Identifying the Location of a Mobile Object in Real-time using PID-controlled Moving Objects Spatio-Temporal Model

Wang Zhi, Kil Young Sung, and Kyou Ho Lee*, *Member, KIMICS*

Abstract—**Trilateration is a typical method to locate an object, which requires inherently at least three pre-recognized reference points. In some cases, owing to out of reachability to communication facilities the target node cannot be reachable always to three base stations. This paper presents a predictive method, which can identify the location of a moving target node in real time even though the target node could not get in touch with all three base stations. The method is based on the PID-controlled Moving Objects Spatio-Temporal Model Algorithm. Simulation results verify that this method can predict the moving direction of a moving target, and then combine with its past position information to judge accurately the location.**

Index Terms— **Real Time Locating, Prediction, PID control, Trilateration, Spatio-Temporal Model Algorithm**

I. INTRODUCTION

IDENTIFYING or tracking the location of a user in real time is essentially required for the u-health service that a user could occasionally be in the situation beyond self-regulation. Real-time locating is usually applicable to mobile objects which communicate with each other and perform metering distances with or without reference to resident systems of coordinates. Trilateration is a generally accepted method to calculate coordinates of the objects, which requires inherently to range from at least three different pre-identified reference points[1]. Such various technologies as ROA(RSSI of Arrival), AOA(Angle of Arrival), TOA(Time of Arrival), TDOA(Time Difference of Arrival), TWR(Two Way Ranging), SDS-TWR(Symmetrical Double Sided–Two Way Ranging), etc. have been presented for ranging[2]-[5].

Users, in some cases, become out of reachability in any such reasons as out of propagation ranges, fault of a communication counterpart, non-existence of possible communication facility, etc.[6]-[8] Such cases could not

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make user devices, i.e. the object nodes, always reachable to all three base stations. An accession of latest location information, even if insufficient references are given for trilateration, can make it possible to identify the location of the object preciously[9].

This paper presents a method of identifying locations of mobile objects in real-time, which is applicable even to the case that an object node could not get in touch with all three base stations. A predictive method, called PID-controlled Moving Objects Spatio-Temporal Model Algorithm, is proposed for the basis of this method. Simulation results not only verify the presented method valid but also the proposed algorithm can perform better than existed ones.

This paper is organized as follow. Section 2 describes the problem of locating a mobile object, which motivates the study of this paper. In Section 3, we propose the PID-controlled Moving Objects Spatio-Temporal Model Algorithm. Section 4 justifies the proposed method through simulation analysis. Simulation results also show that the algorithm outperforms comparatively. This paper is concluded in Section5.

II. PROBLEM OF LOCATING

A. Locating by Trilateration

As shown in Fig. 1, the location of the node A is preciously identified by the trilateration method. R_1, R_2 and R_3 in the figure are three resident reference points, and d_1, d_2 and d_3 are distances between three resident reference points, R_1, R_2 and R_3, and the object node(A), respectively, which could be measured by any ranging method described in Section I.
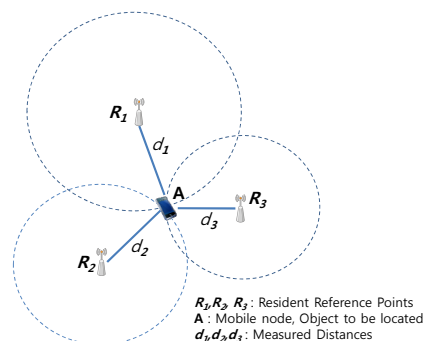

R_1, R_2, R_3 : Resident Reference Points
A : Mobile node, Object to be located
d_1, d_2, d_3 : Measured Distances

Fig. 1. Location identifying by trilateration

B. Locating with Partial Reachability

As described above, the mobile object may not always be reachable those three references. It can be placed in any such cases as out of propagation ranges, fault of a communication counterpart, non-existence of possible communication facility, hardness of constructing resident coordinates, etc. Fig. 2 shows the case that that the object node is reachable to only two resident references. There are two resident references, R_1 and R_2, and two ranging information, d_1 and d_2, which can be recognized by the object node. Such partial reachability is insufficient for the calculus of trilateration.

In Fig. 2, however, it comes to know that the location of A is either A_1 or A_2 by acquiring two range information, d_1 and d_2, which are distances of the object node from R_1 and R_2 respectively. In addition, the latest location information of the node A can be a clue for getting the moving direction of the node. It is easily to conclude the current location of A between A_1 and A_2 by applying such past location data.
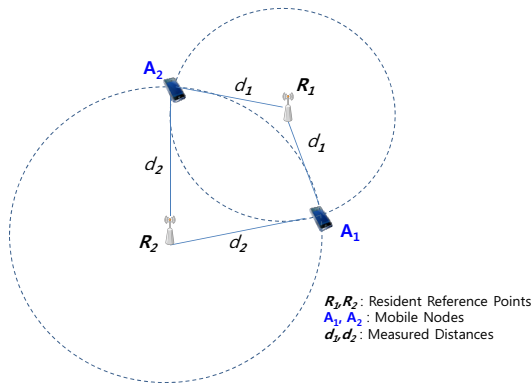

Fig. 2. Identifying by two resident references

The object in the case that only one resident reference is available is located on the circumference of a circle established by the range to the reference. The moving direction of the object is predictive with an accession of its latest location information. The location can be identified by the geometrical cross of the predictive direction and the circumference. The less number of resident references are given, however, the less accurate result should be.

Accuracy in locating with partial reachability depends on how preciously the moving direction is predictive. Thus a prediction algorithm should be significant in that case.

C. Locating with Mobile Reference

All references are not required to be resident in real time locating problem. Since calculation of locating only includes relative ranging data between references and the object, a well-identified mobile node, instead of a resident reference, can also be adopted into references to locate another mobile node. Fig. 3 explains such a case.

The node A in Fig. 3, if its location has already been identified with such a manner as given in Fig. 2, can be used as a reference for locating the new target object B. We consider four different locations of B. In the case of given three references, R_1, R_2 and A, the object B could be easily located. Given any two references, either R_1 and A or R_2 and A, the location of B, i.e. either B_1 or B_2 respectively in Fig. 3, can be identified with the same manner as locating the node A. For the case of B_3, the target object(B) is out of reachable ranges of two existing resident references, R_1 and R_2. B can only be ranged by the node A with measuring the distance d_3. It means that the node B is placed on the arc that the circumference of establishing with a radius, d_3, is not overlapped with any circular area of maximum reachabilities of R_1 and R_2, i.e. d_{1L} and d_{2L} respectively in Fig. 3.

In any case of B_1, B_2 and B_3, it comes to estimate its moving direction with an accession of its latest location information. Both such an estimated direction and well-identified resident and/or mobile references, even if insufficient references are given for trilateration, make it possible to identify the location of the object preciously. As described before, a prediction algorithm should be significant for better accuracy of identification in these cases.
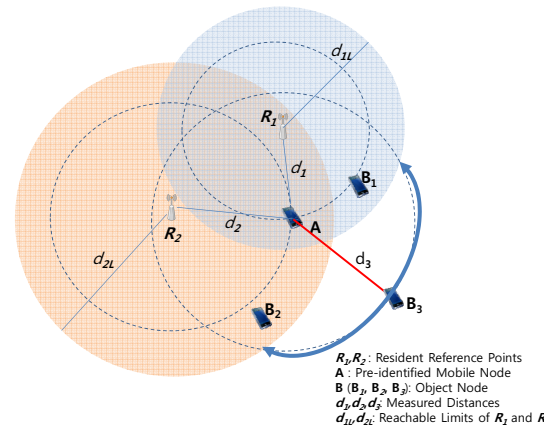

Fig. 3. Locating with Mobile Coordinate

III. PROPOSED ALGORITHM

A. System Model

As shown in Fig. 4, in x-y coordinate, we make the angle between the measured orientation of the object and the x coordinate as the movement direction angle. In this study we introduce three such parameters as the predicted orientation of last moment, the measured orientation of current moment, and the predicted orientation of current moment. The movement direction angle is used as the system state.
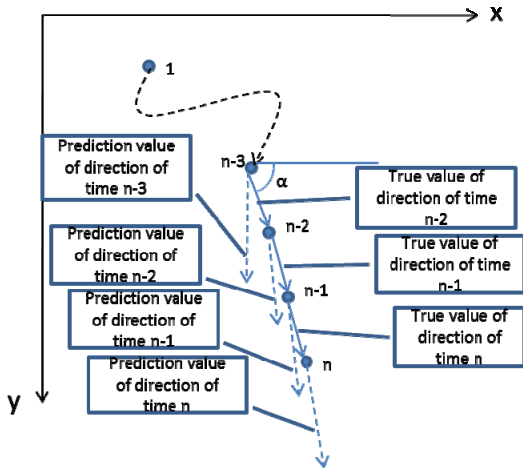
Fig. 4. Movement direction angle

B. PID-controlled Moving Objects Spatio-Temporal Model Algorithm

In a moving-average model of Moving Object Spatio-Temporal (MOST)[10] the scalar part of the prediction speed of time $n+1$ is expressed as following:

$$| \vec{v} | = \frac{1}{p} \sum_{i-1}^{p} v_{n-1},$$ (1)

where v is the speed of a target object at time n, and p is the means of its speed in all previous time. The direction part of the prediction speed of time $n+1$ is equal to the one of the target speed at time $n-1$.

The goal is to make *Prediction Value = True Value*. *True Value* is a true value of direction of time n, while *Prediction Value* is a prediction value of direction of time n. There is no mechanism to reduce an error between *True Value* and *Prediction Value*. So we want to work out a mechanism to minimize the error. Since the PID controller is generally acceptable for optimization in automatic control systems, we choose it as a mechanism to minimize the error[11].

The proposed PID-controlled Moving Objects Spatio-Temporal Model Algorithm can be considered as two parts: controlling part and controlled part. The controlling part is a PID controller. The controlled part is a Moving Objects Spatio-Temporal model algorithm. The input is *True Value* of direction of time n, and the output is *Prediction Value* of direction of time n, supposing the current time is time n. The feedback is *Prediction Value* of the direction of the time $n-1$. Setpoint is the expected value of the error between *Prediction Value* of the direction of the time $n-1$ and *True Value* of the direction of the time n. Obviously, setpoint is 0. A is the error between *Prediction Value* of the direction of the time $n-1$ and *True value* of the direction of the time n. The error is a difference between A and setpoint of the time n.

$$
\begin{aligned}
PID \ Value &= P \ Value + I \ Value + D \ Value \\
&= K_p e(t) + K_i \int_0^\tau e(\tau)d\tau + K_d \frac{de(t)}{dt},
\end{aligned}
$$ (2)

where $e(\tau)$ is the error. K_p, K_i and K_d are the coefficients of *P Value*, *I Value*, and *D Value* respectively.

Thus the whole expression of the PID-controlled Moving Objects Spatio-Temporal Model is as following:

$$\Pr ediction \ Value(t) = True \ Value(t) - PID \ Value(t)$$ (3)

$$PID \ Value = K_p e(t) + K_i \int_0^\tau e(\tau)d\tau + K_d \frac{de(t)}{dt}$$ (4)

$$e(t) = True \ Value(t) - \Pr ediction \ Value(t-1)$$ (5)

Fig. 5 shows a conceptual diagram of the PID-controlled Moving Objects Spatio-Temporal Model proposed in this paper. In this paper, we choose K_p =0.1, K_i =0.005, and K_d =0.
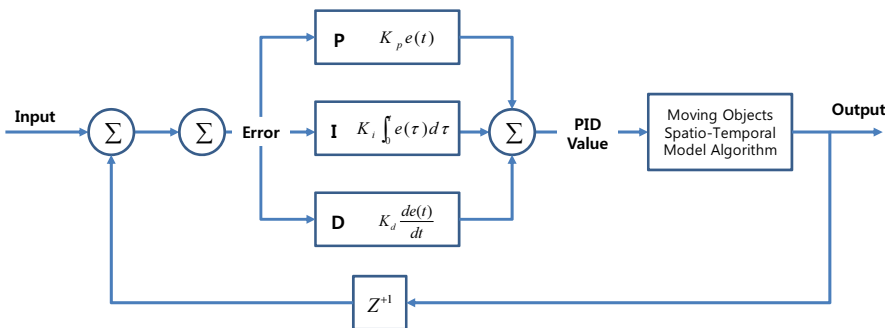

Fig. 5. Proposed PID-controlled Moving Objects Spatio-Temporal Model

IV. SIMULATION RESULTS

Simulation results compare the True direct (*TRUE_A*) with five predictive directions of every point of Target A. Those predictive directions were calculated by the Recursive Least Squares algorithm (*Least_A*), the Kalman Filter estimation algorithm (*Kalman_A*), the Stochastic Approximation algorithm (*Stochasic_A*), the Moving Object Spatio-Temporal Model Algorithm (*Model_A*), and the proposed PID-controlled MOST Model algorithm (*Testalgor_A*).

Fig. 6 shows to compare the true direction with five predictive directions of every point of Target A in each step. Calculated differences between true direction and predictive one of each algorithm are

$\sum |Diff\_Least\_A| = 502.74149,$
$\sum |Diff\_Kalman\_A| = 451.844292,$
$\sum |Diff\_Stochastic\_A| = 485.14598,$
$\sum |Diff\_Model\_A| = 337.151869,$ and
$\sum |Diff\_Testalgor\_A| = 333.661331.$

From these, it can be observed that the case of *Testalgor_A*, i.e. the proposed algorithm, is the closest to the true value. This is similar to result of *Diff_Model_A*.
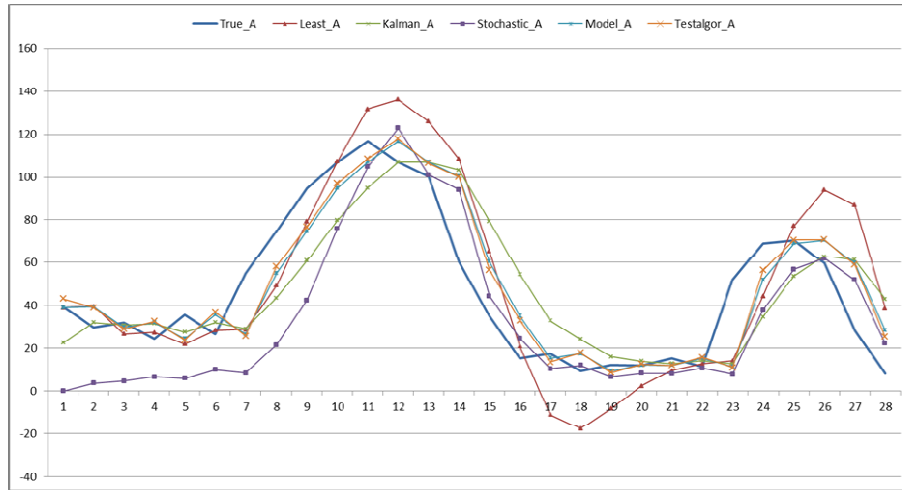

Fig. 6. Simulation results: estimated directions

Fig. 7 shows the differences between the true direction and each of five predictive directions, which is re-shaped from the same result as shown in Fig. 6. The graph of *TRUE_A* displays always zero. For more comprehensive simulation results, cumulative difference values for each of five predictive directions are shown in Fig. 8. It is obvious that *Testalgor_A*, i.e. the proposed algorithm, makes less difference values than any other algorithms according as getting more number of simulation steps.
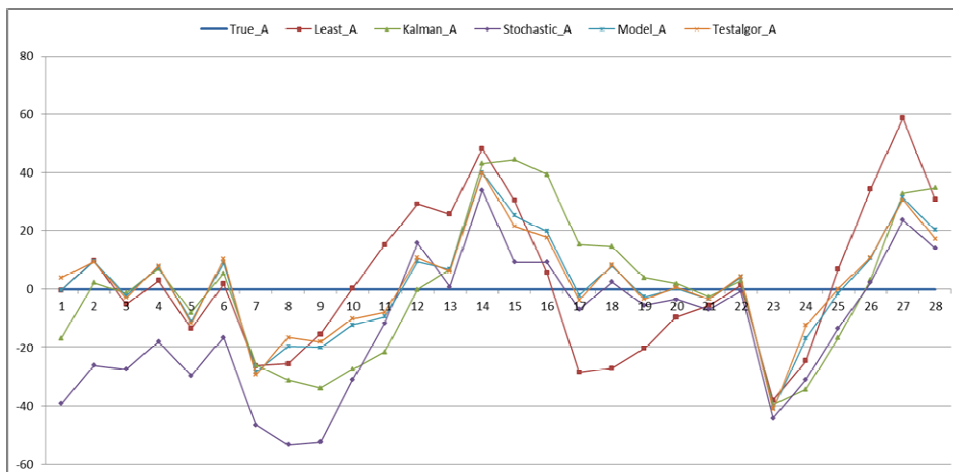

Fig. 7. Simulation results: differences between true direction and each of five predictive directions
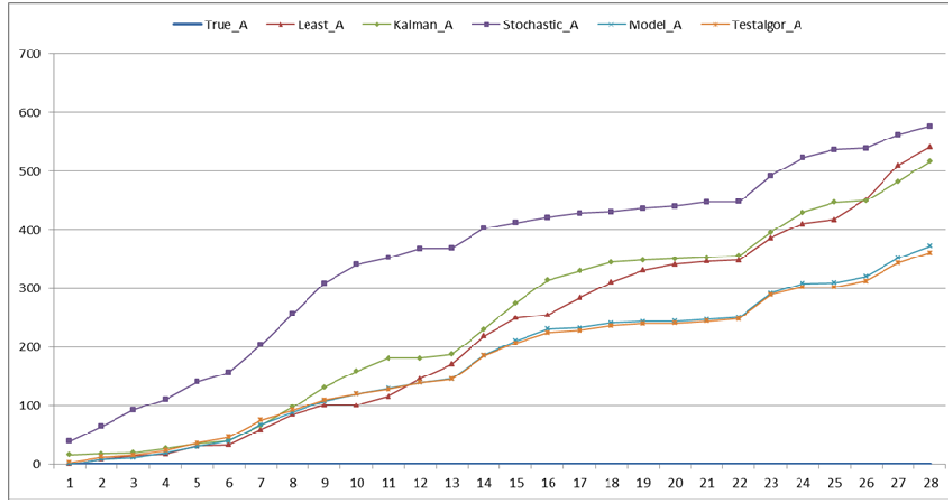
Fig. 8. Simulation results: cumulative differences

Since the difference between predictive direction and true direction is $e(t) \in (-180, 180)$ in theory, it becomes $K_p e(t) \in (-18, 18)$. Supposing the current time is 28 which means the system has got target's situation for 28 times,

$$K_i \int_0 e(t)dt \in (-25.2, 25.2) \qquad (6)$$

and,

$$PID \quad Value = P_p e(t) + K_i \int_0 e(t)dt \in (-25.2, 25.2), \qquad (7)$$

$$PID \quad Value \in (-43.2, 43.2).$$

The output of new algorithm *Prediction valueNew(t)* is equal to the output of the MOST algorithm *Prediction valueMOST(t)* minus *PID Value(t)*, i.e.

Prediction valueNew(t)= Prediction valueMOST(t) −
PID Value, PID Value∈(-43.2, 43.2). (8)

But in simulation environment, the difference between predictive direction and true direction $e(t) \in (-80, 80)$, so $K_p e(t) \in (-8, 8)$. Supposing current time is 28,

$$K_i \int_0 e(t)dt \in (-4.9, 4.9) \qquad (9)$$

and,

$$PID \quad Value = P_p e(t) + K_i \int_0 e(t)dt \in (-25.2, 25.2), \qquad (10)$$

$$PID \quad Value \in (-12.9, 12.9).$$

Prediction valueNew(t)= Prediction valueMOST(t) −
PID Value, PID Value∈(-12.9, 12.9). (11)

The new algorithm is thus similar to the MOST one.

V. CONCLUSIONS

This paper presents a method of identifying locations of mobile objects in real-time, which is applicable even to the case that an object node could not get in touch with all three base stations. A predictive method, called PID-controlled Moving Objects Spatio-Temporal Model Algorithm, is proposed for the basis of this method. Simulation results verified that not only the presented method can be validly enough for applying even to the cases of partial reachability but also the proposed algorithm can outperforms comparatively.

Although using the PID controller in the proposed algorithm makes the result closed to the true value, the result is similar to the original MOST algorithm. The further work is modifying parameters of the PID controller or selecting a better control mechanism in order to achieve better results.

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