Particle Filter-Assisted Positioning Method for Identifying RFID-Tag Implanted in the Organism

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Abstract

We propose a three-dimensional positioning method using particle filter for identifying a miniature RFID (Radio Frequency Identification) tag implanted in the organism. The RFID-based tumor marker for identifying the position and size of the tumor has been proposed. Although it is efficient in some applications, it takes a long time to point out the position because of scanning the sensor antenna for wide area of interest. Furthermore, the position is often lost due to motion of the organism. In order to find and track the RFID-tag position, this paper introduces a particle filter-assisted three-dimensional positioning method. The likelihood function, which is not only take into account the received signal power, but also the attitude and position of the sensor antenna and the motion of the RFID-tag, is applied to the particle filter to estimate the position. Computer simulation result shows that the proposed scheme is capable of estimating the three-dimensional position of the RFID-tag.

Proposed RFID Tag Positioning Method

The block diagram of the proposed method is shown in Figure. 1. In this Figure, the signal emitted from the RFID tag is received by the sensor antenna. The received signal is applied to the demodulator (shown as "Demod." in Figure. 1) and measures the signal power. The position and direction of the sensor antenna are also measured. An operator moves the sensor antenna randomly as shown in Figure. 2. The RFID tag moves slowly during the measuring period while the sensor antenna moves randomly around the target. The signal and sensor antenna position and direction are applied to the particle filter based position estimator. The estimated position is then shown by the position indicator.

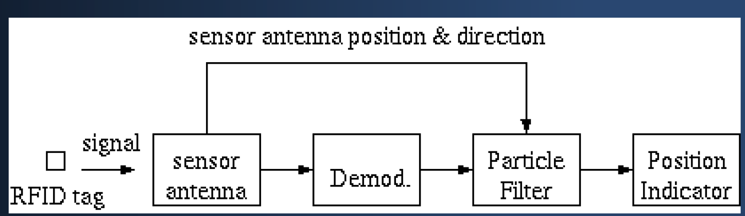

Figure 1. Block diagram of the proposed particle filter-assisted RFID-tag positioning method

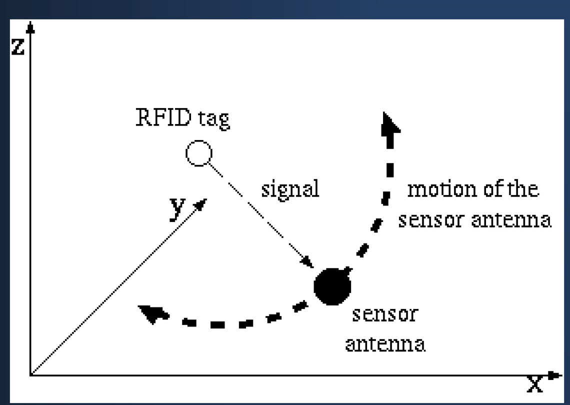

Figure 2. Motion model of the sensor antenna

Figure. 3 shows the position and direction relationship between The sensor antenna and RFID-tag. RFID-tag is modeled As a single loop coil whose radius is denoted as r. We assume r is much smaller than distance between the sensor antenna and RFID-tag, $|\boldsymbol{r}_s(t)-\boldsymbol{r}_i(t)|$.

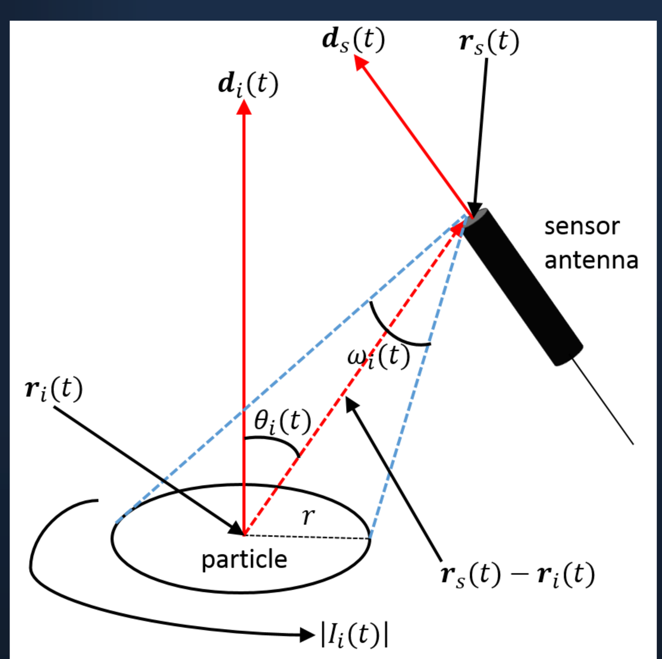

Figure 3. Relationship between the sensor antenna and the RFID-tag

The magnetic field at the sensor antenna, $\boldsymbol{H}_i(t)$ is calculated by the partial derivative of the vector potential, $U_i(t)$. Therefore, the magnetic field is given by

$$\boldsymbol{H}_i(t) = -\nabla U_i(t)$$

where the vector potential is given by

$$U_i(t) = \frac{\omega_i(t)}{4\pi}|I_i(t)|$$

where

$$\omega_i(t) = \frac{\pi r^2 cos\theta_i(t)}{|\boldsymbol{r}_s(t)-\boldsymbol{r}_i(t)|^2}$$

and

$$cos\theta_i(t) = \frac{\boldsymbol{d}_i(t)\cdot(\boldsymbol{r}_s(t)-\boldsymbol{r}_i(t))}{|\boldsymbol{d}_i(t)||\boldsymbol{r}_s(t)-\boldsymbol{r}_i(t)|}$$

Particle Filter

The motion of the particles in the each stage is shown in Figure. 4. At the first stage (I), particles are deployed over the state-space as virtual tags. At the next stage (II), we observe signal emitted from the RFID tag and measures the signal power. Then We calculate the likelihood for each particle at Third stage (III). Likelihood is calculated by comparing the actual received signal power and the expected received signal power when the RFID tag is located at the particle state. At Fourth stage (IV), particles are resampled according to likelihood ratio. In proportion to the likelihood ratio, the new particles are generated. The particles, whose likelihood ratios are less than a certain threshold, are removed from the particle filter. Then, in the bottom stage (V), the state of each particle is changed according to the state transition model. The procedures from (II) to (V) are iteratively carried out.

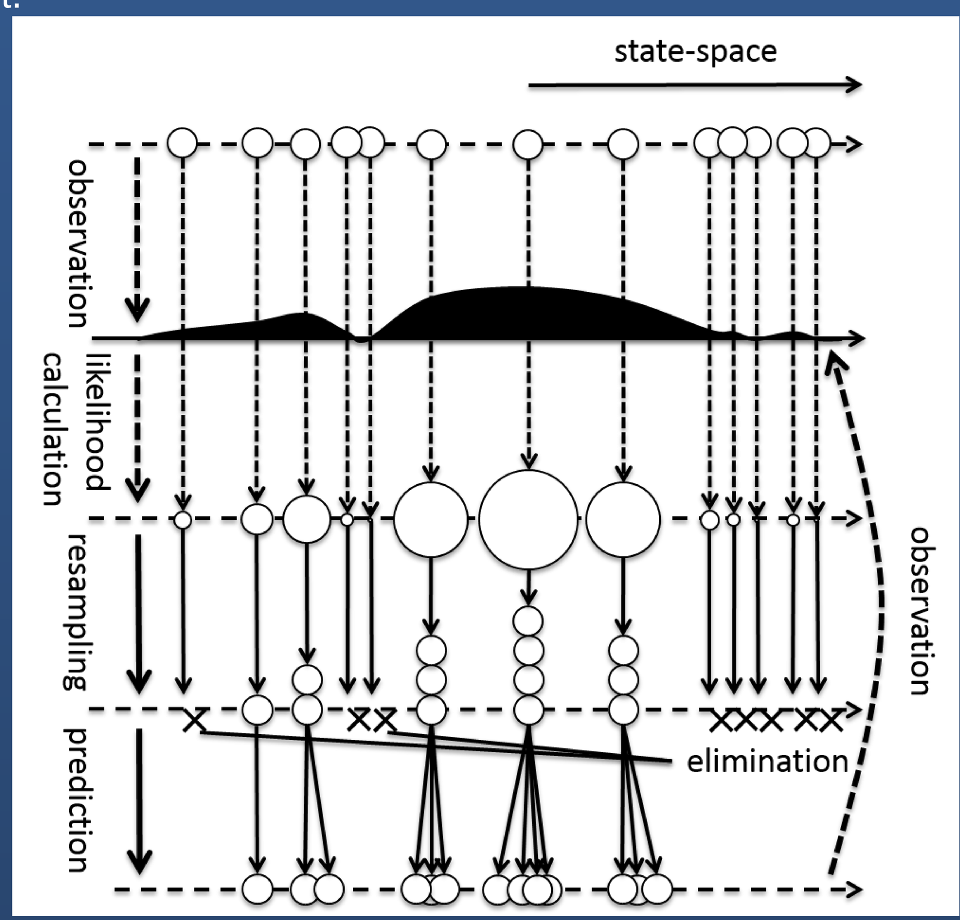

Figure 4. Motion of the Particles

System Model

state vector of a sensor antenna

$$\boldsymbol{S}(t) = \begin{pmatrix}\boldsymbol{r}_s(t)\\ \boldsymbol{d}_s(t)\end{pmatrix} \quad \begin{matrix}\text{position vector}\\ \text{direction vector}\end{matrix}$$

state vector of i-th particle

$$\boldsymbol{P}_i(t) = \begin{pmatrix}\boldsymbol{r}_i(t)\\ \boldsymbol{v}_i(t)\\ \boldsymbol{d}_i(t)\\ \boldsymbol{v}_{d_i}(t)\\ |I_i(t)|\\ v_{I_i}(t)\\ \lambda_i(t)\end{pmatrix} \quad \begin{matrix}\text{position vector}\\ \text{fluctuation vector of position}\\ \text{direction vector}\\ \text{fluctuation vector of direction}\\ \text{electric current}\\ \text{fluctuation of electric current}\\ \text{likelihood}\end{matrix}$$

The state transition model is given by

$$\boldsymbol{P}_i(t+1) = \begin{pmatrix}1&1&0&0&0&0&0\\0&0&0&0&0&0&0\\0&0&1&1&0&0&0\\0&0&0&0&0&0&0\\0&0&0&0&1&1&0\\0&0&0&0&0&0&0\\0&0&0&0&0&0&0\end{pmatrix}\cdot\boldsymbol{P}_i(t) + \begin{pmatrix}\boldsymbol{0}\\ \boldsymbol{v}_i(t+1)\\ \boldsymbol{0}\\ \boldsymbol{v}_{d_i}(t+1)\\ 0\\ v_{I_i}(t+1)\\ 0\end{pmatrix}$$

calculate likelihood after state transition

$$= \begin{pmatrix}\boxed{\boldsymbol{r}_i(t)+\boldsymbol{v}_i(t)}\\ \boldsymbol{v}_i(t+1)\\ \boxed{\boldsymbol{d}_i(t)+\boldsymbol{v}_{d_i}(t)}\\ \boldsymbol{v}_{d_i}(t+1)\\ \boxed{|I_i(t)+v_{I_i}(t)|}\\ v_{I_i}(t+1)\\ \boxed{\lambda_i(t+1)}\end{pmatrix}$$

The likelihood function is given by

$$\lambda_i(t) = \frac{1}{\sqrt{2\pi\sigma^2}}exp\left(-\frac{e_i(t)^2}{2\sigma^2}\right)$$

where

$$e_i(t) = \boxed{Power_T(t)} - \boxed{Power_{P_i}(t)}$$

actual received signal power

i-th expected received signal power

and

$$Power_{P_i}(t) = \left(\boldsymbol{H}_i(t)\cdot\frac{\boldsymbol{d}_s(t)}{|\boldsymbol{d}_s(t)|}\right)^2$$

Results & Discussion

In order to confirm the validity of the proposed method, we have carried out the computer simulation. The system configuration in order to run the simulation is shown in Table I.

Sensor antenna	
Moving range	$100mm * 100mm * 100mm$
Number of sweeps	$200sweeps$
velocity	$80mm/cycle$
Initial direction	$\boldsymbol{d}_s(1) = (0,0,-1)$
Fluctuation of a direction	$\boldsymbol{N}(0,(1e-01)^2)$
Distance & relative angle From RFID tag for noise	$40mm, 0°$
RFID tag	
Moving range	$100mm * 100mm * 100mm$
Fluctuation of a position	$\boldsymbol{N}(0,(1)^2)mm$
Fluctuation of a direction	$\boldsymbol{N}(0,(1e-01)^2)$
Average of electric current	$1e-01$
Fluctuation of electric current	$N(0,(1e-02)^2)$
radius	$0.5mm$
Particles	
Fluctuation of a position	$\boldsymbol{v}_i(t) = \boldsymbol{N}(0,(1)^2)mm$
Fluctuation of a direction	$\boldsymbol{v}_{d_i}(t) = \boldsymbol{N}(0,(1e-01)^2)$
Average of electric current	$1e-01$
Fluctuation of electric current	$v_{I_i}(t) = N(0,(1e-02)^2)$
radius	$r = 0.5mm$
Sigma of likelihood calculation	$\sigma = 1e-08$

Table I. System Configuration

Firstly, Figure. 5 shows the snap shot of the positions of the RFID tag, sensor antenna, and particles. The square mark, "X" mark, and the dots correspond to the positions of target RFID tag, sensor antenna, and the position of the particles, respectively. According to the Figure, most of the particles converge to the target RFID tag position. This implies that the proposed particle filter-assisted positioning scheme can successfully estimate the RFID tag position.

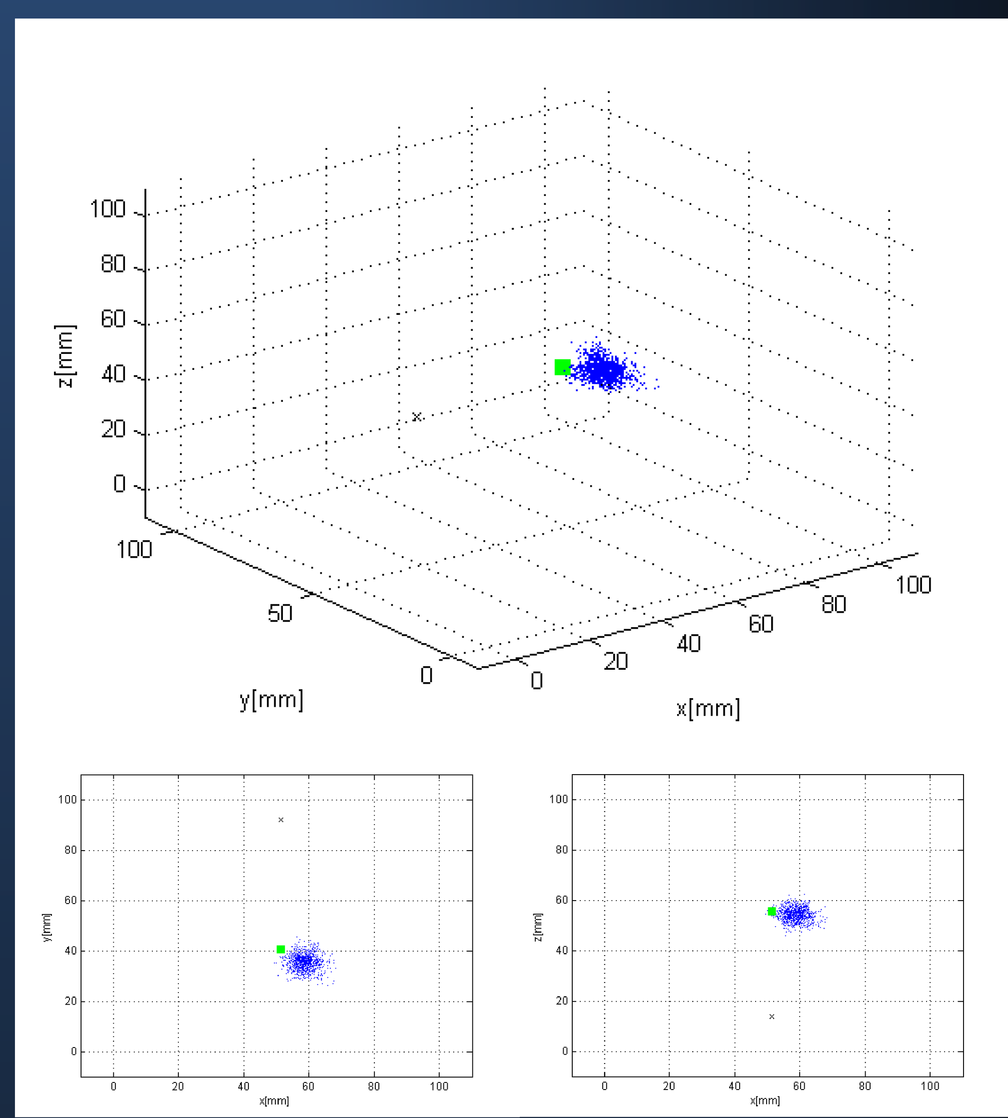

Figure 5. A Snap Shot of the Positions of a RFID Tag, a Sensor Antenna and Particles (1000 particles, 200th sweep and 32dB)

Figure. 6 is the RMS (Root Mean Square) error against SNR (Signal to Noise power Ratio). For comparison, we have made the evaluations at the different number of particles. The RMS error is decreased with increase in SNR. At SNR=32dB, RMS error is less than 10mm when the number of particles is more than 50000. From Figures. 5 and 6, we have confirmed that the proposed scheme is capable of estimating the target RFID tag position.

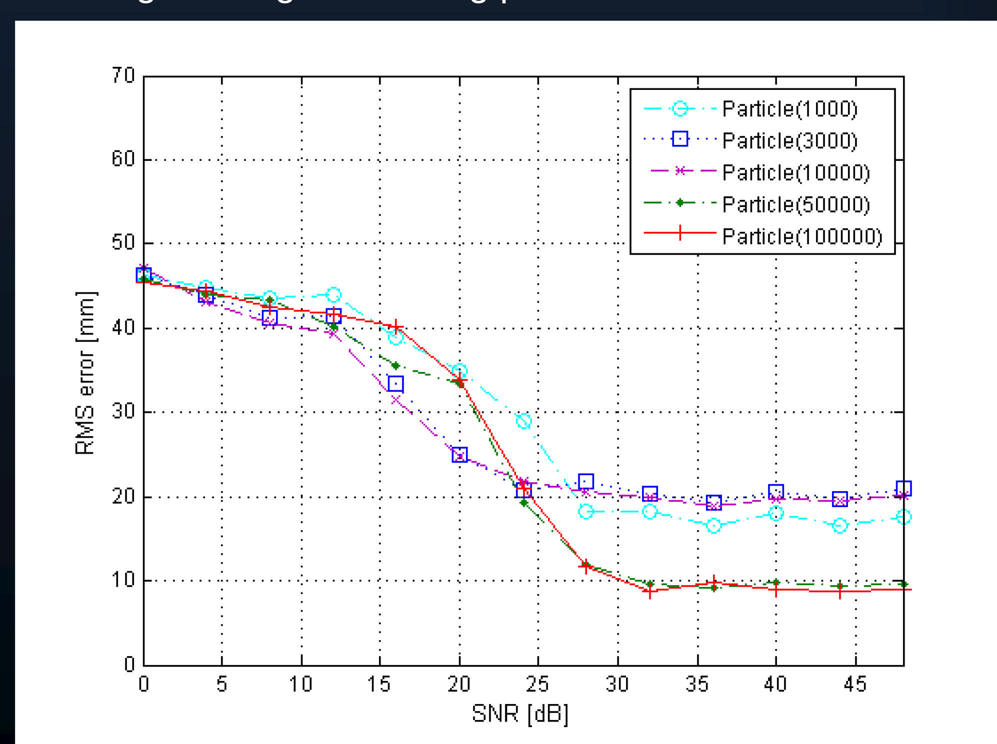

Figure 6. Comparison of the Particles (500 frames)