A Stable and Fast 3-D Imaging Algorithm for UWB Pulse Radars with Fractional Boundary Scattering Transform

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The UWB (ultra-wideband) pulse radar is a promising candidate as an environment measurement method for robots. Radar imaging for a nearby target is known as an ill-posed inverse problem, on which various studies have been done. However, conventional algorithms require long computational time, which makes it difficult to apply them to real-time operations of robots. We have proposed a fast radar imaging algorithm, the SEABED algorithm, for UWB pulse radars [1, 2]. This algorithm is based on a reversible transform, IBST (Inverse Boundary Scattering Transform), between the target shape and the observed data. This transform enables us to estimate target shapes quickly and accurately in a noiseless environment. However, in a noisy environment the image estimated by the SEABED algorithm is degraded because IBST utilizes differential operations. In this paper, we newly introduce a FIBST (Fractional IBST), which is obtained by expanding the conventional IBST, which enables us to deal with the intermediate space between a real and data spaces, and propose a stable 3-D imaging algorithm by using the FIBST.

In our system model, UWB mono-cycle pulses are transmitted at a fixed interval and received by the same omni-directional antenna. We express a real space with the parameters (x, y, z). 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 $Z = ct/(2\lambda)$. The transform from the data space (X, Y, Z) to the real space (x, y, z) corresponds to the imaging we deal with in this paper. We normalize x, y, z, X, Y and Z by λ, the center wavelength. In the SEABED algorithm, quasi-wavefronts (X, Y, Z) are extracted from the received data $s(X, Y, Z)$. Next, we apply smoothing to the quasi-wavefront to suppress noises. Finally, we apply IBST to the smoothed quasi-wavefront to obtain the final image as

$$\left\{\begin{array}{lcl} x & = & X - Z\partial Z/\partial X, \\ y & = & Y - Z\partial Z/\partial Y, \\ z & = & Z\sqrt{1 - (\partial Z/\partial X)^2 - (\partial Z/\partial Y)^2}. \end{array}\right. \tag{1}$$

The smoothing effectively works for concave targets because the quasi-wavefront is smooth for a concave shape. However, for general cases the quasi-wavefront is not necessarily smooth, so the image resolution can be degraded by unsuitable smoothing. To resolve this problem, we introduce FIBST by expanding the conventional IBST, and transform the data to an intermediate space between the real and data spaces, where the smoothing process hardly degrades the resolution. FIBST is expressed as

$$\left\{\begin{array}{lcl} \begin{bmatrix} x_{\theta,\alpha,\beta} \\ y_{\theta,\alpha,\beta} \end{bmatrix} & = & \begin{bmatrix} X \\ Y \end{bmatrix} - ZR(-\theta)\begin{bmatrix} \alpha & 0 \\ 0 & \beta \end{bmatrix} R(\theta)\begin{bmatrix} \partial Z/\partial X \\ \partial Z/\partial Y \end{bmatrix}, \\ z_{\theta,\alpha,\beta} & = & Z\sqrt{1 - \begin{bmatrix} \partial Z/\partial X & \partial Z/\partial Y \end{bmatrix} R(-\theta)\begin{bmatrix} \alpha & 0 \\ 0 & \beta \end{bmatrix} R(\theta)\begin{bmatrix} \partial Z/\partial X \\ \partial Z/\partial Y \end{bmatrix}}. \end{array}\right. \tag{2}$$

In our propsed stable imaging algorithm, we select suitable parameters (θ, α, β) depending on the roughly estimated target shape, and apply the smoothing process to $(x_{\theta,\alpha,\beta}, y_{\theta,\alpha,\beta}, z_{\theta,\alpha,\beta})$ and finally apply FIBST again to obtain the final image.

References

[1] T. Sakamoto and T. Sato, "A Target Shape Estimation Algorithm for Pulse Radar Systems Based on Boundary Scattering Transform," IEICE Trans. on Commun. vol. E87–B, no. 5, pp. 1357–1365, May, 2004.

[2] Takuya Sakamoto and Toru 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.