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An Effective Usage of Transmitted Directivity Information for Target Position Estimation Algorithm

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***Abstract*—We consider localization systems for targets because information of the targets position, such as human, cars, dangerous objects, is very meaningful. Especially, we focus on the estimation of targets that exist in near wide area. In order to cover the wide area, the system, which has multiple networked ranging sensors, is useful. Such networked systems are often called as radar network systems or sensor network. The straight arrangement of the sensors is very useful because of easy setting and installing. Previously, receivers arranged in a straight line would generate a large positioning error in the same direction of the line, that is horizontal direction. In this paper, for reduction of this error, we propose a novel estimation algorithm using the directivity information of the transmitter. The proposed system has a electrical directional antenna in a transmitter. So the transmitter can emit signals to intended directions. In this paper, the error characteristic, which must be solved, is introduced firstly. Then, the proposed algorithm is presented theoretically. Finally, through the results of the computer simulations, the examples of the error reduction are demonstrated under various situations such as different target positions or type of sensors. The obtained results indicate the estimation characteristics that our proposal achieves the some reduction of the horizontal error even the sensors are arranged in a straight line.**

Keywords-*position estimation; localization; directivity of array; sensor network; radar network.*

I. INTRODUCTION

Information of target positions, such as human location, suspicious person detection and dangerous objectives, is very meaningful and attractive. On the basis of these demands, interest in position estimation systems has been growing. For far targets, it is relatively easy because the sensors can be allowed to using a narrow sensing area. However, for near targets, the sensing area is needed as the wide cover area. It is difficult to realize because wide covered antenna has received unintended signals easily. Then we have focused on the estimation of the position of targets in the near wide area before now [1].

To extract the unintended signals and derived information, the multiple sensors, which generate redundancy, is effective solution (Figure 1). So one of potent position estimation systems are built with the multiple sensors that are connected with networks. These sensors achieve reliable detections and accurate position estimation. Even inexpensive devices such as ultrasonic radars, will be able to achieve good performance. Moreover, networked sensors can obviously cover a wide detection area. Several attractive applications of position estimation systems have been suggested, including indoor monitoring systems (Figure 2(a)) and near-range automotive radars (Figure 2(b)) [2], [3].

The multiple sensor networks can be realized by any devices such as laser radars, radio radars, ultrasonic radars. We assume that the sensors in the network can output only measured ranges (a measured range list) to the targets. The reason is that the only ranging function can be realized with low cost and simple components which are used to construct the sensors The estimator must calculate target positions with high accuracy from only measured range lists provided by multiple sensors. For accurate positioning, it is important to discuss data processing of position estimation, which deals with measured range data from all of the sensors. Because the assumed sensors can have only the range function, we call the multiple sensor networks as radar network in this paper.

The system has the multiple sensors. So it is important about how to arrange the sensors. For easy setting within a limited space with simple wiring, a straight-line arrangement is usually preferred. Now we focus on the error of position estimation. The estimation errors depend on the layout of the receivers. In particular, for the case in which the receivers are arranged in a straight line, large errors are generated in the same direction of the line. Because a straight-line arrangement is useful and preferred very much, thus, a novel technique to reduce the estimation errors is needed.

The goals of the presented paper are as follows:

- Introduction of the conventional algorithm (EPEM) theoretically and particularly,
- Clarification of the error performance depending on the

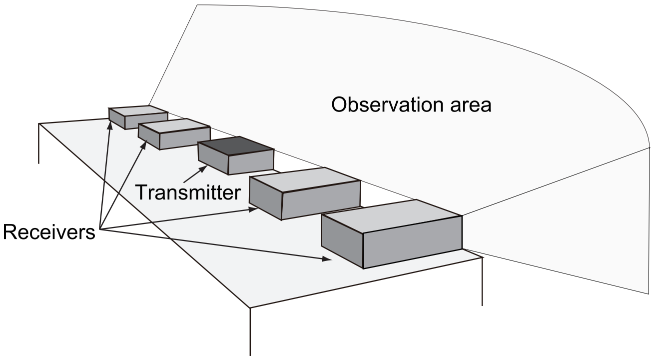
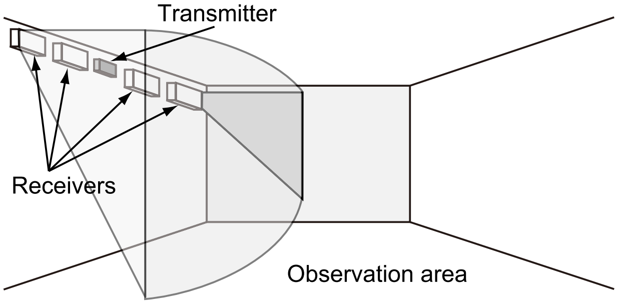
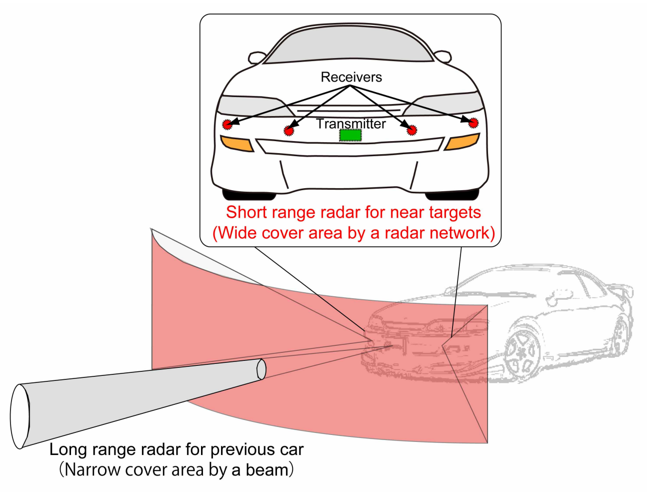


Figure 1. Concept of position estimation system by sensor networks



(a) Indoor monitoring system



(b) Automotive radar system

Figure 2. Example of multiple sensing network systems

sensor arrangement and description of the problem,
- Proposal of the existence probability estimation method with directivity information (EPEMD) algorithm,
- Evaluation of the error reduction through various computer simulations.
- Presentation of the example performance through above evaluations under different conditions.

The proposed radar network in this paper has cooperative transmitter. The transmitter has the function of the variable directivity by electrical array antennas. On the processing of positions estimation, our proposal EPEMD calculates the target existence probability. Especially, the EPEMD algorithm uses the transmitted directivity information effectively. In the case of radar network systems, transmitters often use a directivity scan in order to reduce misdetections and expand detectable ranges for limited power [4]. Moreover, the construction of electrical directivity antennas is advantageous because the sensor device requires a long deliverable range with low power. Therefore, it is meaningful to propose an estimation algorithm that considers the directivity pattern.

The remainder of this paper is organized as follows. In Section II, related estimation algorithms, which use the multiple sensors, are introduced. And problems and advantages of our EPEM and EPEMD are described. In Section III, we present the system model and assumptions of the present study. In Section IV, we introduce the EPEM algorithm, which is a position estimation algorithm. The algorithm is explained theoretically, and the error performance and problems are presented. In Section V, the proposed EPEMD algorithm is presented in detail. In Section VI, the performance of the error reduction is demonstrated and evaluated under various situations. Finally, Section VII summarizes the present study and presents suggestions for further research.

II. RELATED RESEARCH

In this section, we introduce related researches, which estimate the target position by multiple sensors. Over the past few years, researchers around the world have developed several algorithms. The related estimation algorithms with multiple sensing devices are growing on the research area of sensor network systems or radar network systems. Here, some works about sensor networks are presented in the following literatures [5]–[9]. Also, radar network systems have been discussed in [10]–[12].

The typical estimation algorithms are summarized as below:

- Trilateration technique
- Stochastic approach

For estimating target positions, the trilateration techniques using geometric operations are most popular. The accuracy of these techniques is not optimum. Moreover they may also detect “ghost targets”, which are falsely detected about non-existent targets. This often occurs when the measured ranging errors are large [2], [11]. These lacks are generated because the trilateration techniques does not consider the influence of the measurement error.

In other techniques, measured ranges are treated as stochastic variables [13]–[15]. That is, by treatment of the stochastic variables, the influence of the measurement error can be considered. Typical techniques are, for example, estimation algorithms using minimum mean square error (MMSE) and maximum a posterior probability (MAP). The accuracy of these techniques is high compared to the above popular trilateration techniques. Among the stochastic methods, the accuracy of the MAP method is optimum. However, the calculation amount is high because data processing of the MAP method is very complex. Moreover the pre-knowledge, such as number of targets, is needed. Therefore, we proposed a novel estimation algorithm, namely, the existence probability estimation method (EPEM) [16]. The EPEM calculates the existence probability of targets and estimates the target positions. In the proposed method, the measured ranges are also treated as stochastic values. Moreover, the proposed method has approximately the same estimation accuracy and a lower calculation cost compared to optimum MAP methods.

However, problems are still remaining. One of the problems is the estimation error, which depends on the layout of the receivers. As mentioned in Sec. I, for the case in which the receivers are arranged in a straight line, large errors are generated in the same direction of the line. Usually, a straight-line arrangement is useful because such an arrangement is easy to build and can be set up within a limited space with easy wiring. Thus, a novel technique to reduce the estimation errors is needed. In this paper, we will try resolving this problem. That is, we will propose the reduction algorithm by using the directional information of the transmitter effectively.

III. ASSUMPTION AND SYSTEM MODEL

In this paper, we will firstly point out the problem clearly. This section is described about the system model for explanation the conventional estimation and the problem. Figure 1 shows the system model. The assumed system has a transmitter and multiple receivers. First of all, for easy understanding, we explain using our radar network model with 4 radars and 2 targets. This is simple case. In Section IV-B, we introduce a more complicated case.

Figures 3 and 4 show the system model and the flow of data processing. Figure 4 also indicates the necessary parameters for the estimation. Figure 3 shows the sensor layout and the targets which are estimated. The numbers of receivers and targets are 4 and 2, respectively. The origin of the coordinate system is the center of the receivers. The target positions are given as $(x_1, y_1), (x_2, y_2)$. We note that each receiver is assumed to be located on the x-axis because the straight line layout is useful for setting and wiring to variable applications. The x positions of the receivers are $\alpha_1, \alpha_2, \alpha_3, \alpha_4$.

The kth receiver outputs a measured range list composed of the ranges to the targets, namely, $\tilde{R}_k = (\tilde{r}_{k1}, \tilde{r}_{k2})$. We assume the existence of a only direct path between the target and the transmitter/receiver. Subscript (˜) indicates measured values.

Each measured range $\tilde{r}_{kn}$ in the list includes a measurement error:

$$\tilde{r}_{kn} = r_{kn} + \epsilon_k, \qquad (1)$$

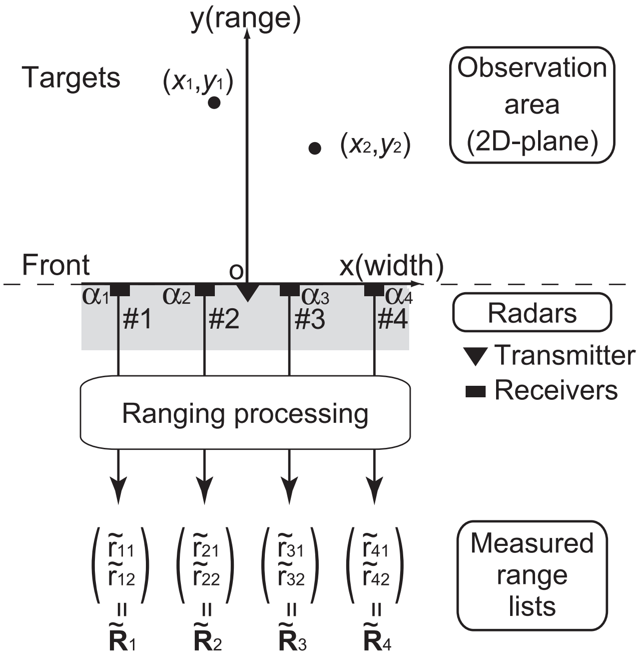


Figure 3. Layout of sensors and targets (4 receivers and 2 targets)

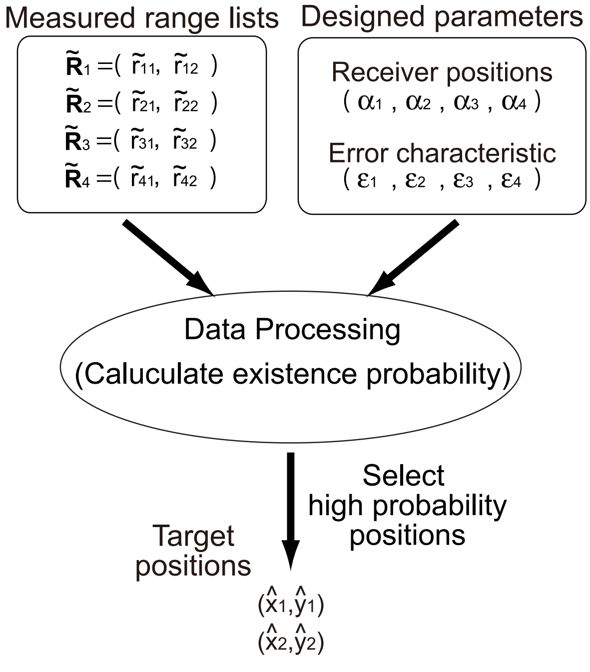


Figure 4. A data flow (4 receivers and 2 targets)

where r_{kn} is the true range between the nth target and the transmitter / the kth receiver, and ϵ_k is a stochastic variable, the variance of which is denoted as σ_k^2. Using the measured range lists obtained from all receivers and the positions of the receivers, the target positions are estimated as shown in Figure 4.

IV. ESTIMATION ALGORITHM AND ITS PROBLEM

The popular estimation algorithm of a target position is trilateration method which uses geometric operations [2], [11]. This is not optimum accuracy because the measurement errors are not considered. It may also detect "ghost target" that the detector outputs false position even there is no targets. This may happens in case of large measurement error or multipath environment. In order to address these problems, the proposed estimation method, which is described below, deals with the measured rages as stochastic variables.

In the first half of this section, we introduce the position estimation algorithm based on the existence probability which is named as the conventional in this paper. The estimation characteristics are then summarized, and the problem is pointed out. The estimation method, which is presented below, is called as EPEM(Existence probability estimation method).

A. Existence probability estimation method (EPEM)

For estimation of the target positions from the measured range lists provided by the receivers, we consider the following existence probability:

$$P(\hat{x}, \hat{y} | \tilde{R}_1, \tilde{R}_2, \tilde{R}_3, \tilde{R}_4). \tag{2}$$

The Equation (2) includes the conditional probability. The above probability is the conditional probability of the target existence at $(\hat{x}, \hat{y})$ when the measured range lists $\tilde{R}_1, \tilde{R}_2, \tilde{R}_3, \tilde{R}_4$ are obtained. Next, by using Bayes' theorem, Equation (2) can be written as follows:

$$\frac{P(\tilde{R}_1, \tilde{R}_2, \tilde{R}_3, \tilde{R}_4 | \hat{x}, \hat{y})}{P(\tilde{R}_1, \tilde{R}_2, \tilde{R}_3, \tilde{R}_4)} \cdot P(\hat{x}, \hat{y}). \tag{3}$$

In Equation (3), the denominator does not depend on the estimated parameter $(\hat{x}, \hat{y})$. Then, when $P(\hat{x}, \hat{y})$ is distributed uniformly, Equation (3) may have the same distribution shape to the following:

$$P(\tilde{R}_1, \tilde{R}_2, \tilde{R}_3, \tilde{R}_4 | \hat{x}, \hat{y}). \tag{4}$$

Each receiver is assumed as independent. Because the measured range is an independent Gaussian variable, Equation (4) can be expressed as follows.

$$\prod_{k=1}^{4} P(\tilde{R}_k | \hat{x}, \hat{y}). \tag{5}$$

There are the relationships between the targets ans ranges. With considering the combinations of targets and ranges, Equation (5) may be expressed as follows:

$$\prod_{k=1}^{4} \left[B_{k,1} P(\tilde{r}_{k1} | \hat{x}, \hat{y}) + B_{k,2} P(\tilde{r}_{k2} | \hat{x}, \hat{y}) \right] \tag{6}$$

where $B_{k,n}$ is the probability that the nth measured range in the measured range list of the kth radar, that is $\tilde{r}_{kn}$, means the range to the focused target. Next, the estimated parameters $(\hat{x}, \hat{y})$ can be transformed with the distance from the transmitter/kth receiver to the target, that is, $\hat{r}_{kn}$ as follows:

$$\hat{r}_{kn} = \sqrt{(\hat{x} - \alpha_k)^2 + \hat{y}^2} + \sqrt{\hat{x}^2 + \hat{y}^2} \quad \text{(for all } n\text{)}. \tag{7}$$

By using the above relational expression, Equation (6) can be converted to the following:

$$\prod_{k=1}^{4} \left[B_{k,1} P(\tilde{r}_{k1} | \hat{r}_k) + B_{k,2} P(\tilde{r}_{k2} | \hat{r}_k) \right]. \tag{8}$$

In this paper, we assume that there is not pre-knowledge at all. It is most difficult case. Hence, the value $B_{k,n}$ is equal value respectively. And the the value $B_{k,n}$ does not also depend on the estimated parameter $(\hat{x}, \hat{y})$. So, the distribution of Equation (8) is the same shape to:

$$\prod_{k=1}^{4} \sum_{n=1}^{2} P(\tilde{r}_{kn} | \hat{r}_k). \tag{9}$$

The probability of $P(\tilde{r}|\hat{r})$ indicates the error characteristic of the receiver. The characteristic of the measurement error must be known as the specifications of the own receivers. Using Equations (7) and (9), the distribution of the existence probability of the target at position $(\hat{x}, \hat{y})$ can be calculated from the measured range lists $\tilde{R}_1, \tilde{R}_2, \tilde{R}_3, \tilde{R}_4$, which can be obtained by the receivers. By selecting the local maximums of the distribution of Equation (9), the target positions can be estimated. For the multiple targets, the estimator may select multiple candidates, which have high probability. The distribution of Equation (9) is called as Existence probability of the targets. The example distribution of the existence probability is presented as Figure 5. Figure 5 shows the probability in case that the position of the target is $(x, y) = (0.5, 9)$[m].

B. Case of N targets and K receivers

The simple case, which is the number of the receivers $K = 4$ and the number of the targets $N = 2$, was presented. Next we introduce more complicated case. That is the number of the receivers K and the number of the targets N. Figure 6 shows the system model. Figure 7 also shows the flow of the data processing.

Figure 6 shows the sensor layout and the targets. The numbers of receivers and targets are K and N, respectively.

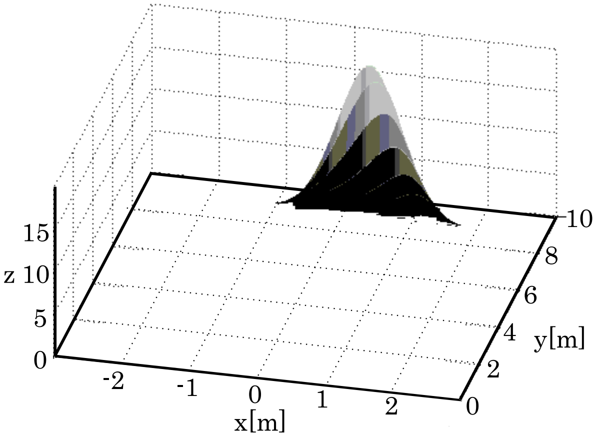


Figure 5. Example of the existence probability (1 target)

The target position is given as (x_n, y_n), $1 \leq n \leq N$. The x positions of the receivers are $\alpha_1, \alpha_2, \alpha_3, \cdots, \alpha_K$.

The kth receiver outputs a measured range list composed of the ranges, namely, $\tilde{R}_k = (\tilde{r}_{k1}, \tilde{r}_{k2}, ..., \tilde{r}_{kN_k})$. Here, $N_k (\leq N)$ is the number of ranges included in the measured range list $\tilde{R}_k$.

For estimation of the target positions, we consider the following existence probability, which includes the conditional probability:

$$P(\hat{x}, \hat{y} | \tilde{R}_1, \tilde{R}_2, \tilde{R}_3, \cdots, \tilde{R}_K) \tag{10}$$

which is the same to Equation (2). The probability of Equation (10) is the conditional probability of the target existence at $(\hat{x}, \hat{y})$ when the measured range lists $\tilde{R}_1, \tilde{R}_2, \tilde{R}_3, \cdots, \tilde{R}_K$ are obtained.

By the transformations which are the same to Equation (3)-(9), above Equation (10) has the same shape of the distribution to:

$$\prod_{k=1}^{K} \sum_{n=1}^{N} P(\tilde{r}_{kn} | \hat{r}_k). \tag{11}$$

The probability of $P(\tilde{r}|\hat{r})$ indicates the error characteristic of the known receiver. Using Equations (7) and (11), the distribution of the probability of the target existence at position $(\hat{x}, \hat{y})$ can be calculated when the measured ranges $\tilde{R}_1, \tilde{R}_2, \tilde{R}_3, \cdots, \tilde{R}_K$ are obtained.

The EPEM has approximately the same estimation accuracy as the MAP method, which is optimum in terms of maximum a posteriori probability [16].

C. Estimation characteristics and problems

In the following, we present the estimation characteristics of the EPEM algorithm described in the previous section. The simulation parameters are shown in Table I. In the simulations, we assume the measurement error as 0.3 m,

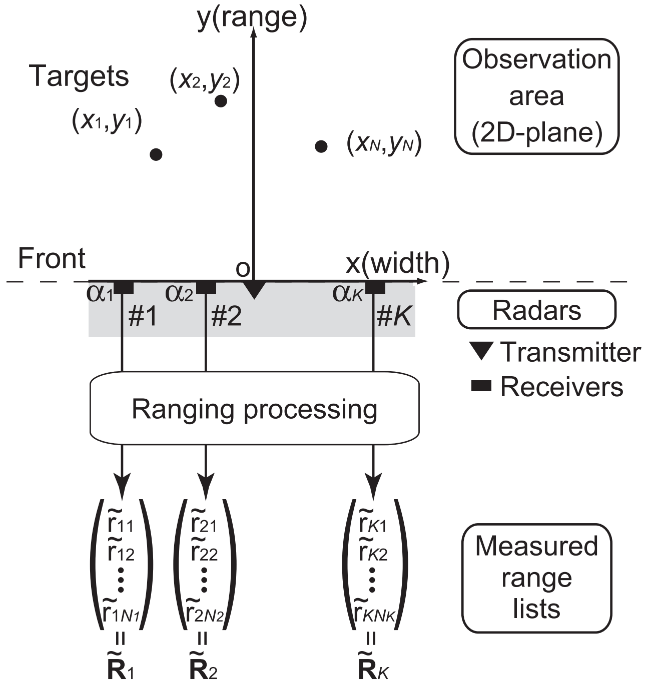


Figure 6. Layout of sensors and targets (K receivers and N targets)

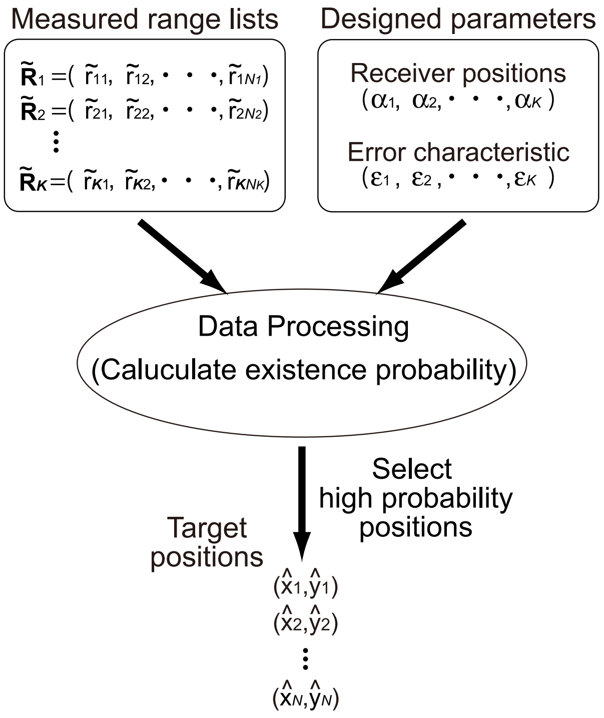


Figure 7. A data flow (K receivers and N targets)

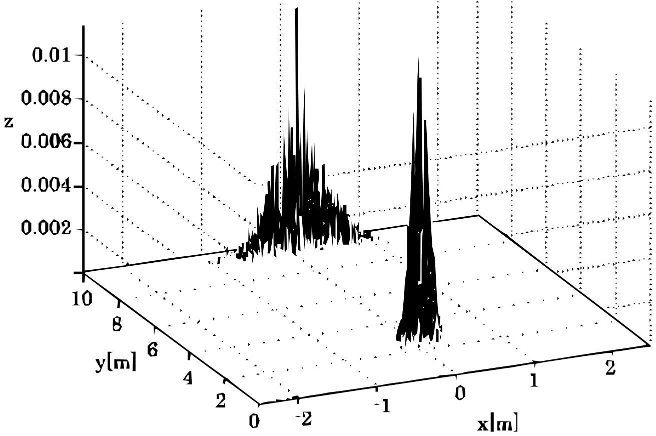


Figure 8. Distribution of estimated target positions (EPEM)

Table I
SIMULATION PARAMETERS

Number of receivers: K	3
Number of targets: N	2
Target positions	#1 $(x_1, y_1) = (0, 2)$[m] #2 $(x_2, y_2) = (0, 9)$[m]
Array width of receivers	2 m
Distribution of measurement error $\tilde{r}$	Gaussian distribution ($\sigma_k = 0.075$)
Number of iterations	50,000

Table II
CHARACTERISTICS OF THE ESTIMATED TARGETS (EPEM)

	Target 1	Target 2
Var$[\hat{x}]$	0.014	0.240
Var$[\hat{y}]$	0.002	0.002

which is typical [17]. According to this value, we set the standard derivation σ_k of the measured ranges ($4\sigma_k = 0.3$ [m]). The estimation trials of the targets are simulated. The trials generate the distribution of estimated positions. The results are shown in Figure 8. Moreover, the variance of the distribution for each of the targets position in Figure 8 are summarized in Table II. Figure 8 and Table II show that the error in the x-direction is larger than that in the y-direction. The reason for this is that the receivers are arranged along the x-axis. That is, large errors are generated in the same direction to the receivers' arrangement. In order to reduce the x-axis errors, we propose an estimation algorithm that uses the directivity of the transmitter.

V. PROPOSAL OF ESTIMATION ALGORITHM USING THE DIRECTIVITY OF THE TRANSMITTER

In this section, we introduce our proposal. The proposal solves the problem of the large error described in the previous section. The proposed algorithm is named as EPEMD (the existence probability estimation method with directivity information).

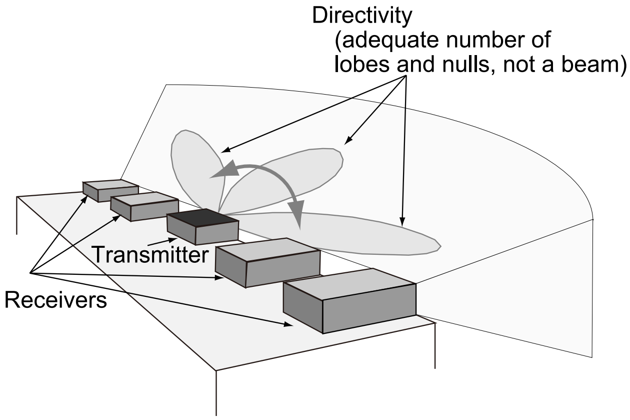


Figure 9. Image of the proposed system

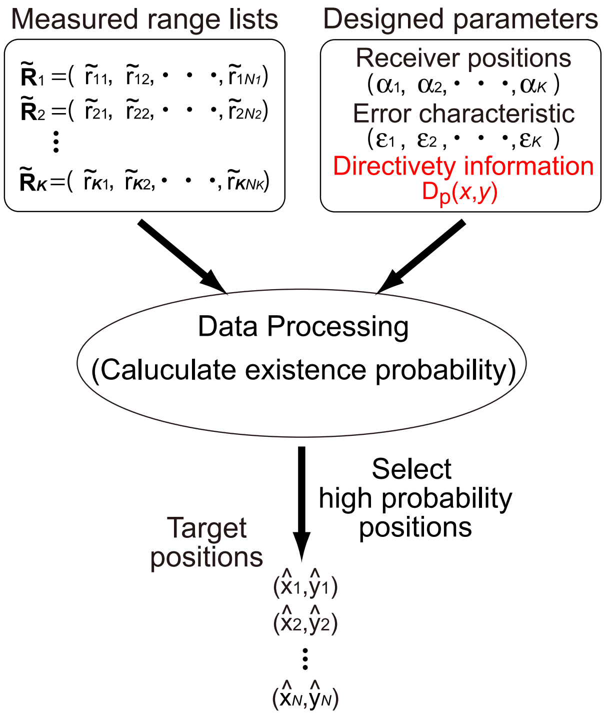


Figure 10. A data flow (Proposal EPEMD)

We illustrate the image of our proposal in Figure 9. And Figure 10 also shows the flow of the data processing, which also indicates the necessary parameters for the estimation. The difference between Figures 1 and 9 is the transmitter of Figure 9 has a directivity. So, as seen in Figure 10, the directivity information can be used.

The system model is the same to Section III. That is, a signal is radiated from the transmitter, which is composed of two or more devices to achieve directivity. The reflected

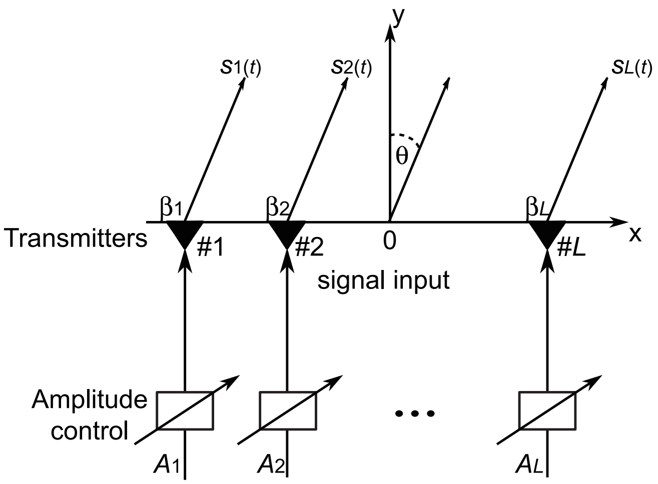


Figure 11. Structure of the transmitter array

signal from the target is received by the receivers, which are placed along a straight line (x-axis).

As shown in Figure 11, a transmission array is composed of L transmitters. The transmitters in the array are arranged symmetrically. The center of the array is the origin of the coordinate. The variables $(\beta_1, 0), (\beta_2, 0), \ldots, (\beta_L, 0)$ mean the positions of the transmitter. The variables A_l indicate the amplitude coefficient, and $s_l(t)$ also indicate the radiated signal from the lth transmitter. The total signal in the θ direction can be expressed as follows:

$$S_{\text{sum}}(\theta, t) = s(\theta, t) \sum_{l=1}^{L} A_l \exp\{j2\pi f_0 (\frac{\beta_l}{c} \sin\theta)\} \tag{12}$$

where f_0 is the center frequency of the signal, and c is the speed of wave. The based signal and common characteristics of the transmitters, such as the directivity pattern of the element, is substituted as $s(\theta, t)$. In the present study, $|S_{\text{sum}}(\theta, t)|$, which indicates the gain generated by the array, is named as the directivity response pattern.

In the proposal, the directivity response pattern can be used effectively when the existence probability is calculated. We try to reduce the horizontal estimation errors using this directivity response pattern. The electrical directivity antenna, such as Figure 11, can change the directivity response pattern arbitrarily. However, for the purpose of clarity, we explain the EPEMD method using an example of a directivity pattern. The example is shown in Figure 12. Considering this directivity response pattern, the signal can be reflected only from targets that exist in the area within the beam, such as Target #1. In contrast, Target #2 cannot reflect the signal. Then, the function to specify the reflectable area is as follows:

$$D_p(x, y) = \begin{cases} 1 & \text{(area that can be reflected)} \\ 0 & \text{(area that cannot be reflected)} \end{cases}. \tag{13}$$

That is, Equation (13) means the area in which the target can reflect the signals or not. So, in this paper, the Equation (13) is called as reflectable area function. The above reflectable area function can be derived from the directivity response pattern.

From now, we explain the derivation of the reflectable area function. The directivity response pattern can be converted to the reflectable area of the $x - y$ plane by way of the following radar equation:

$$S = \frac{\gamma P_t}{R^4}. \tag{14}$$

The parameter S means the electric power of the reflected signal, that is, the signal received at the receiver. The parameter γ is determined on the basis of, for example, the antenna gain and the effective reflection area of the targets. In addition, P_t is the power of the transmitter, and R is the range from the transmitter/receivers to the target.

Then, if S is defined as the minimum detectable power at the receiver, the R means the maximum reflectable range obviously. Equation (14) can be rewritten as follows:

$$R = \sqrt[4]{\frac{\gamma}{S}} \sqrt[4]{P_t} \tag{15}$$

Next, we assume that the transmitting power becomes δP_t, that is δ times. Then, maximum reflectable range R' can be rewritten in terms of R as follows:

$$R' = \sqrt[4]{\frac{\gamma}{S}} \sqrt[4]{\delta P_t} = \sqrt[4]{\delta} R \tag{16}$$

As mentioned above, the absolute value $|S_{\text{sum}}(\theta, t)|$ in Equation (12) means the gain of the array. The gain of the array is related to δ. The maximum reflectable range R' can be calculated from Equations (16) when the gain of the transmitted power is $|S_{sum}(\theta, t)|$. As a result, the reflectable area function, that is Equation (13), can be calculated.

In the proposal EPEMD, the reflectable area function is considered into the existence probability of the targets. From Equations (13) and (9), we obtain the following equation:

$$\left[\prod_{k=1}^{K} \sum_{n=1}^{N} P(\tilde{r}_{kn} | \hat{r}_k) \right] \cdot D_p(x, y) \tag{17}$$

Equation (17) gives the existence probability considering the directivity of the transmission signal. The EPEMD estimates the target positions by searching the high values of the above existence probability. This search is the same to the conventional EPEM algorithm in the description of Section IV-A.

The directive antenna also generates null directions. In order to avoid null directions and cover a wide area, the

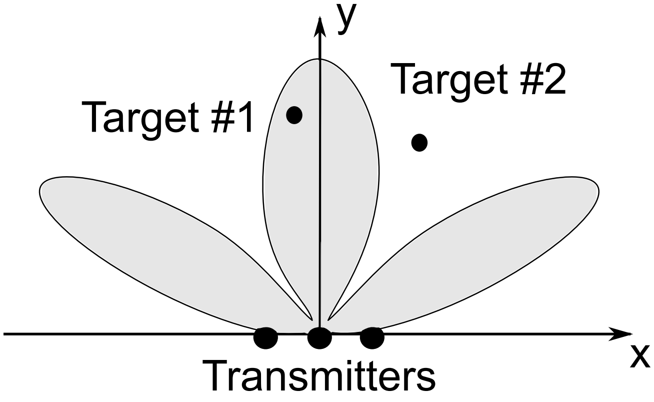


Figure 12. Directivity response pattern and targets

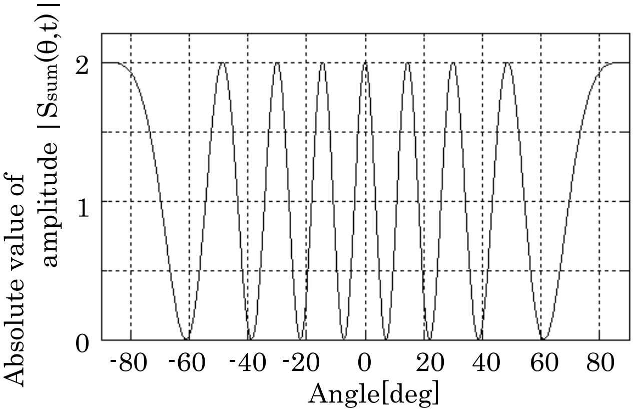


Figure 13. Designed directivity response pattern (Simulation I)

transmitter has to compensate the direction of the nulls. In the case of Figure 11, it is possible to change the directivity electrically, such as beam scans. So, in practice, the direction of the main lobe of the directivity has to be changed a small number of times to compensate the nulls and cover the wide area in a trial.

VI. NUMERICAL EXAMPLES AND EVALUATION

We demonstrate and evaluate the estimation characteristics of the conventional algorithm and the proposed EPEMD algorithm from the viewpoint of error reduction. In this paper, we will present the characteristics in the case of two different types of the sensors. One is the radar sensors and the other is ultrasonic sensors. The results of these sensors are described as below. Especially, in the case of the radar, we simulate various situations which are different about the position of the target.

A. Simulation I

We designed the directivity pattern as shown in Figure 13. The simulation parameters are shown in Table III. Considering that targets exist in the near field, the width of the transmission array is set to 0.1 m. We then converted the directivity pattern into the reflectable area function using Equations (12) and (16). The reflectable area is shown in Figure 14. In the simulations, the maximum value of the $|S_{sum}(\theta, t)|$ is 2 and we assume that the maximum detectable range R' is 10 m. As mentioned in Section V, it is necessary to change the directivity in a detection trial such as beam scanning in order to detect targets over a wide area. However, for the evaluation of the position estimation characteristics of the algorithms, only one fixed directivity pattern is simulated. The parameters of the receivers are shown in Table IV.

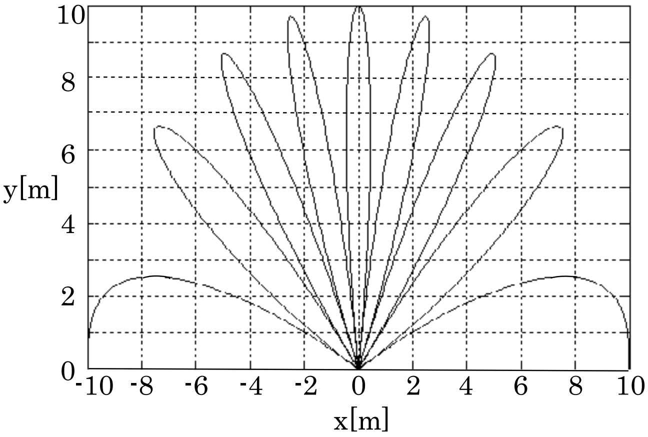


Figure 14. Reflectable area (Simulation I)

We simulate three cases. In Case 1, the target is located at (0,9) [m], which is a relatively long distance from the sensors. In Case 2, the target is located at (0,2) [m], which is short. In Case 3, the target is located at (0.5,5.2) [m], which is middle range. For the evaluation of the estimation errors, we use the variance of the distribution of the estimated positions, which are used in Section IV-C, as the performance measure. The variance is calculated from 50,000 estimation trials.

The results of the variance are shown in Table V. These variances are derived from the distribution of the estimated positions. The obtained distributions in Case 1 are shown in Figure 15. The results of the Case 2, 3 are also shown in Figures 16 and 17, respectively. From Table V, in the case of the EPEMD algorithm, the variance of both the x- and y-directions can be reduced compared to the conventional algorithm. Moreover, in the case of a long distance, the reduction in variance is large compared to the case of a short distance. In particular, the variance in the x-direction, which is the same direction of the arrangement of the receivers, can be decreased significantly.

B. Simulation II

We evaluate our proposal in terms of the use of ultrasonic radar networks. Ultrasonic radars are useful because the

Table III
PARAMETERS OF TRANSMITTER (SIMULATION I)

Frequency: f_0	24 [GHz]
Number of transmitters: L	3
Width of array [m]	0.1
Element positions [m]: B_l	-0.05, 0, 0.05
Amplitude control: A_l	0.5, 1, 0.5

Table IV
PARAMETERS OF RECEIVERS (SIMULATION I)

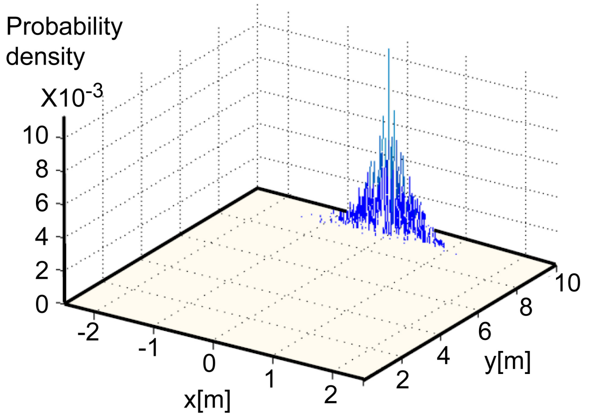
Number of radars K	3
Total width of receivers [m]	2m
Element positions [m]:	-1.0, 0, 1.0
Distribution of measurement error $\tilde{r}$	Gaussian distribution
Standard variation σ_k	0.075
Number of iteration	50,000

Table V
CHARACTERISTICS OF ESTIMATED TARGET (EPEMD, SIMULATION I)

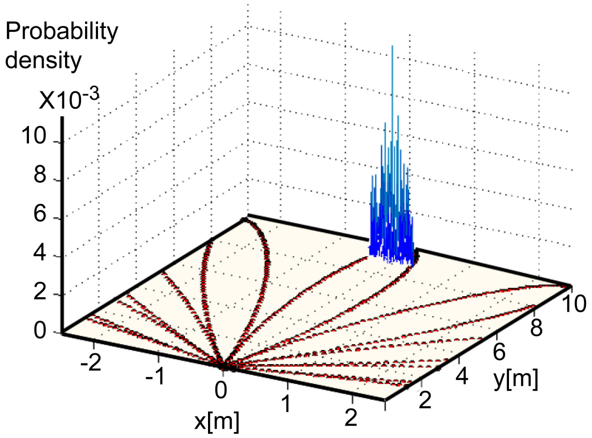
	Target position [m]	Method	Var[$\hat{x}$]	Var[$\hat{y}$]
Case 1	(0,9)	Conventional	0.240	0.00237
		EPEMD	0.0339	0.00179
Case 2	(0,2)	Conventional	0.0139	0.00216
		EPEMD	0.0115	0.00227
Case 3	(0.5,5.2)	Conventional	0.271	0.0507
		EPEMD	0.0932	0.00313

Table VI
PARAMETERS OF TRANSMITTER (SIMULATION II)

Frequency:f_0	40[kHz]
Number of transmitters:L	3
Element positions[m]:B_l	-0.03 , 0 , 0.03
Amplitude control:A_l	1 , 1 , 1



(a) Conventional



(b) Proposed EPEMD

Figure 15. Distribution of estimated positions (Case 1)

Table VII
PARAMETERS OF RECEIVERS (SIMULATION II)

Number of receivers:K	4
x-position of receivers	-0.3, -0.1, 0.1, 0.3
Distribution of $\tilde{r}$	Gaussian Distribution
Standard variation σ	0.025m
Number of iteration	10,000
Observation area	x: -1m $\sim$ 1m y: 0m $\sim$ 3m
Target position	(0, 1.8) [m]

Table VIII
CHARACTERISTICS OF ESTIMATED TARGET (EPEMD, SIMULATION II)

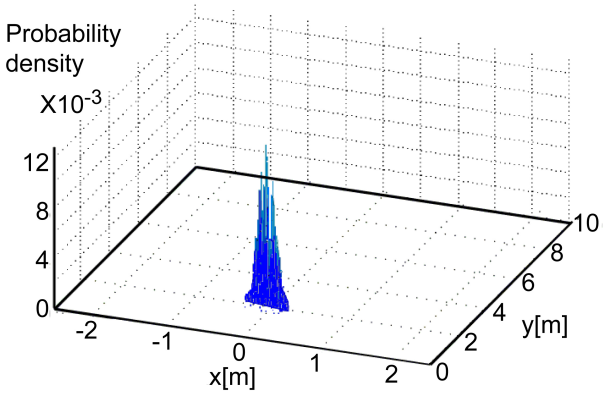
	Var[x]	Var[y]
Conventional	0.241	0.072
Proposal	0.188	0.029

devises are very low cost. In this simulations, we simulate the estimation by using the specification of the real devises.

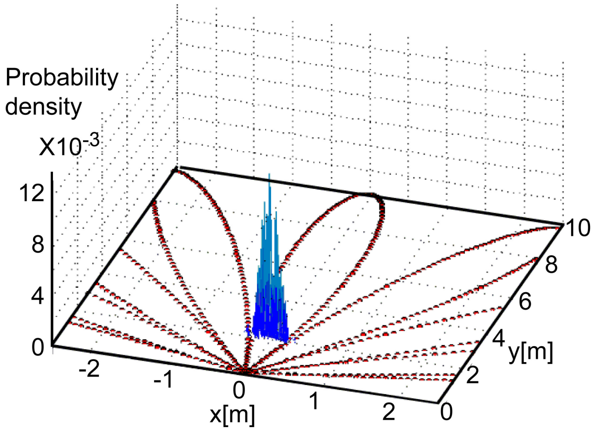
We assume the real devices as MA40S4S and MA40S4R which are made by MURATA corporation [18]. The directivity of the devices is shown as Figure 18. Figure 18(a) is the directivity of the transmitter and Figure 18(b) is that of the receiver.

Using the above directivity, we design the directivity response pattern of the transmitter array. The specification of the array is summarized in Table VI. The directivity response pattern which is designed empirically is presented at Figure 19. And the reflectable area function, which is converted from the directivity response pattern using Equation (16), is also shown at Figure 20. In this conversion, we assume that the maximum value of the $|S_{\text{sum}}(\theta, t)|$ is 3 and the maximum detectable range R' is 3 m.

The estimation performance of the target position is evaluated when the transmitter is the above array. The simulation parameter is summarized in Table VII. The performance measure is variances of the estimated positions. The variances are calculated in terms of x-direction and y-direction respectively. The statistics are derived from 10,000 estimation trials. The variances are shown in Table VIII. From the table, the variance of the proposal EPEMD is lower than that of the conventional method. That is, the proposal can reduce the estimation error. However the reduction



(a) Conventional



(b) Proposed EPEMD

Figure 16. Distribution of the estimated positions(Case2)

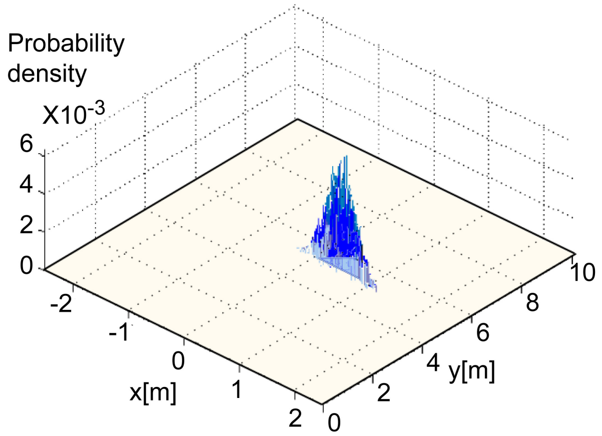
amount is not so large compared to the case of the results in Table V. This is because the target exists in short range.

Compared to the conventional method, our proposal needs the additional complexity such as the electrical directional antenna and the calculating processing. In case of the short range targets, the improvement is small. That is, the nearer the target exists, the smaller the reduction effect becomes. However the problems, which is large errors in case that the target exists in far range (See. Fig. 8), can be reduced by our proposal effectively.

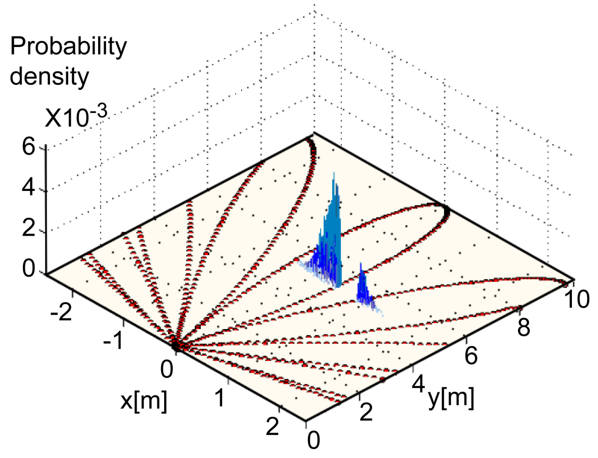
VII. CONCLUSION AND FUTURE WORK

In this paper, we considered the localization algorithm for the targets, which exist in near wide field. In order to cover the wide area, the networked multiple sensors can make sense very well. In our assumption, these sensors has only ranging function because of low cost and simple components. The position of the targets needs to be estimated by only range information. Such networked systems are often called as radar network systems.

The error of the estimation depended on the arrangement of the radars. The straight arrangement of the radars is very useful because of easy setting and installing. However, the radars arranged in a straight line would generate a large positioning error in the same direction of the line, that is the horizontal error. In this paper, for the reduction of this error, we proposed a novel estimation algorithm using the directivity information of the transmitter.



(a) Conventional

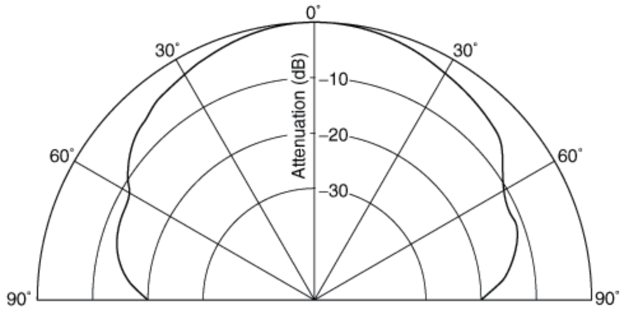


(b) Proposed EPEMD

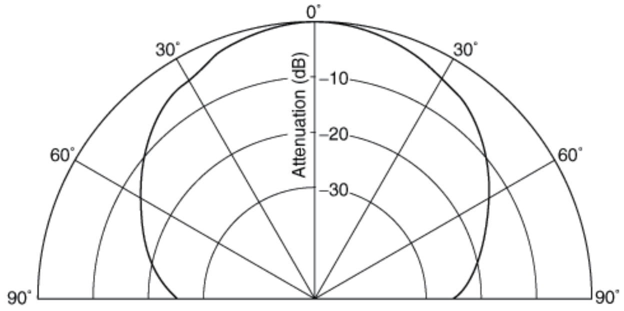
Figure 17. Distribution of the estimated positions(Case3)

In the first half on the paper, to point out the problem clearly, we firstly describe the conventional system model and some estimation performance. After the recognition about the error problem, we introduced our proposed estimation method EPEMD theoretically.

Our system model used the transmitter which had the array component for changing directivity electrically. So the proposed EPEMD algorithm was effectively able to use not only the target existence probability which is calculated based on range but also the directivity information of the transmitter. Later in the paper, we tried various simulations which are different about the type of radars and the target positions for the demonstration and evaluation about our



(a) Transmitter(MA40S4S)



(b) Receiver(MA40S4R)

Figure 18. Directivity of real devices [18]

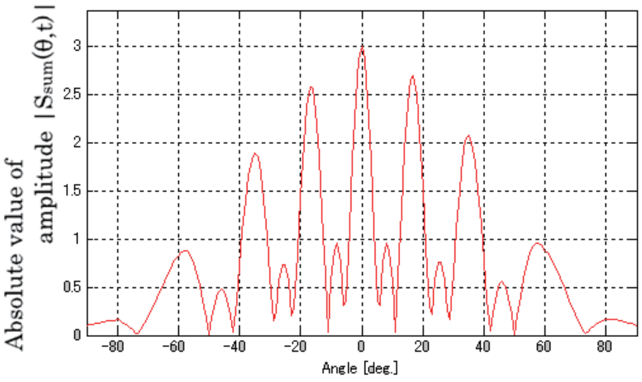


Figure 19. Designed directivity response pattern of the array (Simulation II)

estimation performance. By the computer simulations, we presented the reduction effect. That is, the proposal can reduce the horizontal errors compared to the conventional method. Moreover, the error in the direction of the receivers arrangement was effectively reduced as intended. However, the nearer the target exists, the smaller the reduction effect becomes.

As presented by the results of the computer simulations such as Table V, the position of y-direction can be estimated with very low variance, that is very high accuracy. This means that the radar network systems have significant potential for various applications. However the error in the x-direction is still relatively large compared to the small error in the y-direction. This is still the problem.

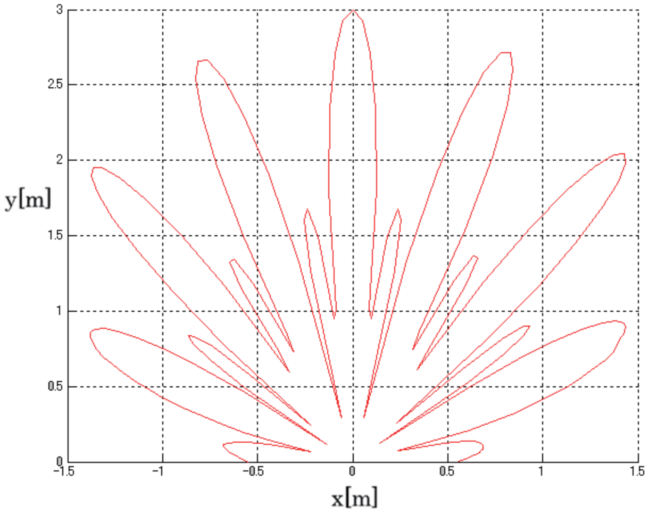


Figure 20. Reflectable area (Simulation II)

As the future work, we will continue to solve this problem. Firstly, we will research suitable directivity pattern of the EPEMD algorithm. This is because the sharper beam will be able to reduce the horizontal error. However, the sharper beam maybe generates the large components and complicated signal processing of the transmitter. So we need to find the suitable directivity pattern. As other challenges for the error reduction, we will apply the reflected signals, which are often dealt with as multipath signals, to the EPEMD algorithm. The reason is that the multipath can surround the target even if the radars cannot surround the target, that is the radars are set as a straight line.

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