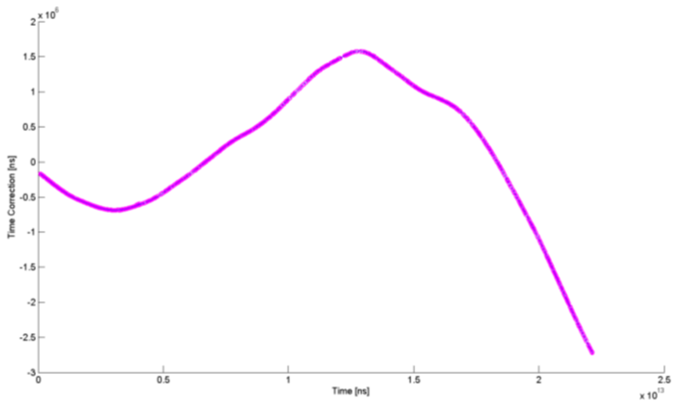

Figure 5. The time drift progression of VE with regard to KN – removed linear component from the correction tend

IV. The Testing Measurement

During the measurement all ADS-B receivers worked in off-line mode and thus multilateration calculation wasn't performed in real time. There were recorded only Mode S messages format DF 17, position extended squitter. Other types of extended squitter messages weren't collected. There were recorded only position squitter messages by the reason of possibility comparison calculated MLAT position with the position announced within ADS-B messages.

TABLE IV. Statistics data from the measurements

Location	Date of measurement	Length of record [hour]	Number of received messages (DF17 position squitter)	Average number of received messages per second
KN	22.7.2013	13.0066753	80120	1,711
VE	22.7.2013	6.12558711	46967	2.13
CH	22.7.2013	6.0612499318	11320	0.519
MO	22.7.2013	7.8025285939	52977	1.886
PO	22.7.2013	3.6989794592	10765	0.808
PB	22.7.2013	5.8727566112	8977	0.425

The mathematical description of finding the aircraft position by means of multilateration method represents the Equation 1.

$$c\cdot(T_1-T_2)=\sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2}-\sqrt{(x-x_2)^2+(y-y_2)^2+(z-z_2)^2}$$
$$c\cdot(T_1-T_3)=\sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2}-\sqrt{(x-x_3)^2+(y-y_3)^2+(z-z_3)^2}$$
$$c\cdot(T_1-T_4)=\sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2}-\sqrt{(x-x_4)^2+(y-y_4)^2+(z-z_4)^2}$$

(Eq. 1)

Where:

x, y, z - unknown target (aircraft) position coordinates
x_1, y_1, z_1 ... x_4, y_4, z_4 - receiver stations position coordinates
T_1 ...T_4 - time of message receiving in particular receiving stations.

For 2D positioning it is necessary to receive the signal at least on three stations. For 3D positioning you must receive the message at least on four stations. Due to the fact that the spectrum is shared among all cooperative surveillance systems without any coordination of transmission causes that the messages might be garbled (overlapped) in a receiver. That results in incorrect message decoding and subsequently to loss of message. Thus it is obvious that the message don't have to be successfully received by the station in spite of a transmitter (airplane) is within the coverage. The probability of a message corruption in general depends on: 1090 RF band saturation, length of message (the longer message the more probability that the message will be garbled) and on a receiver (performance of the system and applied methods for decoding). As far as last point is concerned the low cost ADS-B receivers seem to be very inefficient. Nevertheless this issue will be subjected to an additional research.

The paragraph above explained one of the reasons why we realized measurement only in 2D despite of the fact that it brings certain decrease in precision because of vertical coordinate had to be estimated only within the calculation. But even so we were able to calculate only 593 plots by MLAT method from recorded data. But on the other hand we must realized that there was used only one type of 1090 ES messages. Other types or formats of Mode S messages were nonutilisable from the point of view of the precision MLAT measurement analysis. Of course for tracking there would be commonly used all types of received messages by the MLAT system.

Horizontal position error of MLAT measurement was determined according the Eq. 2 and Eq. 3. For every plot position calculated by MLAT system with GPS position reported in the message was compared. Resulting error is presented in graph in fig. 8.

$$error=\sqrt{\Delta x^2+\Delta y^2} \qquad \text{(Eq. 2)}$$

$$error=\sqrt{(x_{MLAT}-x_{GPS})^2+(y_{MLAT}-y_{GPS})^2} \qquad \text{(Eq. 3)}$$

It is necessary to note, that taking the position information transmitted within 1090 ES message as a reference position could be misleading. Due to fact that in Europe isn't any mandate for carriage ADS-B technology nowadays, there exist many aircraft whose transmitting positions information suffer from quite large errors. (It could be caused by incorrect Mode S transponder installation, or the source for position information isn't GPS receiver, or many others.) From that reason there were set the error limit interval 0-20 km for the statistical analysis. (Resulting error outside this limit was declare as not caused by MLAT system or MLAT measurement.)

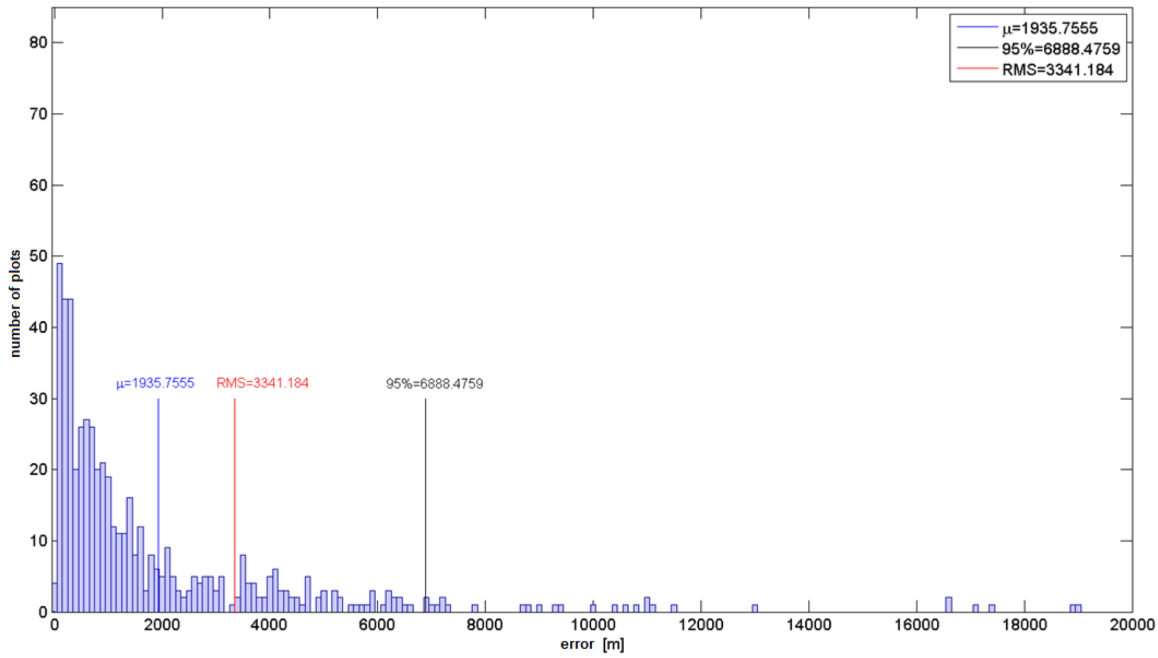

Figure 6. Statistic of targets (aircraft) position measurement error

V. CONCLUSION

The aim of this experiment was the primary examination of the feasibility of MLAT measurement based on usage low-cost ADS-B receivers. On the basis of the presented results above, it is possible to say that creation of such systems would be feasible all the more if the receivers with the GPS synchronization module would be used. Such low-cost ADS-B receivers are available today, which give us another benefit. Nevertheless there is still long way in front of us to create full-value system that works in real time with parameters suitable for our utilization.

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