Feasibility Study on Aircraft Positioning by Using ISDB-T Signal Delay

Junichi Honda and Takuya Otsuyama

***Abstract*—This letter is concerned with experimental results of aircraft positioning by using terrestrial digital broadcasting signal delay. Passive bistatic radar (PBR) is expected to be a conventional primary surveillance radar alternative, and it can also achieve expanding coverage area of the conventional radar. The PBR sensors allow the detection and tracking of noncooperative targets illuminated by transmitters of opportunity such as communication systems [digital terrestrial television broadcasting (DTTB), AM/FM, 3G/LTE base stations, etc.] or conventional radar system. Especially, the DTTB signals are the most expected radio waves. In this letter, we show experimental results of aircraft positioning by using the signal delay profile of DTTB whose type is Integrated Services Digital Broadcasting–Terrestrial (ISDB-T) used in Japan. It will be shown that the ISDB-T signal delays are useful surveillance systems.**

***Index Terms*—Aircraft surveillance, digital terrestrial television broadcasting, Integrated Services Digital Broadcasting–Terrestrial, multistatic primary surveillance radar (MSPSR), passive bistatic radar, signal delay.**

I. Introduction

RECENTLY, a new aircraft surveillance system based on passive bistatic radar (PBR) [1]–[3] has been expected to be used as a conventional primary surveillance radar (PSR) [4] alternative. The characteristics of PBR are to use not only an original transmitter but also various objective signals such as digital terrestrial television broadcasting (DTTB), AM/FM, 3G/LTE base stations, GNSS, and so on. We have been investigating the multistatic primary surveillance radar (MSPSR) [3], which consists of the networks of PBRs. The MSPSR operates by combining some transmitters or some receivers. As mentioned above, the advantage of PBR and MSPSR is to select appropriate signals, resulting in expanding the coverage area and increasing the operation security. In addition, new systems can be used as a backup system because it is independent noncooperative surveillance [3]. However, there is not enough information as to whether new systems are useful for aircraft surveillance. It is important for civil aviation to investigate the usability of the MSPSR using various signals.

Among some signals, DTTB signals are the most expected radio waves to cover larger area because the transmitted signals are always present and the transmitted powers are relatively large. Some studies using DTTB have been reported so far [5]–[8]. They discussed the numerical simulations, and they reported how unneeded signals are suppressed by using the method such as MUSIC algorithm. In addition to them, a few experiments using Doppler shift have also been reported so far [9], [10]. However, as far as we know, there are no experimental reports using original characteristics of DTTB. Hence, we propose the method of aircraft positioning by using DTTB signal delays. This study is quite different from other studies using other DTTB signals [9], [10]. Our proposed method does not need special signal processing.

The Japanese DTTB has adopted the Integrated Services Digital Broadcasting–Terrestrial (ISDB-T) [11]. We have so far investigated the scattered powers caused by aircraft and detection rate from the viewpoint of numerical simulations [12], [13]. In those studies, we have found that scattered powers caused by aircraft can be detected by commercial antennas. Comparing the numerical simulation to the experimental results, it was found that the numerical results are acceptable. This fact leads to the estimation of the appropriate receiver location before the system is deployed.

In this letter, we show experimental results of aircraft positioning by using ISDB-T. Our system concept is to use ISDB-T signal delays. This is achieved by using the original system of ISDB-T employing the orthogonal frequency-division multiplexing (OFDM) modulation. We describe characteristics of ISDB-T and explain the principle of aircraft positioning based on the PBR. Then, we show experimental results that were performed near Tokyo International Airport by using the high-power signals from a main tower called TOKYO SKYTREE. It will be shown that the proposed estimation method is useful for the detection of moving targets.

II. Aircraft Positioning

In this section, we describe a principle of moving target positioning. First, we describe characteristics of ISDB-T and the detection method of delayed signals. Second, we explain the method of aircraft positioning based on the bistatic ranging.

A. ISDB-T

The ISDB-T system is one of the DTTB standards. ISDB-T provides reliable high-quality video, sound, and data broadcasting. The system is rugged and reliable because it employs the OFDM modulation, 2-D interleaving, and concatenated error correcting code [14]. Its modulation scheme is called band

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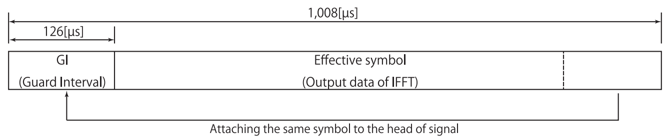

Fig. 1. GI with one-eighth of the effective symbol length.

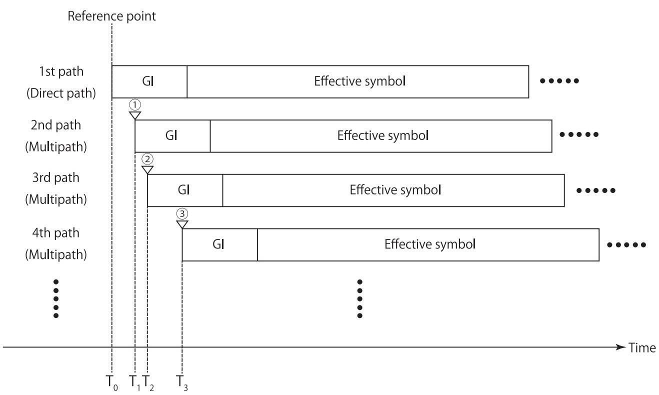

Fig. 2. Detection of starting time of GI. T_n corresponds to the arrival time from each target.

segmented transmission–OFDM (BST-OFDM), and accordingly, it has better multipath immunity than other methods.

The Japanese DTTB is assigned to ultrahigh-frequency band from 470 to 770 MHz. There are three transmission modes: modes 1, 2, and 3 [14]. Especially, mode 3 is often used in Japan. Each bandwidth is 5.572 MHz, and it is also divided into 13 OFDM segments that have different carrier modulations and encoding rates of error correction. Therefore, ISDB-T can simultaneously provide some services.

One of the significant properties of ISDB-T is the guard interval (GI), as shown in Fig. 1. The aim of GI is to absorb interferences of delayed signals caused by multipath. GI is generated by attaching a portion of latter effective symbol to signal heading. In the mode-3 system, the length of GI is one-eighth of the effective symbol length. Therefore, each signal length is 1008 μs with GI of 126 μs.

By using the characteristics of GI, delayed signals are detected. We are able to deal with the delayed signals by the following procedure:

1) searching signal heading by autocorrelation with a bit longer time than the effective symbol, or finding pilot carriers used to estimate and track the channel status;
2) defining the minimal FFT windows including as many signal delays as possible (can be possible to carry out autocorrelation by using effective symbol length, after finding signal heading);
3) peak searching of delayed signals (see Fig. 2).

B. Principle of Aircraft Positioning

In our previous studies, we have found that the received power increases when the target passes in front of a directional antenna [12]. In that case, we can pick up signal delays from scattered waves caused by the aircraft. Once we obtain the delay profile,

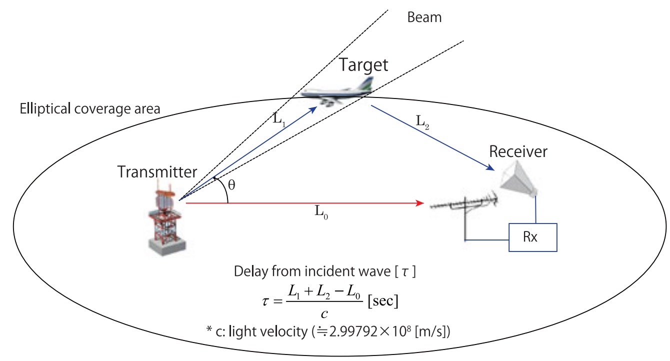

Fig. 3. Image of a bistatic radar.

we can compute the distance from a receiver to a moving target based on the PBR principle, as shown in Fig. 3. The estimated target position is indicated on the elliptical curve. The delayed time is defined by

$$\tau = \frac{L_1 + L_2 - L_0}{c} \text{ [s]} \tag{1}$$

where L_0 is the distance from the source to the receiver, $L_1 + L_2$ is the total distance from the source to the receiver via a target, and c is the velocity of light. In the experiment, source and receiver positions are known parameters, and time delay τ is estimated by the idea described in the Section II-A. Therefore, it is easy to compute the relationship between L_1 and L_2. As shown in Fig. 3, the target position is defined on the elliptical curve.

III. Experimental Results

We show some experimental results of aircraft positioning. The experiment was performed at Higashi–Ogishima–Higashi park located near Tokyo Bay. This is also located near Tokyo International Airport (Haneda Airport). We used radio waves emitted from TOKYO SKYTREE, whose height is 634 m. Channel 21 in range between 518 and 524 MHz was used, and its output power was about 10 kW. The distance from the source to the receiver is 23 145 m.

In the experiment, we used a COTS Yagi antenna with 30 elements. The antenna specification is 15.3 dBi absolute gain, 23 dB forward-and-back ratio, and 21° half-width at channel 21. The directional antenna plays an important role in the proposed estimation system. Scattered fields caused by moving targets become so small, and they are sometimes obscured by the strong delayed signals from fixed structures (e.g., office buildings). Therefore, unnecessary signals should be suppressed as possible. On the other hand, the directed waves are necessary to determine the starting time for signal delays, but they are always large received powers. The relative received powers for directed field should be as small as possible so that delayed signals with small received powers are distinguished. As a result, the directional antenna is used for increasing scattered powers from moving aircraft and suppressing directional and unnecessary fields. In this system, the target is determined in any range

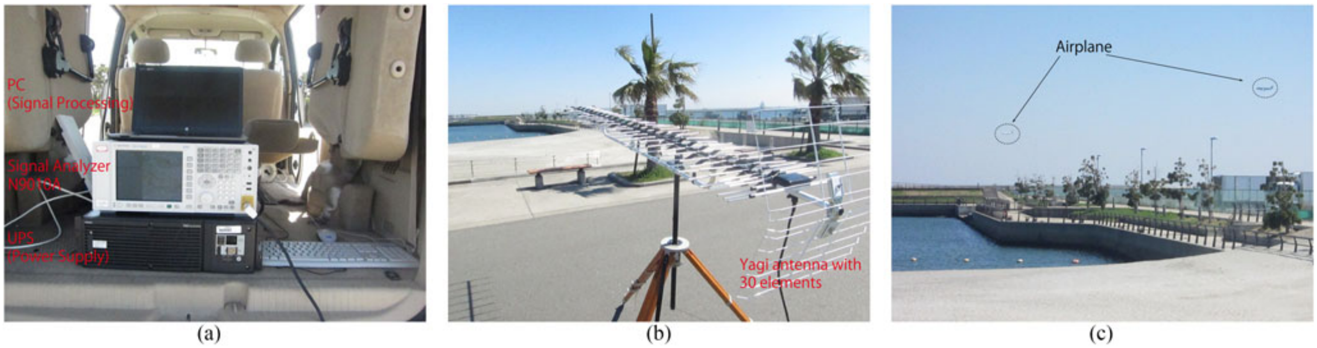

Fig. 4. Experimental landscape. (a) Experimental system. (b) Yagi antenna with 30 elements. (c) Moving airplanes.

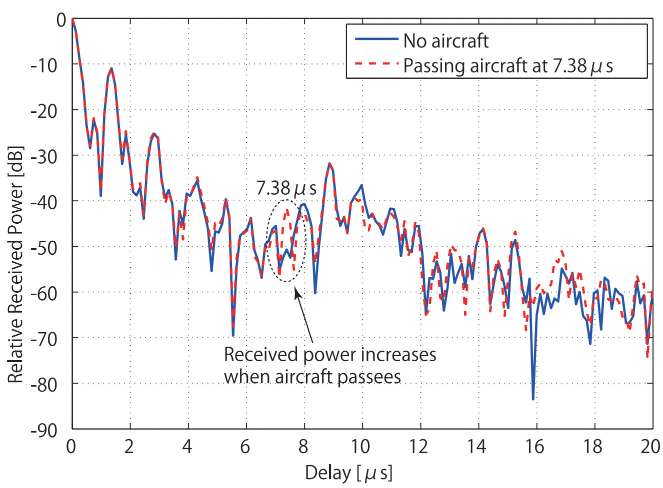

Fig. 5. Delay profile in comparison.

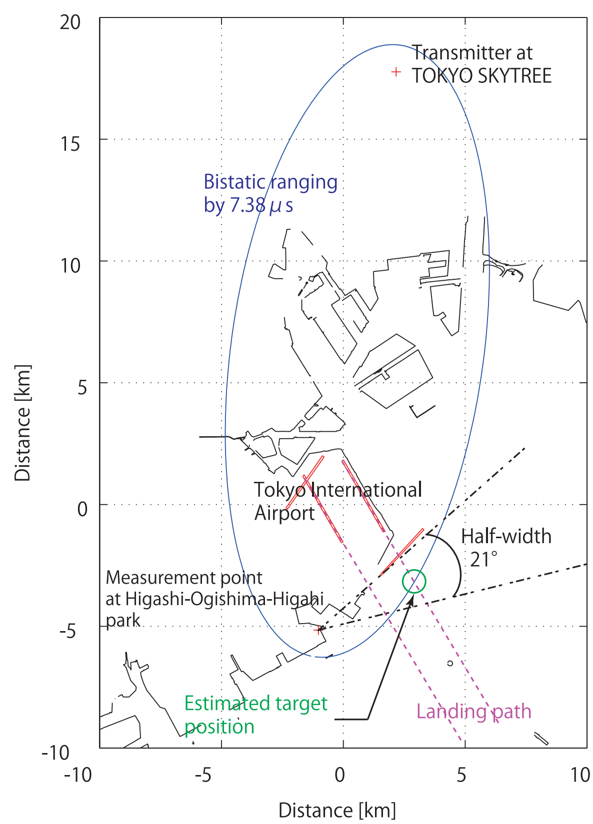

Fig. 6. Estimated aircraft position.

by intersection between the antenna direction and the ellipsoid curves obtained by bistatic ranging.

Fig. 4 shows the experimental landscape and system. Fig. 4(a)–(c) shows the experimental system, a used antenna, and a picture of moving aircraft in front of the antenna, respectively. In this experiment, we aimed at landing aircraft. The incident wave and scattered waves by aircraft are first received by the antenna. Next, the apparatus detects signals and computes signal delays. In the experiment, we used a signal analyzer "Keysight Technology N9010A with software N6155A." The principle of this measuring apparatus is almost the same as that in Section II. The installed software plays the role in computing the delay data and recording them. The apparatus is operated by the software "LabVIEW" in the external PC.

Fig. 5 shows relative received power versus delays. The solid curve is the delay profile without moving target, and the dotted curve is the delay profile when the target passed in front of the antenna. It is shown that the received power increases clearly at 7.38 μs delayed time. It has been found in this experiment that signal delays are detected when moving targets pass in front of the directional antenna. We computed the distance from the receiver to the target. Fig. 6 shows the computed bistatic ranging result. This is obtained based on the PBR principle. The figure also shows the positional relations such as the source, the receiver, the antenna direction, and so on. An elliptical curve represents the ranging data computed by signal delay with 7.38 μs, corresponding to the previous result. Another delay also appears at about 17 μs in Fig. 5. We have estimated that it would be obtained by the next aircraft. Additionally, some peaks of fixed obstacles are received. Analyzing their delays is also important to suppress unnecessary signals, but it will be next work.

Next, we considered another approach to detect aircraft. Fig. 7 shows delay profiles like spectrogram. This figure shows relative received powers for signal delays and measurement time. These data with the update rate of 0.2 s were much faster than the conventional PSR with that of 4.0 s. Two lines are shown in this figure. They correspond to two airplanes, as shown in Fig. 4(c). It has been found that the received power increases when the target moves in the range of antenna half-width. The interesting feature is to separate several aircraft. They have enough information to

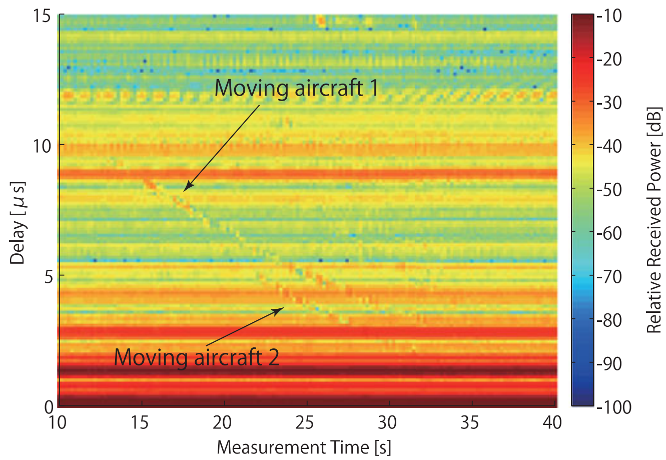

Fig. 7. Delay profile.

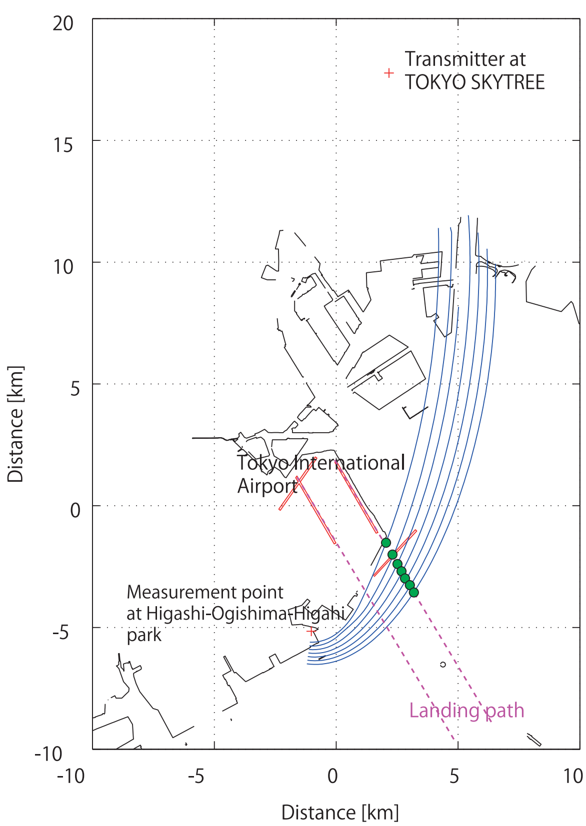

Fig. 8. Target tracking (signal delay = 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0 μs).

compute the distance from the receiver to the target. Based on those data, we can put the aircraft positions along the landing course. Fig. 8 shows a numerical example.

Through the experiment, we have found the following.

1) Signal delays caused by moving aircraft can be detected by the simple estimation method using the original characteristics of the ISDB-T.
2) Several delayed signals can be separated by the proposed method.
3) The much higher update rate can be achieved (4.0 s in the conventional PSR, 0.2 s in this letter).
4) The positional accuracy was not taken into account.

In this letter, we have employed DTTB signals. Other signals using OFDM can also be used for aircraft positioning. However, radio signals such as 3G/LTE are not expected to expand coverage area due to low power and antenna pattern. In addition, AM/FM would expand coverage area, but resolutions are not good. Consequently, the DTTB signal would be the best signal for aircraft surveillance.

IV. Conclusion

In this letter, the aircraft positioning by using ISDB-T signal delays has been discussed. First, we mentioned the principle of ISDB-T and the estimation of signal delays caused by the moving target. Next, we described the ranging method based on the PBR system. Finally, we showed the results of the experiment performed at Higashi–Ogishima–Higashi park near Tokyo International Airport. In the experiment, it has been found that the configured system is able to detect the scattered waves from moving targets when aircraft pass in front of the antenna. Based on the PBR system, the bistatic range and the aircraft position were estimated by using delayed signals. It has been found that the proposed system would be useful for estimating the aircraft position.

We would like to confirm the accuracy of the estimated target position by comparing it to other surveillance data such as secondary surveillance radar (SSR) and automatic-dependent surveillance–broadcasting (ADS-B). In addition, we would like to expand this system to multistatic-type radar. These will be our future works.

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