Acceleration Algorithm for Range Points Migration Based Human Body Imaging with UWB Multi-static Radar

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***Abstract*—Self driving system strongly requires a promising sensor being robust to harsh environment, *e.g.,* in the presence of fog, clouds, or dark smog. The promising technique for the above issue is microwave of millimeter wave ultra-wideband (UWB) radar, which is suitable for short-range surveillance or watching sensors with alleviating the privacy violation issue. The range points migration (RPM) is recently established imaging approach for achieving an accurate and real-time three-dimensional (3-D) imaging. However, in order to address with human like objects with many scattering points, this method requires much higher computational cost. This paper proposes the acceleration algorithm for the RPM based 3-D imaging method for multi-static radar model, where a new evaluation function is introduced. The results from finite difference time domain (FDTD) based numerical test, introducing realistic human body, verify that our proposed method remarkably reduces the computational cost without degrading the reconstruction accuracy.**

***Index Terms*—Ultra-wideband (UWB) radar, Range points migration (RPM), Hunam body imaging**

I. Introduction

Recent demand for auto-driving system drives us to develop environmentally robust sensor, for human detection or collision avoidance. One promising approach for the above sensor, the microwave or millimeter wave ultra-wideband (UWB) radar, because it has higher range resolution and applicability to optically harsh environments *e.g.,* densely fog, dusty air or through-the-wall situations. The above advantages are also suitable for the applications such as through-the-wall scenario, or watch sensors for elderly or disabled persons living alone with alleviating a privacy issue. Synthetic aperture radar (SAR) approaches [1] are developed for the above application. However, these type of methods usually require an expensive computational cost to obtain the full 3-D image, and suffer from inaccuracy due to sidelobe effect.

On the other hand, the range points migration (RPM) method has some advantages in terms of accurate and high-speed 3-D imaging, which efficiently converts each observed time delay (called range point) to each corresponding scattering center [2]. However, the RPM has an inherent problem that the required calculation cost largely depends on the processed data amount, namely, the number of RPs, which considerably increases in the case that target has many scattering centers, like human body.

To address with the above limitation, our former study [3] introduces the sampled-point extraction algorithm, where each scattering center is retrieved from the preliminarily sampled points. However, the study [3] only assumes the mono-static observation, and then, this paper extends the above algorithm, being suitable for multi-static observation model, where the evaluation function is appropriately modified. The finite difference time domain (FDTD) based three-dimensional (3-D) numerical simulations deal with a realistic human body, demonstrate that the proposed method remarkably reduce computational cost compared with the original RPM method, without degrading the imaging accuracy.

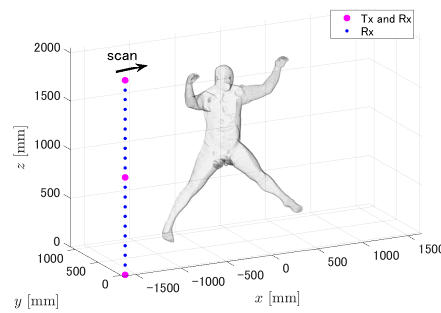

Fig. 1. Observation model.

II. Observation Model

Figure1 shows the observation model. The one-dimensional array, assuming multiple input and multiple output (MIMO) radar, along the z axis is scanned along the x direction. The locations of the transmitting and receiving antennas element are defined as $\boldsymbol{L}_T = (X_T, 0, Z_T)$ and $\boldsymbol{L}_R = (X_R, 0, Z_R)$, respectively. For each combination of $\boldsymbol{L}_{\rm T}$ and $\boldsymbol{L}_{\rm R}$, the recorded electric field is denoted as $s'(\boldsymbol{L}_{\rm T}, \boldsymbol{L}_{\rm R}, t)$, where t denotes a fast time. $s(\boldsymbol{L}_{\rm T}, \boldsymbol{L}_{\rm R}, t)$ is the output of the each filter of $s'(\boldsymbol{L}_{\rm T}, \boldsymbol{L}_{\rm R}, t)$ calculated. $s(\boldsymbol{L}_{\rm T}, \boldsymbol{L}_{\rm R}, t)$ is converted to $s(\boldsymbol{L}_{\rm T}, \boldsymbol{L}_{\rm R}, R)$, using $R' = {\rm c}t/2$ with the radio wave speed c. $\boldsymbol{q} \equiv (\boldsymbol{L}_{\rm T}, \boldsymbol{L}_{\rm R}, R)$ is defined as the range point, which is extracted from the local maxima of s($\boldsymbol{L}_{\rm T}$, $\boldsymbol{L}_{\rm R}$, R).

III. Proposed Method

The range points migration (RPM) is recently established as promising imaging approach, however, in dealing with object with many scattering points, like human body, the RPM suffers from serious increase in computational cost due to the large number of intersection points of the three spheroids. The method [4] enhances the calculation speed and the reconstruction accuracy by in the RPM imaging, by the Doppler-based RP clustering, however, this method still needs the calculation of intersection points of three spheroids determined by all RPs in the cluster, and its computational complexity costs at the order of $O(N^5)$, when N denotes the number of available RPs.

To reduce its computational complexity, our former algorithm [3] designs new evaluation function, not based on the intersection points extraction, but the sample points extraction. However, [3] specifies on the mono-static observation, and then, this paper extends the algorithm for multi-static observation. In this scheme, we focus on the fact that the interval of azimuth angle, from the intersection points to the sample point on the assumed spheroid, is almost proportional to the distance defined as;

$$L(\boldsymbol{p}^{\mathrm{g}}_{i,k}, \boldsymbol{q}_j) \equiv \left| ||\boldsymbol{L}_{\mathrm{T},j} - \boldsymbol{p}^{\mathrm{g}}_{i,k}|| + ||\boldsymbol{L}_{\mathrm{R},j} - \boldsymbol{p}^{\mathrm{g}}_{i,k}|| - 2R_j \right| /2, \quad (1)$$

where $\boldsymbol{p}^{\mathrm{g}}_{i,k}$ is a sample point generated on the rotational ellipse, whose focus points are defined as $\boldsymbol{L}_{\mathrm{T},i}$ and $\boldsymbol{L}_{\mathrm{R},i}$, and major axis is denoted as R_i. Then, the scattering center corresponding to each range point $\boldsymbol{q}_i$ is calculated as:

$$\hat{\boldsymbol{p}}(\boldsymbol{q}_i) = \arg\max_{\boldsymbol{p}^{\mathrm{g}}_{i,k}} \sum_{\boldsymbol{q}_j \in Q_i} s(\boldsymbol{q}_j) \times \exp\left\{ -\frac{D(\boldsymbol{q}_i, \boldsymbol{q}_j)^2}{2\sigma_x^2} \right\} \times \exp\left\{ -\frac{L(\boldsymbol{p}^{\mathrm{g}}_{i,k}, \boldsymbol{q}_j)^2}{2\sigma_L^2} \right\}, \quad (2)$$

where σ_x and σ_L are constants, $D(\boldsymbol{q}_i, \boldsymbol{q}_j)$ denotes the separation of antenna locations between $\boldsymbol{q}_i$ and $\boldsymbol{q}_j$. Note that, the computational complexity of this method is estimated as $O(M^2N)$, where M denotes the total number of sample points.

IV. Evaluation by Numerical Simulation

The 3-D FDTD based numerical tests are investigated here. The transmitting signal forms a pulse modulated signal, with 5.0 GHz center frequency and 2.0 GHz bandwidth. The realistic human phantom as shown in Fig. 1 is introduced, where a dielectric property of each tissue is modeled as in literature [5]. The 1-D linear array antennas are composed of 3 transmitting antennas and 21 receiving antennas, where the separation of transmitting and receiving antennas are 1000 mm and 100 mm, respectively. This array antenna is scanned along the x axis for -1600 mm $\leq x \leq$ 1600 mm, where the sampling interval is set to 200 mm.

Figures 2 show the reconstruction results by each method. Here, the reconstruction error denoted as e is introduced as the minimum distance between an actual target boundary and each reconstructed point. The accumulation proportions satisfying $e <$100 mm are 98.8% for the original RPM method and 93.4% for the proposed method, respectively. On the other hand, the calculation time is more than 2.5×10^5 sec (approximately 70 hours) for the original RPM method, and 425 sec for the proposed method, using Intel(R) Xeon(R) CPU E5-2680 v4 2.40GHz and 128GB RAM, which is 600 times shorter, than that of the original RPM method. For reference, Fig. 3 show the image obtained by the DAS algorithm. Fig. 3 demonstrates that the DAS algorithm does not offer significant boundary shape of the human body, which is also contaminated by sidelobe effect.

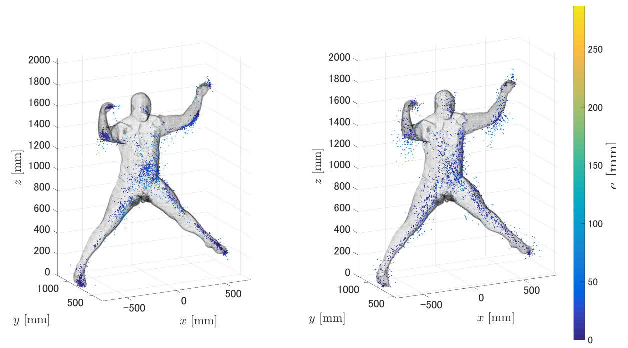

Fig. 2. 3-D reconstruction results obtained by the RPM method. left:Original RPM (intersection point extraction), right:Proposed RPM (sampled point extraction). The color denotes reconstruction error as e.

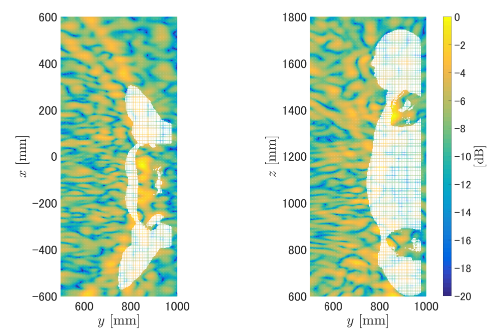

Fig. 3. Sectional view of reconstruction results obtained by the DAS method. left:x=0 mm. right:z=1300mm.

Acknowledgment

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