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Modeling Analysis of Attitude Perception of Engineering Manipulator Supporting Wireless Communication and Internet of Things

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Abstract: In the field of construction machinery manufacturing, the development of robotic arm (RA) is very rapid and widely used. Many intelligent engineering RAs can improve industrial production processes and improve production efficiency under the action of IoT sensors. This paper constructs an engineering manipulator control system based on the combination of wireless communication network and Internet of Things technology, which is used to control the operation of the manipulator, adjust the grasping posture of the manipulator at the end, and drive the rotation and operation of the manipulator in the industrial production process. However, the traditional attitude sensing method is inefficient. Therefore, this paper constructs a model of the attitude sensing method of the engineering manipulator based on the Euclidean Distance Matrix (EDM) algorithm. The accuracy of the robot arm attitude perception (AP) is higher.

1. Introduction

For the structural characteristics and motion characteristics of the construction manipulator boom, if these prior information can be better used, the performance of the AP model of the manipulator can be improved. In the existing research, the use of wireless sensors to obtain the prior information of the target to be measured is of great help to improve the efficiency of the algorithm for AP, especially the engineering manipulator with distinct structural features has a good application prospect.

Many scholars have conducted in-depth research on the AP of engineering manipulators, and have achieved good research results. At present, many deep learning-based pose estimation algorithms first predict the depth map of the target through a neural network, then convert it into a point cloud map, and then register it with the point cloud model of known pose to calculate the pose

[1]. When some scholars use the neural network algorithm to calculate the attitude estimation problem, the researchers obtain the depth map of the target by establishing an accurate point cloud model of the target, and then use the spatial point cloud of a known attitude of the target as a reference point cloud, and calculate the known attitude by calculating the known attitude. The transformation relationship between the point cloud and the current point cloud obtains the current robot arm target pose [2]. Depth cameras such as Kinect can directly obtain the depth information of various postures of the human body, which facilitates the communication between the computer and the user. This communication method can achieve relatively stable results, but it is extremely dependent on hardware equipment requirements and has limited application scenarios. In the current social environment, ordinary cameras are widely used, and the attitude estimation and application stability of monocular cameras have good economic benefits. Studies on imitating the human arm [3-4]. Due to the late start of research on RAs in my country, the research on AP accuracy and efficiency improvement is even more lacking. It is necessary to develop the core technology of RA control to meet the various requirements of industrial production for the operation of RAs.

This paper firstly introduces that the motion of the manipulator is to imitate the posture of the human body, and there will be a delay; then design the manipulator control system based on the wireless communication technology and the Internet of Things technology, the system can complete the operation intelligently under these technologies; Perception model, and by comparing the absolute error, relative error and time complexity of the EDM algorithm and other traditional AP methods, it is verified that the AP accuracy of the EDM algorithm is better.

2. Motion of Engineering Manipulator

2.1. Manipulator Attitude Description

To control the robot in practical applications, it is necessary to establish a mathematical representation of the position and attitude of the robot. Common mathematical descriptions include X-Y-Z fixed angle, Z-Y-X Euler angle, equivalent axis coordinate and quaternion four types of representation [5]. In multiple experiments, there may be a long delay in the imitation behavior of the RA. This part of the delay exists in multiple stages of the simulated behavior. There is a delay in the process of sending the joint angle information to the RA through TCP. Because the sent data is very small, there is no problem of sending multiple data at the same time. After optimizing this part of the delay Has been minimum [6-7]. Secondly, it takes a certain amount of time for the robot arm to receive the command to make the corresponding action. This part of the time is uncontrollable, the difficulty of conversion between different postures of the robot arm is inconsistent, and the movement time of each joint is uncontrollable [8]. Therefore, there is a large delay for the RA to follow the movement of the human arm.

2.2. RA Control System Based on Wireless Communication and IoT

The ideal situation for the design of the engineering RA is to combine with artificial intelligence technology, wireless network technology, and Internet of Things technology, so that the RA has autonomous capabilities. In this case, the RA can analyze the working environment, find the problem location, and locate it autonomously [9]. Figure 1 shows a RA based on a wireless communication network-DSP. The wireless communication network module mainly transmits the instructions encoded by the encoding tool remotely, and then receives these instructions locally, and decodes them with the decoding tool to execute [10]. The local service PC has two main functions. The first is to read the trajectory point sequences of those RAs that we expect. The motor in the control box drives the manipulator to move [11]. The remote client will transmit the tasks planned by the RA to the local server through the wireless network. In order to facilitate checking the working process anytime and anywhere, the data about the motor's geographic location is continuously collected through the I/O interface, and the quality of the servo can be detected according to the collected data. These data can also be converted to control the speed of the servo motor., to achieve our ultimate goal of controlling the RA [12].

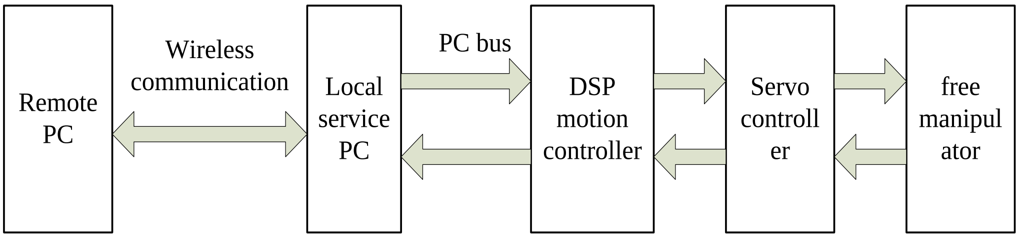

Figure 1. Engineering manipulator control system based on wireless communication network-DSP

3. AP Method Modeling of Structural Features of Engineering Manipulators Based on EDM Algorithm

3.1. Overview of AP Methods of Traditional Engineering Manipulators

Most of the traditional boom attitudes sensing methods are based on the measurement of the inclination sensor of the Internet of Things. An inclination sensor is installed between the two connecting rods, and then the attitude of the boom is obtained in turn from the turntable to the arm tip; The geometric structure of the hydraulic cylinder is used to measure the elongation of the hydraulic rod through the stroke sensor of the hydraulic cylinder, and then calculate the angle between the connecting rods to determine the attitude. Particle swarm localization is also used for source localization and pose estimation [13-14]. The traditional AP method requires the angle between the connecting rods, and these angles are also the key parameters constituting the kinematic equation of the engineering manipulator.

3.2. Comparison of Traditional Method and New Method

The traditional method has high computational complexity, has accumulated errors and elastic deformation, and has low efficiency and low accuracy for AP. The Euclidean Distance Matrix (EDM)-based algorithm for AP is directly used. Compared with SDP, it has less complexity when the accuracy is comparable, which can solve the delay problem and improve the accuracy. [15]. However, in the case of a large number of non-line-of-sight errors (NL0OS) in the ranging model, SDP needs to optimize the model according to different scenarios. As the number of nodes increases, the SDP algorithm has too many constraints and the complexity also increases [16].

3.3. Basic Idea of Attitude Positioning of RA

The construction manipulator is basically composed of a limited number of joints and connecting rods (the redundant construction manipulator is not considered here). Considering the rotation and extension, the degree of freedom of the general construction manipulator is 3 to 6. For example, the construction manipulator is composed of a rotating Tower with five cylinders to control movement with 3 degrees of freedom. The basic idea of using the EDM algorithm to directly perceive the attitude of the construction manipulator is as follows:

(1) Treat each joint point as an unknown node in the wireless sensor network, whose coordinates are unknown to be determined, and arrange 3 to 4 base stations within the radio range, and the coordinates of the base stations are known, which constitutes a wireless transmission The problem of sensor network localization [17].

(2) According to the wireless sensor network positioning algorithm based on ranging, the distance between the base station and the unknown node is measured by ranging, and the distance between the unknown nodes can also be generally measured, and then the coordinates of the unknown node are calculated by the three-dimensional positioning algorithm, using Lines connect adjacent points in turn, which can basically constitute the attitude of the construction manipulator [18].

3.4. Modeling of Wireless Location-Based Problems

There are several objective function models commonly used in wireless positioning problems. Here are several objective function models based on ranging, among which the least squares model based on ranging.

$$\min_{x} \sum_{i=1}^{n} (r_i - x - a_i^2) \tag{1}$$

When the ranging error is a Gaussian distribution and the covariance matrix is a unit matrix, the above model is actually the model of maximum likelihood estimation. The above model is non-convex, and it is difficult to guarantee the global optimal solution and convergence speed. Many people try to use semi-definite Relaxation method to optimize this model. Another different least squares model is the one based on the squared value of the odometry, known as the least squares model based on the squared odometry [19].

$$\min_{x} \sum_{i=1}^{n} (x - a_i^2 - r_i^2)^2 \tag{2}$$

Among them, x is the target vector, a_i is the ranging matrix, and r_i is the ranging error.

3.5. Construction of Euclidean Distance Array (EDM) for Engineering Manipulator

Assuming that there are four base stations, there are five links in this engineering manipulator, so A={1, 2, 3, 4} in the constructed Euclidean distance matrix represents the labels of the four base stations in this problem, and F is the number to be The label of the node to be measured, $G \in E^{9\times 9}$ is the Euclidean distance matrix, where E=A∪F, is the square value of the distance between the nodes to be measured or the square value of the distance between the node to be measured and the base station, Qi, Pi are the known base stations respectively and the coordinates of the unknown node to be measured. In the actual project, there may be inability to communicate between the nodes to be tested, that is, the distance D_{ij}, i, j∈S between the nodes to be tested cannot be measured. At this time, the Euclidean distance matrix can be estimated by using the Node coordinates are approximated instead. At this point, the EDM for the AP problem of the engineering manipulator can be expressed as:

$$G=\begin{cases}(Q_i-Q_j)^2; i,j\in A\\ D_{ij}^2; i\in A, j\in F\\ (P_i-P_j)^2; i,j\in F\end{cases} \tag{3}$$

4. Simulation Analysis of AP of Engineering Manipulator Based on EDM Algorithm

4.1. Optimization Package Selection

In order to verify the feasibility of the EDM algorithm, the simulation experiment was completed on Matlab, in which the Sedumi toolkit in the convex optimization tool CVX was used to solve the semi-definite programming (SDP) problem and the proposed model. The construction manipulator has five links. All the results in the experiments are compared with EDM algorithms, such as the positive semi-definite programming (SDP) method, the least squares method based on the square of ranging (SR-LS).

4.2. Analysis of Simulation Results

The observation distance Dij in the simulation is the real distance plus additive noise, which obeys a standard normal distribution with a mean of 0 and a standard deviation of σ. In this simulation experiment, σ takes three different scale values: 1, 0.1 and 0.01, where it is necessary to ensure that all distance measurements are positive values. After 1000 times of simulation experiments, the average value is obtained, and the average absolute error and relative error are simulated for each boom section. The results are shown in Table 1.

Table 1. Absolute errors of the five links of the boom

	1	2	3	4	5
EDM	0.493	0.426	0.447	0.405	0.412
SR-LS	0.672	0.974	1.511	1.986	1.543
SDP	0.524	0.537	0.548	0.565	0.569

In Table 1, it can be seen that the absolute error of different algorithms for each link of the boom after 1000 experiments, that is, the difference between the measured value and the real value, the engineering manipulator in the simulation has five links, and each link The length of the rod is fixed. It can be seen from Table 2 that the absolute error of the EDM algorithm for each link is relatively small, followed by the positive semi-definite programming SDP method, and the absolute error of SR-LS based on least squares is relatively large.

Table 2. Relative errors of the five links of the boom

	1	2	3	4	5
EDM	5.471	6.824	6.343	4.752	3.967
SR-LS	7.834	13.506	22.415	22.533	17.824
SDP	5.642	7.955	8.231	6.408	6.145

From Table 2, we can see the relative error of three different algorithms for each link of the boom after 1000 experiments. It can be seen that the EDM algorithm has the smallest relative error in the measurement of each link, followed by the positive semi-definite programming SDP, and the SR-LS based on least squares has the largest relative error.

After simulation, it can be found that the results of the semi-positive definite programming SDP and EDM algorithms are very similar, and they do not reflect their respective characteristics. Therefore, the simulation analysis of the root mean square error RMSE and time complexity is continued.

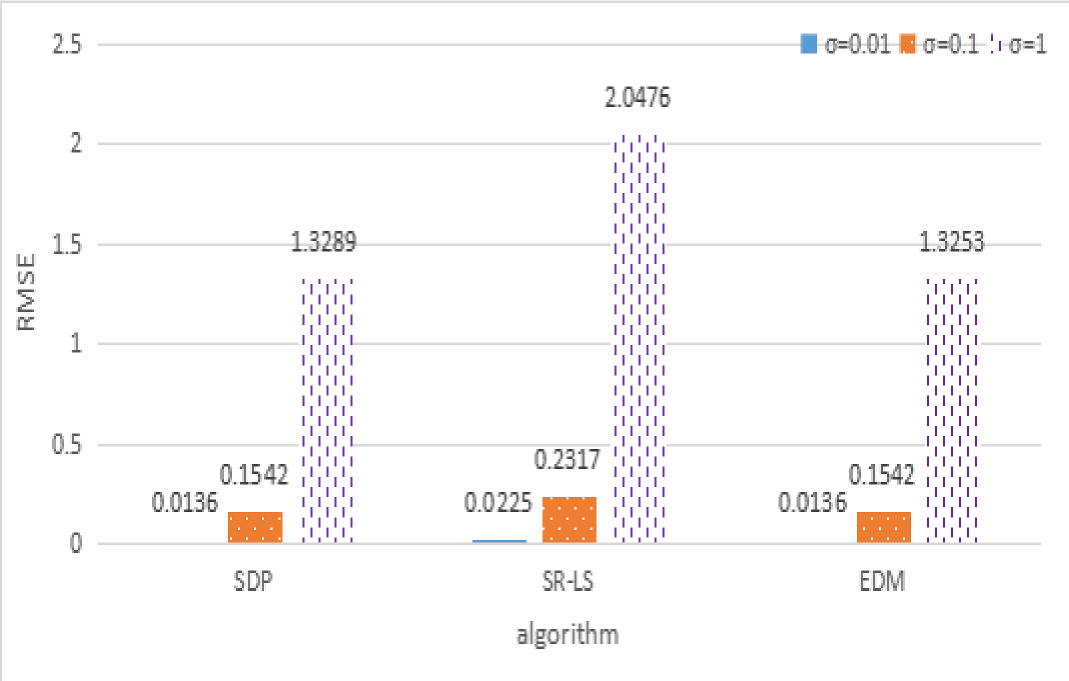

Figure 2. RMSE of each algorithm

As can be seen from Figure 2, after 1000 simulation tests, the comparison values of the root mean square errors of the three algorithms can be seen. It can be seen that the EDM algorithm uses the special structural characteristics of the engineering manipulator, the error value is smaller, and the accuracy relatively improved.

The comparison value of the time complexity of the three algorithms can be seen from Figure 3. Compared with other methods, the time complexity of EDM algorithm is the lowest. In addition, by synthesizing the simulation results, we also found that the complexity of the EDM algorithm is much smaller than that of the SDP algorithm of positive semi-definite programming when the accuracy is comparable. This shows that the AP method based on the EDM algorithm constructed in this paper has the best accuracy.

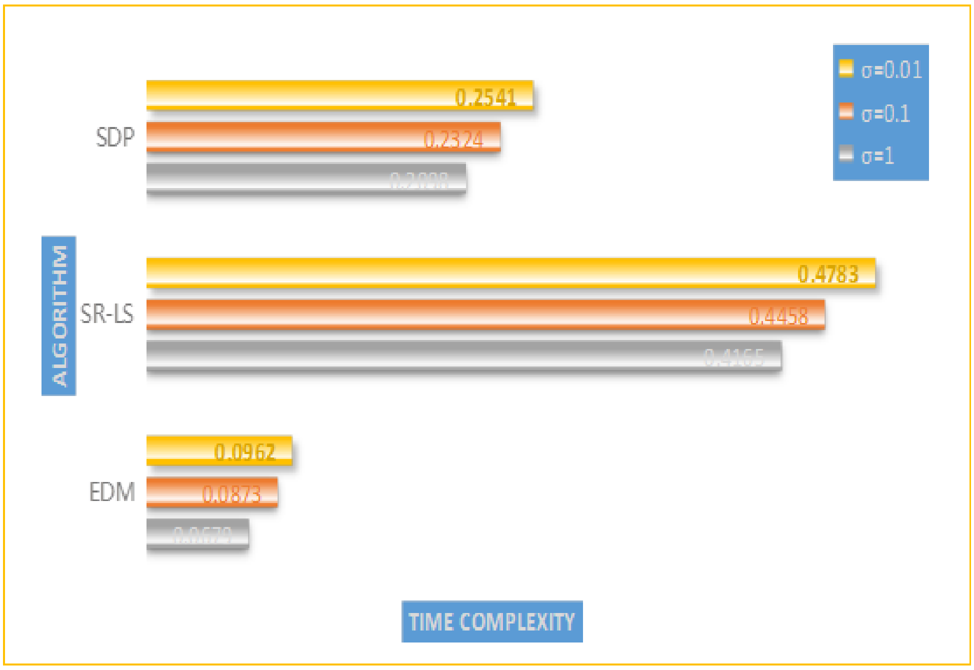

Figure 3. Time complexity of each algorithm

5. Conclusion

In this paper, an engineering manipulator control system is established by combining wireless communication and IoT technology, and the traditional methods of AP of engineering manipulators and the methods of direct sensing by EDM algorithm are reviewed and compared. The non-redundant engineering manipulator is used as the For example, a set of attitude sensing methods for engineering manipulators are proposed by using the structural characteristics of engineering manipulators. The experiments verify that the EDM algorithm improves the attitude sensing accuracy of engineering manipulators, so as to obtain more accurate sensing attitudes.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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