Lightwave Robot Positioning based on Composite Codes Acquisition and Evolutionary Computations

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***Abstract*—Lightwave robot positioning with composite codes acquisition is investigated in this paper. The indoor robot positioning system was previously examined with single Pseudo-Noise (PN) signal sequence. In views of correlation acquisition, the longer the code acquisition time, the longer the path estimation distance, and the worse the robot positioning accuracy. Under comparable period lengths, acquisition time for composite PN codes can be shorter than that of pure PN codes, thus can largely enhance the robot positioning accuracy. In the devised system configuration, three transmitters continuously send out their light coding signals to the robot receiver. The robot evaluates its current position by measuring time difference of arrival (TDOA) among the three paths. Memetic algorithms (MA) can then be used with the measured TDOAs to obtain a more accurate robot location. Finally, we provide a general analysis of the relationship between correlation value and robots position.**

Keywords- M-sequences; Parallel codes acquisition; Time difference of arrival (TDOA); Memetic algorithms (MA) .

I. INTRODUCTION

With the mature technology, the functionality of robots is more and more complex. For example, different service types of robots, such as the navigation robot, the cleaning robot, etc. need to move around when they execute their tasks. Therefore, the accuracy of positioning is very important, and the error of measurements between robot and sensor must be solved. For example, the multipath propagation is caused by interference, because the light is transmitted in all directions. As a result, multipath propagation will occur when the light collides with obstacles. Transmitting signals may be cut by obstacles so that a longer distance and a large time delay are produced. Time of Arrival (TOA) [1][2] and Time Difference of Arrival (TDOA) [3][4] in positioning are easily influenced by errors so that the positioning accuracy is reduced.

We need to improve indoor lightwave positioning accuracy, so the robot object can be more precisely positioned, and capture light signals in the process. How to confirm the capture of light signals to the correct sources and reduce errors is the most important issue to study.

Several previous works have used the coding techniques of the light signal to determine the robot position, using Pseudo-Noise sequences (PN sequences) [5][6], Gold sequences [7], Loosely Synchronous sequences (LS sequences) [8], Golay codes [9] and Barker codes [10].

This paper proposes a new coding scheme of Composite Pseudo-Noise code sequences [11], which uses composite codes to encode the transmission signals. We constructed indoor light positioning based on Direct Sequence Spread Spectrum (DSSS) system, and a different orthogonal code is assigned to every transceiver. Using composite codes, we can determine the approximate position of a robot by hyperbolic triangulation of the distance obtained from the measurement of the difference in TDOA between a transceiver and the others. By using composite codes acquisition [12], we analyze the accuracy of the positioning and expect to improve the accuracy of the indoor positioning systems. We utilize Memetic algorithm (MA) to look for the absolute position of the object.

MA, which is similar to Genetic algorithm (GA), is also called Genetic algorithm combined with local search. The speed and changes of cultural evolution are more dramatic and alarming than the biological evolution, such as the basic structure of the genetic algorithm, generated populations carry out crossover and mutation to produce offspring. Differently from GA, the information of the previous generation is passed to the next generation, and this operation is called local search [13]. Local search finds local optimum values among the offspring, and the value of the global optimum is searched from all local optima. The proposed method is a wireless communication positioning system to reach the goal of improving positioning accuracy.

In this paper, we combine the positioning method with MA to estimate the location of MS. The code acquisition is described in Section II and how MA works is discussed in Section III. The compared correlation value and the robot are described in Section IV. Section V presents our conclusion.

II. ROBOT POSITIONING SYSTEM ARCHITECTURE

Figure 1 depicts a conceptual schematic of the proposed indoor robot positioning system. The reason we use light instead of other signals is for making use of LED to realize the positioning of the robots. Because the place is too small, we choose suitable chips rate for indoor positioning of

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robots. Take as comparative numerical figures for the high or low modulation rates. With 21-chip lengths per code frame and suppose 5-frames time is needed to confirm code acquisition. On using RF chips rate of 2000-kHz ($2x10^6$ chips/sec), the estimated object distance will be $21x5/2x10^6 = 5x10^{-5}$m. This figure is hardly distinguishable on the robot distance to the transceiver. We make the chips rate the same as ultrasonic, 20-Hz (20 chips/sec), the same code length and acquisition frame will yield an estimated object distance of 21x5/20 = 5m. This figure is something acceptable. In practice, acquisition chips period length in mobile positioning can reach up to $2^{13}-1 = 8191$ chips per frame to yield a distinguishable object distance.

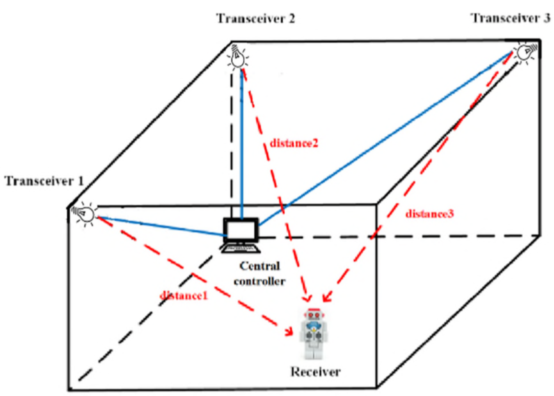


Figure 1. Overview of the indoor positioning system.

In the robot receiver, so as to calculate the distance from each transceiver, the robot needs to separate the incoming signals from different transceivers. The robot bears the same signal carrier wave and composite code sequences as those of the transceiver signals, which are called the replica signals. When correlating the received code signals with local replica signals, the robot can separate correlation peaks for the matched transceiver code from correlation nulls for the unmatched ones. This procedure for correlation detection of code signals is called code acquisition.

A. Code acquisition with correlation detection

In the code acquisition, we note that the correlation characterizations of the assigned composite codes are related to their code weights. If code vectors $T^iC_1(X)$ and $T^jC_2(X)$ have the respective code weights w_1 and w_2, then composite code $C^{(i,j)}(X) = T^iC_1(X) \oplus T^jC_2(X)$ possesses the following code weights

$$W(C^{(i,j)}) = w_1(n_2 - w_2) + w_2(n_1 - w_1) \qquad (1)$$

$$= \begin{cases} \frac{n_1(n_2+1)}{2}, & if\ w_1 = 0,\ w_2 = (n_2+1)/2. \\ \frac{n_2(n_1+1)}{2}, & if\ w_1 = (n_1+1)/2,\ w_2 = 0. \\ \frac{(n_1 n_2 - 1)}{2}, & if\ w_1 = (n_1+1)/2,\ w_2 = (n_2+1)/2. \end{cases} \qquad (2)$$

Here, we have taken advantage that a binary ($n_l=2^{ml}-1$, $k_l = m_l$) M-sequence code has all of its n_l nonzero code vectors the same code weight of $(n_l+1)/2 = 2^{ml-1}$. Corresponding to the weight distribution of (2), the periodic correlation between composite codes $C_u^{(i_u,j_u)}$ and $C_v^{(i_v,j_v)}$ can be derived to be

$$\theta_{u,v} = \begin{cases} \left(\frac{n_1 n_2 - 1}{2}\right), if\ u = v \\ \left(\frac{n_1 n_2 - n_2 - 2}{4}\right), \left(\frac{n_1 n_2 - n_1 - 2}{4}\right), \left(\frac{n_1 n_2 - 1}{4}\right), if\ u \neq v \end{cases} \qquad (3)$$

From the correlation distribution of (3), we see that correlations between reference transceiver and interfering transceivers can be separated by the correlation operation to track the desired transceiver sequences.

The robot positioning block chart for acquiring signal codes and estimating their flight time is shown in Figure 2. Figure 2 depicts every transceiver performed light signal modulation with assigned signature code, and emits this light signal continuously. Once the signal is received by the robot, the receiver turns the signal from analog to digital, and demodulates it into a corresponding code sequence. Since the receiver needs to identify the intended sequence code among all received signals, the demodulated code sequence is connected to three parallel correlators to calculate each assigned code. The output correlation passes through a peak detector to estimate the time of flight from transceiver to the robot. The robot then evaluates its current position by measuring TDOA from the three transceiver paths.

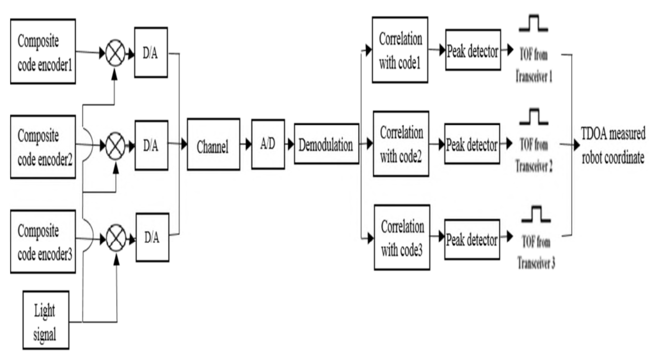


Figure 2. Block chart for robot positioning system.

With regard to the block diagram of Figure 2 for robot positioning system, we will give detailed descriptions on codes correlation acquisition/detection, acquisition time difference and time error, and relative distance/locations determination of robot object in the following subsections.

B. Code acquisition time difference and time error

A flow chart for the above composite codes correlation acquisition processes is shown in Figure 3. For the purpose of finding relative code sequences, the parallel correlator uses a local replica code sequence to perform correlation computations. Next, the system determines whether the correlation results are the peak of interval n_i=3 or n_j=7. If the correlation results meet the peak of interval n_i=3 or n_j=7, the system will immediately determine whether the correlation results meet the common peaks of interval n_{ij}=21, and confirm the code sequence. These results, which do not meet the correlation peaks. will advance chips and then perform correlation computations again. And these results, which meet the correlation peak will execute the two steps. One step is estimating the time error of code acquisition, and the other is estimating the time of flight.

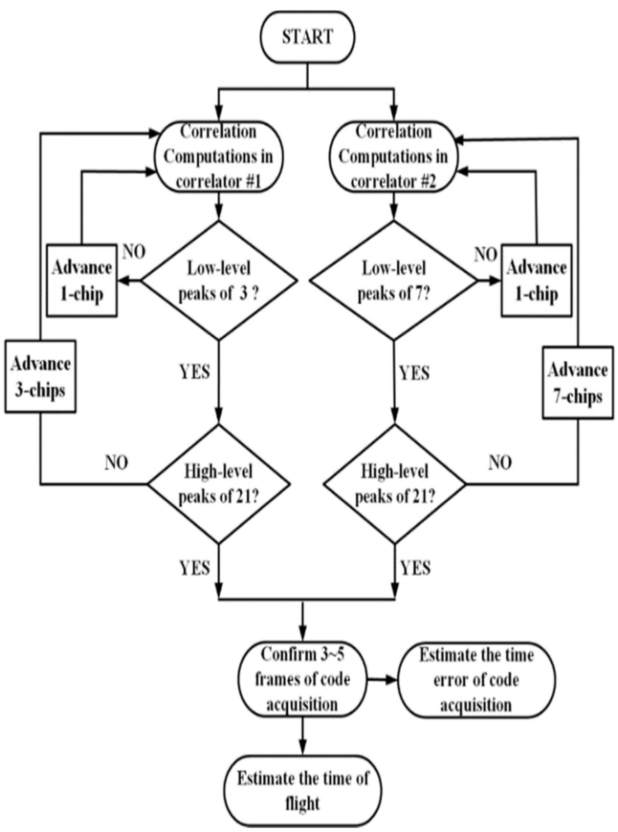


Figure 3. Flow chart for PN codes' correlation acquisition processes.

On estimating the flight time of coding signals, we note that the distance estimation between transmitters and the mobile robot is based on the cross-correlation method. Through the cross-correlation method, the robot calculates the number of frame peaks between the local replica sequence and the transmission sequence, and then offer robot to estimate the distance of transmitters. The information of the distance of transmitters will further perform optimization algorithms to obtain the absolute location of the robot.

C. *Determine the position of the robot receiver*

In order to obtain the position of the robot, the range measurement is acquired by TDOA of the light signals of the transceivers. In the TDOA scheme, the system locates a receiver by processing signal arrival-time measurements at three or more transmitters. Instead of the absolute arrival time, TDOA determines the relative difference on distance by measuring the difference in arrival time at any two transmitters. Each TDOA measurement can be regarded as a hyperboloid curve, and the receiver location must lie on this hyperbola.

Since there are more than two TDOA measurements, at least two hyperbolas can be drawn. Hence, the receiver location is at the intersection of the hyperbolas. Generally speaking, any two transmitters produce a hyperbola. Therefore, to get the intersection as the receiver location, it is required that more than three transmitters be detected. The TDOA will be biased by the time error of code acquisition that can degrade the positioning estimate. Therefore, the time error of code acquisition needs to be included in the calculation.

In this paper, we determine the receiver location by utilizing the intersection of the two hyperbolas in 2D environments, where r_1, r_2 and r_3 are the estimated values of the time of flight that we obtain from the number of frame peak between local code and received sequence. And then, once we get these estimated values, we take these values to subtract with each other to obtain the values ΔT_{12}, ΔT_{13} and ΔT_{23}. These values will substitute into (4) to solve the TDOA equation.

$$r_1 - r_2 = \Delta T_{12},\ r_1 - r_3 = \Delta T_{13},\ r_2 - r_3 = \Delta T_{23},$$
$$d_{ij} = \mathrm{c} * (\Delta T_{ij} + e_{ij}),\ i \neq j$$
$$= \sqrt{(x_i - x)^2 + (y_i - y)^2} - \sqrt{(x_j - x)^2 + (y_j - y)^2} \quad (4)$$

where (x, y) is the real position of mobile robot while (x_i, y_i) and (x_j, y_j) are respectively the estimated position of robot receiver to the i-th and the j-th indoor transmitter, i, j = 1, 2, 3. The term d_{ij} are the value of TDOA; c is the ultrasonic wave speed; ΔT_{ij} is time difference measured by code acquisitions; and e_{ij} is the value of the time error of code acquisition to subtract with each other. The equations above represent hyperbolas, and their intersection gives the estimated positioning of the receiver. The area is enclosed with hyperbola represented the possible position of the receiver.

III. EVOLUTIONARY COMPUTATION MEMETIC ALGORITHM

MA is motivated by Dawkin's notion of a meme. Meme as a unit of information is processed on behalf of the evolution of culture. Instead of genes, the elements of MA are called memes. It is used to include an extensive class of metaheuristics, such as combing evolutionary algorithms with local search. In the unique viewpoint of MA, all individuals of offspring desired the information from the previous generation by local search [14]. MA reduces the probability of divergence and computation complexity. It combines the power and superiority of genetic algorithm and local search at the same time. Similar to the GAs, MA also needs the evolution mechanisms such as reproduction, crossover and mutation, as shown in Figure 4. The following steps describe the processes of MA approach.

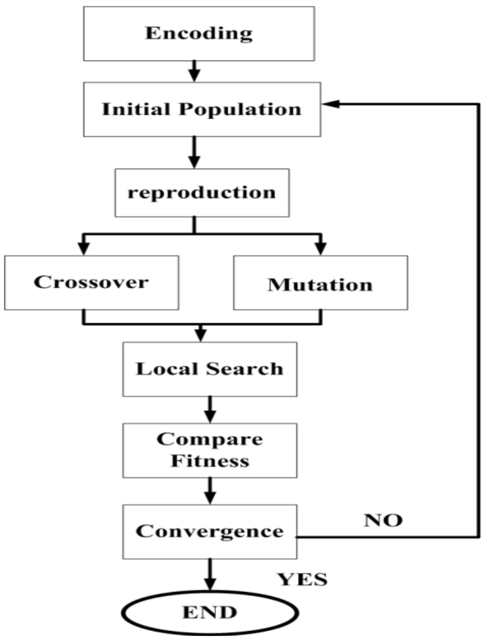


Figure 4. The flow diagram of Memetic Algorithm.

Step 1: Encoding:

To make evolution more convenient, the optimization parameters are always transformed to the binary sequences. The straight binary algorithm transforms the real numbers to the binary bits in this step. The range of real number and the bit length should be defined. For example, a variable is ranging from 0 to 10, and the bit length is 3. The range of real numbers is assigned to each code uniformly. By utilizing the coding schemes, the real numbers of horizontal coordinate is transformed to the binary sequence. Each binary sequence represents as a different individual.

Step 2: Initial Population:

After encoding, the individual is represented as a bit sequence. The first generation is generated through the random bit string generator from the overlap of three circles.

Step 3: Reproduction:

Based on comparing the object function value, a new population of individuals is generated by the selecting schemes. Individuals with better performance based on object function have a higher chance of being selected for the next generation.

Step 4: Crossover and Mutation:

Crossover and mutation operators are applied, similar to GA. These schemes are designed to promote the performance of individual's multiplicity. Especially, individuals avoid trapping in the local optimum of the object function by mutation in MA.

Step 5: Local Search:

In MA, local search is an important step. The mission of local search in MA is to search the optimum solution efficiently. By searching the neighbor individuals, the initial coordinate is changed to the neighbor coordinate with better performance. In local search, each individual is tuned by changing bits near the tail of the sequence to constrain the local search range. It ensures that the local search individuals are close to the original one, as shown in Fig. 5. Most of existing MA uses some local search procedures to generate solutions discovered from the neighbors of offspring individuals [15]. It helps to generate a better individual with lower object function value. Local search is applied on all the offspring individuals in every generation. A local search procedure is implemented on top K neighbor individuals, where K is the number of individuals that we will search.

The number of neighbor individuals is also affected by the local search range d, whose units depend on the number of bits. Local search range means the number of tuned bits. The end of bits is changed preferentially. Different searched bits are also discussed, and the searched bits are less than two in this paper. With increasing the local search bits d, the number of searching neighborhoods K is also increasing.

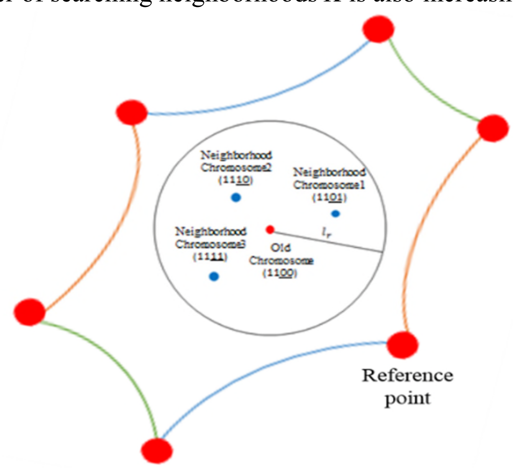
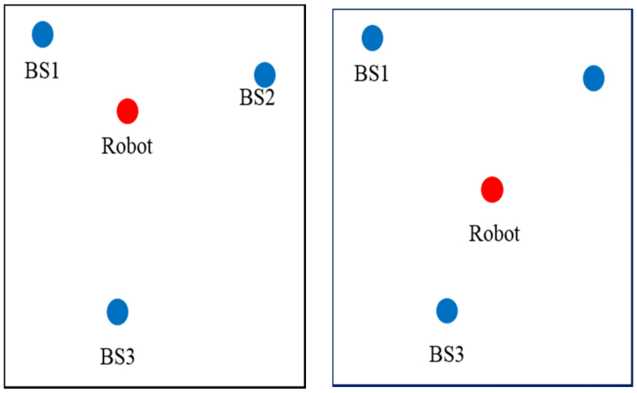


Figure 5. The local search procedure by comparing with neighborhoods.

Local search is applied for searching a better individual near each offspring individual. S is defined as the old individual, which is the offspring individual after the crossover and mutation step in Figure 5. We apply and discuss three different methods of local search sequentially.

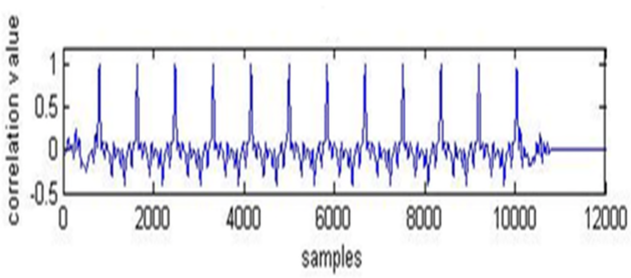
IV. SIMULATION

We consider the problem of indoor positioning using TDOA measurements and utilize MA algorithm to improve the positioning accuracy in 2D environment. In the following, we analyze how the correlation value will be affected by the position of the robot.

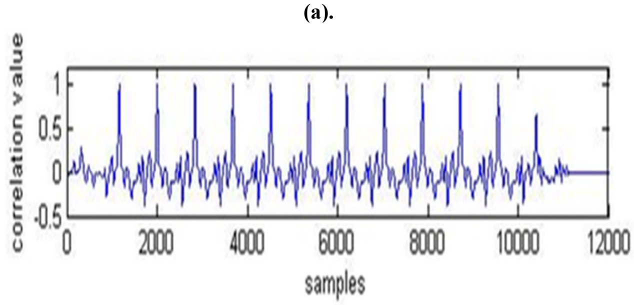


(a) **(b)**

Figure 6. The possible position of robot. (a). Possible position #1. (b). Possible position #2.



(a).



(b).

Figure 7. The correlation value. (a). for the possible position #1; (b). for the possible position #2.

Figure 6 (a) is a possible robot position and the matched correlation value is base station 1 in Figure 7 (a). The same discussion applies for the possible position #2 in Figure 8 (b). Figures 6 and 7 represent robot position makes the correlation value difference. Also, we describe the situation of correlation value and illustrate the different between two possible positions of robot.

IV. CONCLUSIONS AND FUTURE WORK

We have proposed a composite code acquisition to implement indoor lightwave robot positioning based on DSSS system. Each transceiver is modulated the light signal with a 3×7 bits composite code, which has a particular auto-correlation and cross-correlation in a cycle. By using code acquisition, the robot receiver detects the arrival time of codes and the error time of code acquisition, and the robot will use information to determine its absolute location.

Through comparing with traditional M-sequence code, we find that composite codes have more advantages. First, the code length is more flexible, it is not limited by 2^m-1. Second, other robot users are difficult to acquire the location of the designated robot because the code combination is more complex. Third, with the same location distance, the positioning accuracy and the error time of code acquisition of composite coding is more precise than the conventional M-sequence coding. In this paper, we used a location algorithm based on MA to determine the location of MS. We also improve the positioning accuracy by memetic algorithm.

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