An Experimental Study on a Fast and Accurate 3-D Imaging Algorithm for UWB Pulse Radar Systems

Takuya SAKAMOTO†, Shouhei KIDERA†, Toru SATO†, Tomohiko MITANI††, Satoshi SUGINO‡
† Dept. of Commun.& Computer Eng., Kyoto University, Kyoto, 606-8501, Japan
†† Research Institute for Sustainable Humanosphere, Kyoto University, Kyoto, Japan
‡ Advanced MEMS Development Center, Matsushita Electric Works, Ltd., Japan

I. Introduction

It is hoped that rescue robots save human lives in the near future. The UWB(Ultra Wide Band) pulse radar is a promising candidate for the environment measurement for robots because they have high range resolution. Radar imaging is known as one of ill-posed inverse problems, for which various algorithms have been proposed. Their computation time is too long because they are based on iterative methods, which is not acceptable for the realtime operation of robots. We have already proposed a fast imaging algorithm SEABED for UWB pulse radars, which can estimate target shape in a remarkably short time [1]. The performance of this algorithm has been investigated only with ideal numerical simulations [2], which does not contain the waveform distortion by the scattering. In this paper, we study this algorithm with realistic numerical simulations with FDTD method and experiments.

II. System Model and SEABED Algorithm

We assume a mono-static radar system in this paper. An omni-directional antenna is scanned on a plane. UWB pulses are transmitted at a fixed interval and received by the antenna. The received data is A/D converted and stored in a memory. We express real space with the parameter (x, y, z). These parameters are normalized by the center wavelength λ. $s(X, Y, Z)$ is the received signal at the antenna location $(x, y, z) = (X, Y, 0)$, where we define Z with time t and speed of the radiowave c as $Z = ct/(2\lambda)$. We define a quasi-wavefront $Z(X, Y)$ which is a equi-phase surface extracted from $s(X, Y, Z)$.

SEABED algorithm is based on a reversible transform BST and its inverse transform IBST. IBST describes the target shape (x, y, z) with the quasi-wavefront (X, Y, Z) as

$$\begin{cases} x = X - Z\partial Z/\partial X \\ y = Y - Z\partial Z/\partial Y \\ z = Z\sqrt{1-(\partial Z/\partial X)^2-(\partial Z/\partial Y)^2}. \end{cases} \quad (1)$$

We can obtain the target image by calculating the right-hand side of Eq. (1).

III. Estimated Image by SEABED Algorithm with FDTD Data

Fig. 1 shows the estimated target shape by applying SEABED algorithm to the FDTD data, where the true target shape is a U-shape metallic object. The upper side of the target is estimated because the antenna is scanned over the target. The entire computation time is 13msec with one Xeon 2.8GHz processor. Fig. 2 shows the difference between the estimated image and the true image. The true shape is the same as the estimation by an ideal numerical simulation [2]. The averaged error of the image is 4.4×10^{-2} wavelength. The error is large in the region where the antenna is close to the target because the received signals are influenced by the near field. In order to suppress this effect, we replace Z by $Z - aZ\exp(-bZ)$ in Eq. (1), where the parameters $a = 0.154$ and $b = 1.08$ are determined by the least-mean-square-error criteria. The estimated image with this compensation gives the averaged error 1.6×10^{-2} wavelength. We also apply the SEABED algorithm to the data obtained by an experiment, which shows an efficient performance of the proposed algorithm in both of computation speed and accuracy.

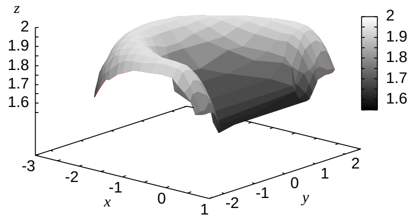

Fig. 1. Estimated target shape by SEABED algorithm with FDTD data. Computation time for the entire imaging is 13msec.

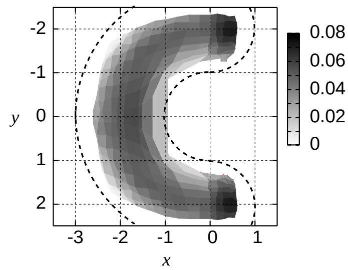

Fig. 2. Difference between the ideal image and estimated image.

References

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[2] T. Sakamoto and T. Sato, "A fast algorithm of 3-dimensional imaging for pulse radar systems," Proc. 2004 IEEE AP-S International Symposium and USNC/URSI National Radio Science Meeting, vol. 2, pp. 2099–2102, June, 2004.