A high-speed imaging algorithm for UWB pulse radars

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Introduction

It is hoped that rescue robots help human lives in the near future. Recently, UWB(Ultra Wide Band) has been standardized in the USA, and it enables us to develop pulse radars with high range resolution. This technology is a promising candidate for the environment measurement for robots. Radar imaging is known as one of ill-posed inverse problems, for which various algorithms have been proposed. Most of them were developed for continuously distributed media such as the ground. Their calculation time is too long because they are based on iterative methods, which is not acceptable for the realtime operation of robots. On the other hand, most of in-house objects have clear boundaries, which enables us to simplify the models. We have already proposed a fast imaging algorithm SEABED for UWB pulse radars, which is based on a reversible transform by utilizing this simple model. The performance of the SEABED algorithms has been investigated with numerical simulations and experiments.

This study is located in the field of the wireless, optical and satellite network technology in our COE program. Our study is related to the sensor network, which gives an additional important function to the existing communication networks.

Major Achievements

1. A novel reversible transform between the real and data spaces

We define a real space as the space expressed with the parameters (x,y,z), where targets and the antenna are located. All of x, y and z are normalized by l, the center wavelength of the pulse. The antenna is scanned on the x-y plane in the real space. We define s'(X,Y,Z) as the electric field received at the antenna location (x,y,z)=(X,Y,0), where we define Z with time t and the speed of the radiowave c as Z=ct/(2l). It should be noted that the received data is expressed with (X,Y,Z) in the data space, and target shapes are expressed with (x,y,z) in the real space. The equiphase surface in the data space (X,Y,Z) is called a quasi wavefront.

The transform from a point (x,y,z) on the target boundary to a point (X,Y,Z) on the quasi wavefront is BST (Boundary Scattering Transform) expressed as

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

We have clarified that the inverse transform of the BST is expressed as

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

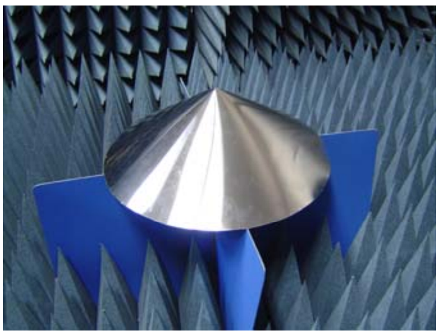

Fig.1 Target shape for the experiment.

which is called IBST (Inverse Boundary Scattering Transform). We have developed a fast radar imaging algorithm, SEABED algorithm based on the IBST.

2. Performance investigation of the stabilized SEABED algorithm

We apply the SEABED algorithm to the experimental data in this section. Fig. 1 shows the true target shape for our study here. This conical metallic object includes both of an edge and a smooth surface. The original SEABED algorithm is sensitive to noise contained in the experimental data because it utilizes the derivative operations in the IBST. The estimated image with the original SEABED is shown in Fig. 2. The quality of the image is poor both for the resolution and stability due to the noise. We have modified the original SEABED algorithm in order to stabilize the obtained image, by utilizing the characteristic of the quasi wavefront. We have analytically proved that the quasi wavefront for a convex target is necessarily smooth, whose lower bound has been also derived. The estimated image with the stabilized SEABED algorithm is shown in Fig. 3. This image is stable including the smooth surface and the sharp edge point. As for the calculation time, the stabilized SEABED algorithm requires 0.1sec to obtain the entire image, while SAR(Synthetic Aperture Radar) requires about 18min to obtain the image with almost the same quality.

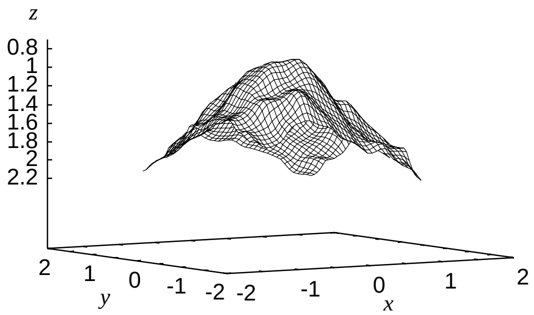

Fig. 2 Estimated image with the SEABED

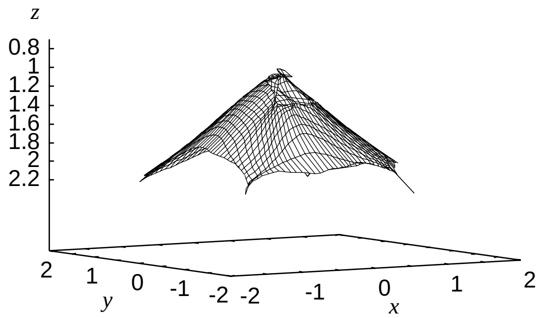

Fig. 3 Estimated image with the stabilized SEABED.

3. Development of the experiment system for UWB pulse radar with linear antenna array

The SEABED algorithm enables us to obtain the image with a UWB radar only if the data is given. However, the measurement time is too long compared to the signal processing for the imaging because our previous experimental site utilizes a pair of UWB antennas by sequentially scanning the antennas on a plane. In order to overcome this issue, we are now developing a linear antenna array as in Fig. 4. In this figure, 18 antennas are vertically located and the whole array is scanned horizontally.


Fig. 4 Linear antenna array.

Significance and Impacts

Our study on the imaging algorithms for UWB pulse radars enables us to develop the real-time radar imaging systems. The realtime radar system can be applied to many areas including robots and surveillance cameras. At present, optical cameras are utilized for most of these areas because of its cost, size, and realtime operation. However, by utilizing our high-speed radar imaging algorithm, we can offer the UWB radar as a completely new option for a variety of application fields.