A TARGET TRACKING METHOD WITH A SINGLE ANTENNA USING TIME-REVERSAL UWB RADAR IMAGING IN A MULTI-PATH ENVIRONMENT

Takuya Sakamoto and Toru Sato

Graduate School of Informatics, Kyoto University
Department of Communications and Computer Engineering
Yoshida-Honmachi, Sakyo-ku, Kyoto 606-8501, Japan

1. INTRODUCTION

UWB (Ultra Wide-Band) radar systems are of great interest because they cover a variety of application fields including landmine detection, robotics, and security systems. In particular, surveillance systems have attracted much attention because they are indispensable in ensuring safety in our society. Although cameras are often used for surveillance systems due to their economical cost and high resolution, UWB radar technology can provide additional capabilities to current systems. UWB radars can obtain 3-dimensional images with relatively high resolution that are unachievable with conventional systems. The TR (Time-Reversal) method [1, 2] is an imaging algorithm for UWB radars, which provides a high-resolution capability in a multipath environment. Conventional TR methods have been applied to antenna array systems but lead to a complex system that is too costly to use in practice. Our previous work [3] proposed a TR method with a single antenna, which can be applied to a low-cost simple radar system. In practice, this approach removes the cost restriction when applying radar systems to common commercial products. In this study, we propose a radar system with a single antenna on a vehicle in a multipath environment. This vehicle is assumed to get close to a moving target by adaptively tracking the target location.

2. SYSTEM MODEL

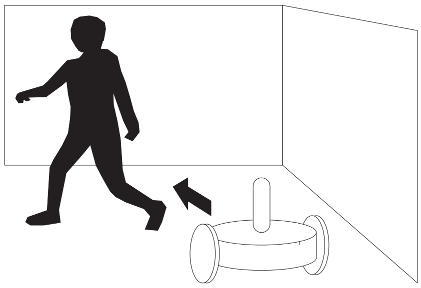
Figure 1 (a) shows the schematic of the proposed security system. The proposed system consists of a robot-like mobile machine with a UWB antenna, a transmitter, a receiver and a signal processing unit for imaging and control processes. This machine moves towards a detected target position to check it closely with, for example, an optical camera. Note that the radar system with the TR method and using multiple reflection waves can obtain an image in a blind-spot where many targets are not directly visible to the radar system or cameras.

For simplicity, electromagnetic wave propagation and room models are assumed to be 2-dimensional. The room is composed of two flat metallic walls as in Fig. 1 (b). It is assumed that a mono-static radar system with a single omni-directional antenna is located at $\boldsymbol{x}_{\mathrm{a}}(T) = (x_{\mathrm{a}}(T), y_{\mathrm{a}}(T))$ and moves according to the imaging results. This antenna is used as a transmitter and receiver. A mono-cycle pulse with a center frequency of 1.0 GHz is transmitted from the antenna and the same antenna receives the echoes. The received signal is A/D converted and stored in memory. A filter matched to the transmitted pulse is applied to the received signal and the output $s(t)$ is obtained. Fig. 2 shows an example of the signal $s(t)$ at $T = 0$, in which we see multiple scattering echoes. This signal is numerically generated by employing a ray-tracing algorithm.

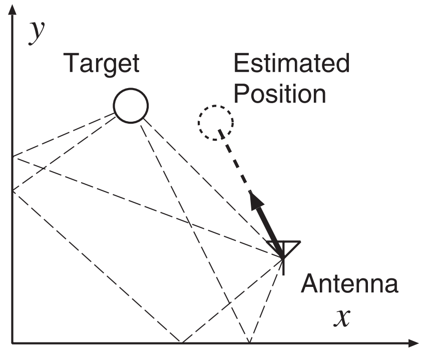
3. TIME-REVERSAL IMAGING AND TRACKING

The target location cannot be obtained by a single antenna in a free space because the radar system can estimate only the distance to the target, but not the angle. By using multiple reflection echoes, however, a simple radar system with a single antenna can estimate the target position. This means that a target locating system can be realized by a low-cost practical system if it is placed in a multipath environment. Time-reversal imaging is recognized as a method that can obtain a high-resolution image unachievable by conventional methods. The TR image $I(x, y)$ is calculated as

$$I(x, y) = \left| \sum_{i,j} s(\tau_i(x, y) + \tau_j(x, y)) \right|, \tag{1}$$



(a) Tracking security system.



(b) System model..

Fig. 1. A proposed security system and the system model.

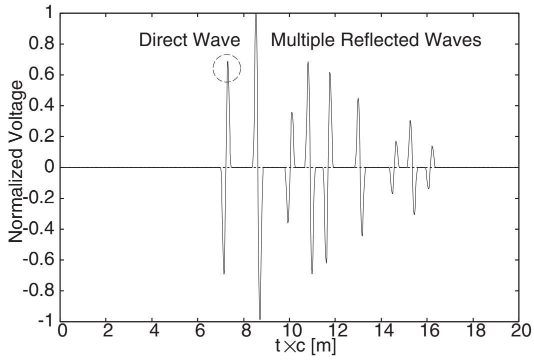


Fig. 2. An example of received signal at $T = 0$.

where $\tau_i(x, y)$ is defined as the time delay between the antenna and the target via the i-th path. Fig. 3 shows each path between the antenna and the target. The target position is updated to get closer to the estimated target position as

$$\boldsymbol{x}_{\mathrm{a}}(T + \Delta T) = \boldsymbol{x}_{\mathrm{a}}(T) + \frac{(\boldsymbol{x}_{\mathrm{target}}(T) - \boldsymbol{x}_{\mathrm{a}}(T))}{|\boldsymbol{x}_{\mathrm{target}}(T) - \boldsymbol{x}_{\mathrm{a}}(T)|} v\Delta T, \tag{2}$$

where v is the constant speed of the antenna on the vehicle. The tracking procedures are as follows:

1. Transmit a mono-cycle pulse and receive the scattered signal.
2. Subtract the reflections due to walls that are measured in advance from the scattered signal.
3. Apply the matched filter to the residual signal to produce $s(t)$.
4. Obtain the image by calculating Eq. (1) and extract the maximum valued pixel.
5. Move the system toward the estimated target position for a certain time ΔT as in Eq. (2).
6. Go back to the 1st step.

4. APPLICATION RESULTS

In this section, we assume the target is point-like and moving in a circle with the center at $(3.0\mathrm{m}, 3.0\mathrm{m})$ and a radius of 2 m at a speed of 1.6 m/sec. The security system with an antenna is assumed to be operated according to the procedure in the previous

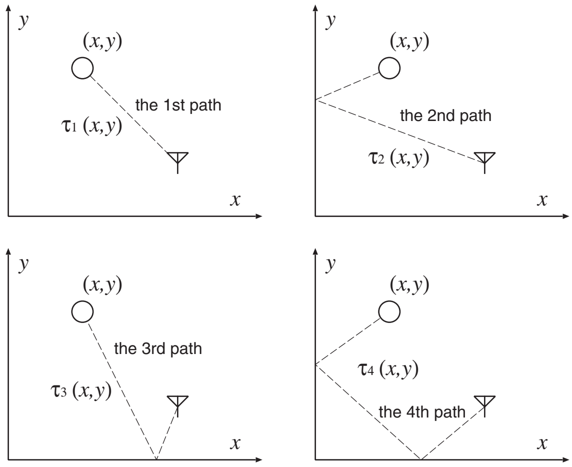
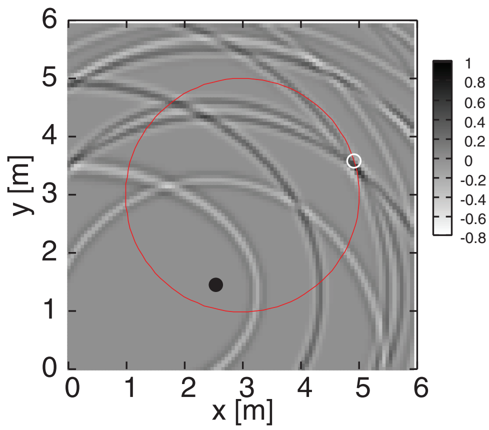
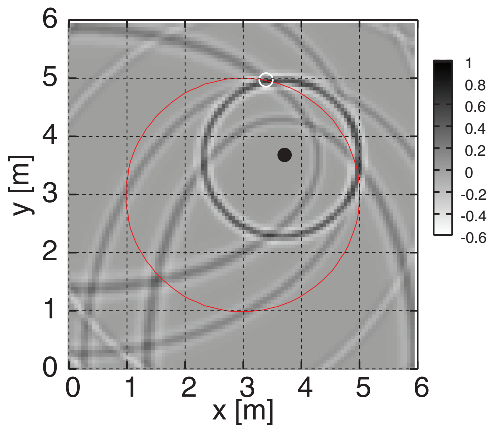


Fig. 3. Propagation paths between the antenna and the target via multiple reflections.



(a) Estimated image at non-symmetric antenna position.



(b) Estimated image at symmetric antenna position.

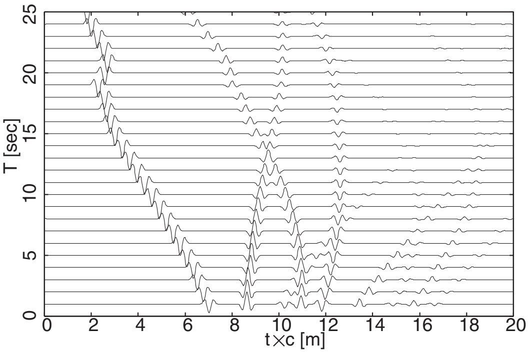
Fig. 4. Estimated images using time-reversal imaging.

section, with a speed of 2.0 m/sec. Figure 4 shows the estimated images at two different antenna positions. In these figures, white circles show antenna positions, and black circles show target positions. In Fig. 4 (a), multiple circles intersect and give the maximum value near the true target position. On the contrary, in Fig. 4 (b), the image is completely symmetrical about the line $y = x$ because the antenna is located on this line and multiple reflection waves from the wall on x axis and the wall on y axis cannot be distinguished. Therefore, there is another peak at the symmetric position in addition to the true target position. This must be taken into account to determine the antenna motion, which is an important future task.

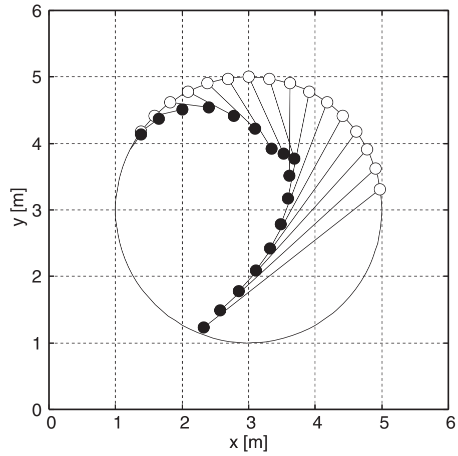
Figure 4 shows the received signals and the result of the tracking process, where black circles show the antenna position, and white circles show the target position. In Fig. 4 (a), the leftmost echoes are direct waves without any reflections by the walls. As T increases, the delay time of the direct echo becomes smaller, meaning the antenna is getting closer to the target except the irregular motion around $T \simeq 20\mathrm{sec}$ It is observed that the antenna is moving toward the target position, which means that target locating based on the TR imaging works effectively throughout the entire process. However, when the antenna is close to the symmetric line $y = x$, the antenna motion malfunctions due to the above-mentioned reason.

5. CONCLUSION

In this paper, we proposed a security system with a robot-like machine with a UWB radar system. This radar system was assumed to be a simple low-cost one and to make use of multiple reflection waves to estimate target positions. We investigated



(a) Estimated images by time-reversal imaging.



(b) The result of tracking process.

Fig. 5. The received signals and the result of tracking process.

the performance of the system with a numerical simulation and confirmed the basic characteristics of the system. The imaging became inaccurate when the antenna came close to a symmetric position, due to the ambiguity of the estimated image. Future task is aimed at improving the stability of the system by adaptively changing the processing depending on the multipath environment. The current detailed performance evaluation is in a realistic two wall environment while multiple wall environment (more than 2) are important issue to be tackled in the future.

6. REFERENCES

[1] A. J. Devaney, "Time reversal imaging of obscured targets from multistatic data," IEEE Trans. Antennas and Propagt., vol. 53, no. 5, May 2005.

[2] M. E. Yavuz and F. L. Teixeira,"Space-frequency ultrawideband time-reversal imaging," IEEE Trans. Geoscience and Remote Sensing, vol. 46, no. 4, Apr. 2008.

[3] Takuya Sakamoto and Toru Sato, "Time-reversal UWB imaging with a single antenna in multi-path environments," Proc. 3rd European Conference on Antennas & Propagation (EuCAP) 2009, Mar. 2009.