Optical-Fiber-Connected Passive Primary Surveillance Radar for Aeronautical Surveillance

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Abstract: A new radar system using a radio over fiber (RoF) is proposed. The proposed system is optical-fiber-connected passive primary surveillance radar (OFC-PPSR), which is based on a passive bistatic radar approach and uses RoF technology. A separate receiver unit uses the waves scattered from aircraft and the radar reference data transmitted by the RoF. The reference data include the radio frequency signals of the transmitter unit and the processing data of the controller unit, such as radar rotation angle. We first present the principles of OFC-PPSR and the experimental system, which was deployed at the Sendai airport in Japan. Moreover, we present some preliminary experimental results obtained with the proposed system. The proposed system is capable of detecting moving aircraft, as demonstrated by a comparison of the experimental results with real surveillance data.

Keywords: Primary surveillance radar, multistatic primary surveillance radar, radio over fiber, aeronautical surveillance, air traffic management

Classification: Sensing

References

[1] M. I. Skolnik et al., Introduction to RADAR systems, 3rd ed., New York, NY, USA: McGraw-Hill, 1962.
[2] M. C. Stevens, Secondary Surveillance Radar, Norwood, MA: Artech House, 1988.
[3] Steffen Marquard, “Suitability of Multi-Static Surveillance System for Aeronautical Use (Passive Radar),” International Civil Aviation Organization Working Paper, Montreal, WP ASP12-12, March 2012.
[4] ICAO (International Civil Aviation Organization) : Doc 9924, Aeronautical Surveillance Manual, 1st edition, 2010.
[5] J. Honda and T. Otsuyama, “Feasibility Study on Aircraft Positioning by Using ISDB-T Signal Delay,” IEEE Ant. and Wireless Propaga. Letters, DOI.10.1109/LAWP.2016.
[6] T. Ito, R. Takahashi, S. Morita and K. Hirata, ”Experimental result of passive bistatic radar with unknown transmitting radar pulse,” Proc. 2013 European Radar Conference, pp. 455-458, Nuremberg, Oct. 2013.
1 Introduction

Airport surveillance radar typically include both a primary surveillance radar (PSR) [1] and a secondary surveillance radar (SSR) [2]. Since the SSR uses the reply signals from an aircraft and provides the aircraft’s position, identify and altitude, it has become the main surveillance system in air traffic management. On the other hand, PSRs play an important role as backup and in improving the security of operations, because it uses the waves scattered by aircraft and is a type of independent noncooperative surveillance [3]. However, the update and detection rates of PSRs are lower than those of SSR technologies. Therefore, PSR application technologies are required to improve operational security.

Recently, multistatic primary surveillance radar (MSPSR) [4] has been expected to be used as a conventional PSR alternative. One interesting property is the selection of some signal sources, e.g., present radar signals, digital terrestrial television broadcasts, mobile communication (e.g. 3G and LTE), global navigation satellite system, and so on [5]. Our final goal is to develop a combined surveillance system using several signals. As one core technology of MSPSR, we consider passive radar using the PSR signal. The purpose of this system is to expand the present PSR coverage and to contribute to the spectral efficiency. The present PSR coverage is about 60 NM, and the required detection rate is about 70%. Since PSR depends on the waves scattered from obstacles, undetected area exists, e.g., aircraft at low altitude and the shadowed areas behind mountains or buildings. To overcome this problem, we propose optical-fiber-connected passive PSR (OFC-PPSR) to expand the present PSR coverage. One of the strengths of this proposal lies in its use of radio over fiber (RoF), which enables radio frequency (RF) signals to be transmitted to a separate receiver over a long distance by an optical fiber. Consequently, OFC-PPSR is capable of operating in the same manner as conventional PSR. In addition, because a receiver unit is connected to a transmitter unit by RoF, the receiver always computes the target position, even if the incident waves cannot be detected. The signal-to-noise ratio (S/N) would also be better than that using incident waves propagating in the atmosphere. Moreover, as one application, the existing infrastructure can be shared by collaborating with other surveillance systems such as multilateration (MLAT).

In this letter, the system concept and its operating principle are described first. Then, a prototype system deployed at Sendai airport is introduced. Finally, we show the experimental results. It is shown that the proposed system can detect aircraft through comparison with real surveillance data.
2 Optical-Fiber-Connected Passive Primary Surveillance Radar

In general, a radar has a transmitter unit combined with a receiver unit [1]. As the receiver unit always receives the information of the transmitted signals (transmitted timing, antenna rotation angle, etc.), estimation of the target position is relatively easy. However, in a passive radar system, the separate receiver unit does not have this information. Hence, it requires some signal processing [6] and a mechanism to estimate the transmitted waves. In order to overcome these problems and to simplify the system, we propose a new radar concept based on passive bistatic radar [7].

The proposed system employs RoF technology, which enables the transmission of RF signals over long distances in comparison with a coaxial cable. An OFC-PPSR receiver unit is connected to the transmitter at a radar site by an optical fiber. Thus, OFC-PPSR can stably use the original RF signals as a reference. Hence, the receiver unit can be located far from the transmitter unit, even if the directed waves do not arrive at the receiver side. Consequently, similar to the present radar, the receiver unit can easily estimate aircraft positions by using the transmitted timing, radar rotation angles, trigger and others. Given that the proposed system is capable of using scattered waves that do not return to the radar site, it is expected to be capable of expanding the coverage area of the current PSR. Moreover, owing to RoF, the S/N is expected to be improved in comparison with the use of incident waves propagating in the atmosphere. It should be noted that sharing the same infrastructure with other surveillance systems such as MLAT is an advantage. Therefore, OFC-PPSR is expected to be used as a PSR distributed surveillance system, in correspondence with the common use of SSR applications.

Figure 1 shows the system conceptual diagram of the proposed system, and an ellipsoidal curve illustrating the principles of passive bistatic radar (PBR). An RoF transmitter unit is located at the radar site, and it collects the RF signals transmitted by a rotating antenna and some information in the controller unit, and they are provided to the separate receiver unit by RoF. On the other hand, the receiver unit consists of a receiving antenna for the scattered waves, a preamplifier, a downconverter, a signal processing unit, and an RoF receiver unit.

The estimation procedure is summarized as follows:

- Adjust the signal delays corresponding to the optical fiber length from the transmitter unit to the receiver unit
- Measure the RF signals (1. scattered waves from aircraft, 2. RF signals transmitted by RoF) and collect radar information (1. timing when PSR faces north, 2. RF transmitted timing)
- Analyze the bistatic ranging from the time difference of arrival between the radar transmitted timing and the waves scattered from aircraft
In the above procedure, the signal delay $\tau$ is given by

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

where $L_1 + L_2$ is the total distance from the source to the receiver via obstacles, $L_0$ is the direct distance from the source to the receiver, and $c$ is the velocity of light. These relations are shown in Figure 1b. In the proposed system, $L_0$ is modified by the optical fiber length and the source and receiver positions. $\tau$ is computed by the receiver unit, as mentioned above. However, since $L_1$ and $L_2$ are unknown parameters, one of them is required to obtain a solution. $L_1$ is computed by

$$L_1 = \frac{\triangle (\triangle + 2L_0)}{2L_0(1 - \cos \theta + \triangle/L_0)}$$

where $\triangle$ is defined by $\triangle = c\tau$, and the angle between the directions of the radar and the target is given by $\theta$. The result computed for $L_1$ (or $L_2$) is an ellipsoidal curve.
3 System Deployment and Experimental Results

A prototype system has been developed and deployed at Sendai airport in Japan, and preliminary experiments were performed to confirm the basic operation of the OFC-PPSR system. Figure 2 shows the experimental environment and setup. In this experiment, a training radar was used; it is located at the southern part of the airport where the RoF transmitter unit is also located. A general PSR produces an asymmetric beam shape known as a fan beam, and the vertical plane is the cosecant-squared elevation pattern. The RoF transmitter unit is connected to the RoF receiver unit located at the western part of airport by an optical fiber.

The PSR emits a short pulse of 1 μs and a long pulse of 80 μs. Long pulses are modulated by FM chirp. Since the long pulse is emitted after transmitting the short pulse, the coverage area of the short pulse is limited by the time interval between the short and long pulses. The frequency is assigned to the S band. The distance from the radar site to the OFC-PPSR receiver is ~1800 m. The signal processing unit separately analyzes both pulses, and a standard horn antenna is selected as the receiver.

Figure 3 shows the experimental results. This is illustrated by overlapping five scans (=20 s) of data, and the figure is converted from the estimated bistatic ranging to the PPI scope. In this figure, there are large echoes on the left side. We confirmed that the echoes are located at Mt. Zao on the map. On the right side of the airport, waves reflected from a moving object are also observed. In order to check whether the moving object is an aircraft, we compare the experimental results with the real surveillance data obtained by automatic dependent surveillance - broadcast (ADS-B). The right side of Fig.3 shows a magnification and comparison. The ADS-B tracks are indicated...
by red circles. The positions between the echoes from the moving object and ADS-B are slightly different. However, as ADS-B has some errors and the results obtained by the proposed system disregard the height, the echo of the moving aircraft and the ADS-B tracks are almost identical. Therefore, we conclude that these echoes represent a moving aircraft.

4 Conclusion

In this letter, we proposed OFC-PPSR as a new radar system by using RoF. One of the characteristics is the use of original RF signals at a separate receiver unit. This results in the same operation as conventional PSR, even if the receiving antenna is in the non-line-of-sight of the transmitter. Moreover, a better S/N can be maintained by RoF. Experiments were performed at Sendai airport in Japan. It was shown that the proposed system detects the echoes from a mountain and moving object. Comparing the experimental results with ADS-B, it was demonstrated that the moving object was an aircraft.

The proposed system is expected to expand the coverage area of present aeronautical surveillance systems. However, all signal processing in the proposed system was disregarded. Our future work will consider some radar signal processing techniques such as moving target indication (MTI) and constant false-alarm rate (CFAR) in order to suppress unnecessary signals from fixed structures. It will be our future work.

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