Research on Intelligent Anti-collision Monitoring for Construction Tower Crane Group Based on GNSS Sensors

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Abstract: A novel anti-collision monitoring method is proposed based on GNSS single-epoch positioning technology via high-precision carrier phase observations, which is applied to intelligent anti-collision monitoring for construction tower crane group. GNSS-based anti-collision monitoring principles are given in detail. A set of GNSS-based anti-collision monitoring auxiliary system named as GNSS_ACS for construction tower crane group is designed and developed. It can realize three kinds of alarm monitoring function consist of C-level, B-level and A-level respectively. The monitoring accuracy in the GNSS_ACS system ,for 600 consecutive epochs of the rover station such as rover_1727, the min-error of N-RMS is 0.007m, the max-error of N-RMS is 0.012m and the avg-error of N-RMS is 0.010m; the min- error of E-RMS is 0.005m, the max-error of E-RMS is 0.008m and the avg-error of E-RMS is 0.011m; the min-error of U-RMS is 0.015m, the max-error of U-RMS is 0.029m and the avg-error of U-RMS is 0.022m, is obtained in cm-level which verifies the effectiveness and feasibility of the proposed solutions in the experimental results. It can provide a new solution for intelligent anti-collision monitoring of construction tower crane group.

Key words: GNSS single-epoch positioning, anti-collision monitoring, hoisting operation, construction tower crane.

1. Introduction

In recent years, the accurate management and control technology including intelligent anti-collision monitoring of construction tower crane group has become an important means to ensure the safety and reliability operation of tower cranes, and it is one of the research hotspots [1], [2]. GNSS receiver is one of important sensors for anti-collision early warning and monitoring for construction tower crane group, which has innate unique advantages. However, due to the low accuracy of positioning based on GNSS pseudo-distance observations, it will not meet the developmental requirements of intelligent anti-collision monitoring for tower cranes [3], [4]. Therefore, a novel method of anti-collision monitoring is proposed based on GNSS single-epoch positioning technology via high-precision carrier phase observations [5], [6], which is suitable for the complex working environment of construction tower crane group. It is applied to anti-collision monitoring of construction tower crane group, and the corresponding function modules are designed and developed. The correctness and effectiveness of the function modules are verified by the experiments, which are adapted to the intelligent developmental needs, and this to improve the modernization level of safety management for intelligent construction tower cranes. It will play an important role in promoting of intelligent ant-collision monitoring applications.

2. GNSS-Based Anti-collision Monitoring Principles

Regarding the means of solve problem for anti-collision monitoring of construction tower crane group, it can be divided into two kinds [7]: one is anti-collision monitoring of two tower cranes, and the other is anti-collision monitoring of single tower crane. The classification of anti-collision monitoring of tower cranes is shown in Fig. 1.

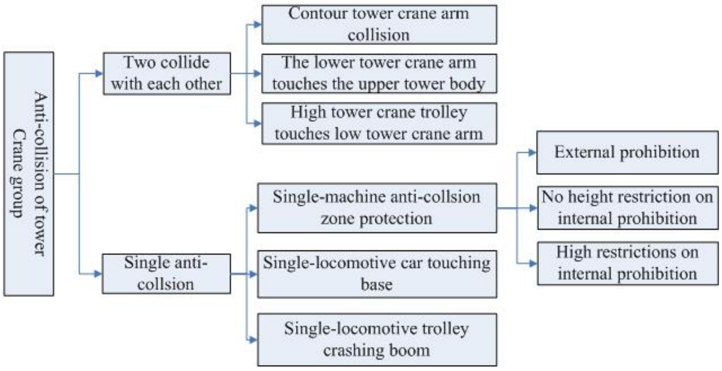


Fig. 1. Classification of anti-collision monitoring of tower crane group.

2.1. GNSS Single-epoch Positioning Technology

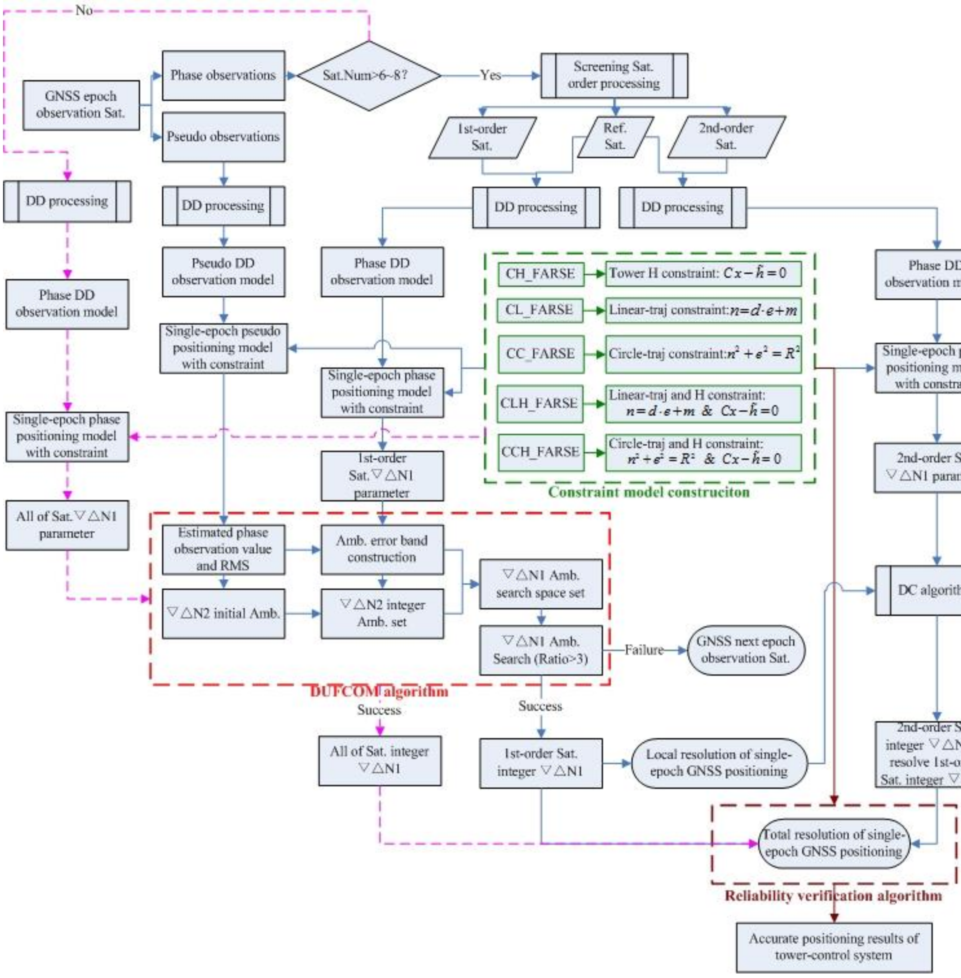


Fig. 2. Flowchart of core algorithm of single-epoch positioning.

A novel anti-collision monitoring method is proposed based on GNSS single-epoch positioning technology which the flowchart of core algorithm of single-epoch positioning is shown in Fig. 2.

2.2. Monitoring Parameters Determination

In order to improve the operation stability, the safety and reliability of hoisting operation, it is necessary to implement security measures to ensure the safe operation for tower crane group. When the tower crane is in danger of collision, there is a buffer time for the operation of the tower crane group. The purpose of developing the anti-collision monitoring system for the tower crane group is to monitor the operation of tower crane boom or mobile trolley in real-time, and to prevent the tower crane collision accidents caused by the driver's wrong operation or emergency.

The common essence of many existing anti-collision calculation models is to predict the future interference among tower planes in order of priority according to the current position information, velocity information and trajectory information obtained by each tower. In view of this, a novel anti-collision monitoring method is proposed based on GNSS single-epoch positioning technology via high-precision carrier phase observation. It can monitor the spatial position, velocity information and motion trajectory of the current boom according to the GNSS receiver installed on the tower crane boom. Suppose one GNSS receiver named as rover_A is installed on tower boom *A*, and the real-time plane coordinates are obtained as (X1, Y1), and then another GNSS receiver named as rover_B is installed on tower boom *B*, and the real-time plane coordinates are obtained as (X2, Y2). Then, the plane geometric distance *D* between the two tower booms *A* and *B* can be carried out in real time as follows:

$$D=\sqrt{(X1\text{-}X2)^2+(Y1\text{-}Y2)^2} \tag{1}$$

where, *D* is the length that can be used for the basic monitoring parameters of anti-collision monitoring of hoisting operation for construction tower crane group [8]. It is worth mentioning that the anti-collision monitoring situation of construction tower crane group is very complicated. It is necessary to comprehensively determine the standard value of monitoring parameters based on the actual operation of construction tower crane group and also considering many index factors.

2.3. Kinematics Relationship between Tower Crane Group

When only the same height index factor is considered, the trajectories of the two tower booms have two motion modes: relative movement mode and chasing movement mode.

For the relative movement mode, the schematic diagram of anti-collision monitoring of the two tower cranes during operation is shown in Fig. 3. Similarly, for the chasing movement mode, the schematic diagram is shown in Fig. 4.

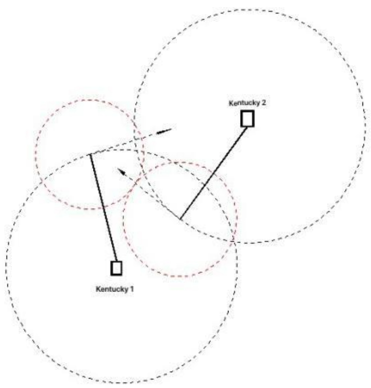


Fig. 3. Relative movement mode.

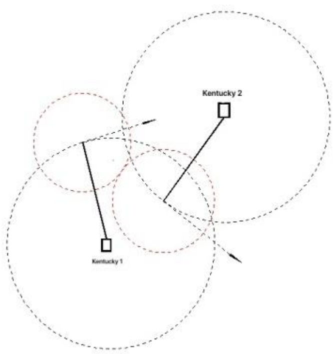
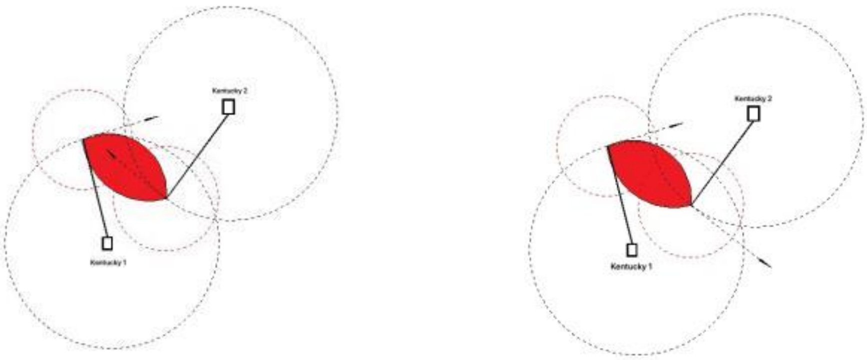


Fig. 4. Chasing movement mode.

As shown in Fig. 3, it maybe has the possibility of collision for the relative movement mode, the driver's may consider stopping in order to give way for two tower cranes. As shown in Fig. 4, it maybe has the possibility of collision for the chasing movement mode, the driver's may consider only choose the chasing tower crane to stop giving way, but not influence the normal operation of the tower crane pursued.

2.4. Collision Hazard Zone

According to the performance of tower crane itself and activities covering the range of features, it set the priorities among tower cranes. For example, it is easier for the kinematics tower crane to give way than the static tower crane, so the dynamic-order of the kinematics tower crane under the static tower crane. In the actual work of the tower crane of which the positions lifting arm, hook and rover car are constantly changing. So the collision hazard zone must be divided according to their positions information. The collision hazard zone of relative movement mode and chasing movement mode are the same, which can be divided into three collision warning zones named as A, B and C-level by positions division as shown in Fig. 5, where the collision hazard zone in red color.



(a) Relative movement mode. (b) Chasing movement mode.

Fig. 5. Collision hazard zone of two tower crane movement modes.

From Fig. 5, It conventions as follows in the GNSS_ACS system [4].

$$D=\begin{cases}15 \text{ meters, C-level alarm critical point}\\ 6 \text{ meters, B-level alarm critical point}\\ 2 \text{ meters, A-level alarm critical point}\end{cases} \tag{2}$$

where, D is defined as the geometric distance between tower crane 1# and tower crane 2#.

3. GNSS-Based Anti-collision Monitoring Auxiliary System

The GNSS-based anti-collision monitoring auxiliary system for construction tower crane group, named as GNSS-based anti-collision system (GNSS_ACS), is one of the main functional modules of GNSS-based accurate management and control system for construction tower cranes (GNSS_TCIAC) [4].

3.1. System Composition

The GNSS_ACS system mainly consists of four parts as follows:

(1) The GNSS reference station. It is set in a wide-view of ground observation satellite to receive the GNSS signal and transmit the comprehensive error correction signal processed by differential of navigation satellites to GNSS rover station through data communication chain.

(2) The GNSS rover station. It is set on the top of the support frame of rover trolley of the tower crane.

The GNSS rover station is comprised by a navigation positioning device and a coordinate calculating device. The navigation positioning device is used to collect the navigation satellite observations, and the coordinate calculating device is used to calculate the three-dimensional coordinates of the antenna phase center of the GNSS rover station.

(3) The alarm device. It is a sound alarm device for sounding according to the alarm signal, and a light alarm device for flashing light according to the alarm signal.

(4) The monitoring platform. It is used to receive monitoring data from the GNSS rover station and send warning instructions to the alarm device according to the early-warning monitoring mechanism.

3.2. Developmental Ideas

For two tower cranes, the developmental ideas of GNSS_ACS system are shown in Fig. 6.

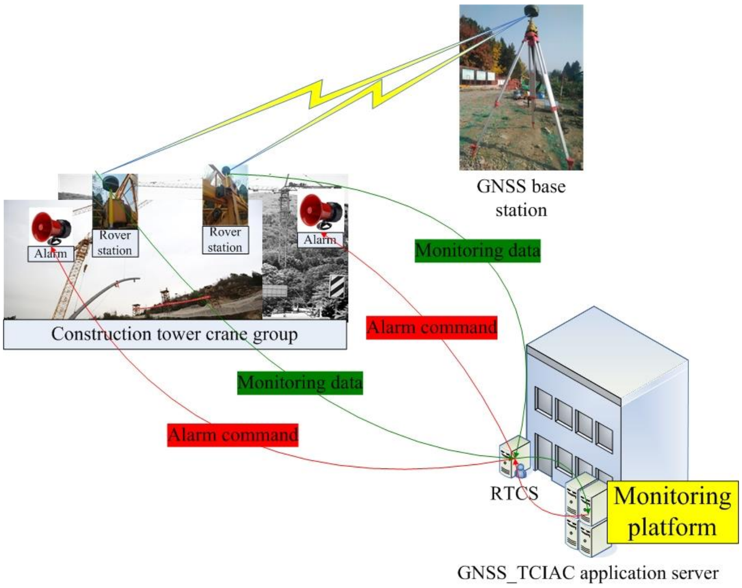


Fig. 6. Developmental ideas of GNSS_ACS system.

As shown in Fig. 6, the GNSS reference station is erected in the open filed-vision of the construction site. At the same time, a GNSS rover station is set on the top of the support frame of rover trolley of tower crane. The GNSS rover station receives the comprehensive error correction signal from the reference station in real time. It is forming a "1+N" GNSS RTK positioning mode to achieve the cm-level high-precision positioning function for anti-collision monitoring of construction tower crane group.

3.3. System Implementation

Fig. 7. Interface design based on Google Map.

Fig. 8. Interface design based on human-computer.

Base on GNSS single-epoch positioning technology, a set of GNSS_ACS system is designed and implemented using C# programming language of VS2010 development platform, which is GNSS-based the high-sampling rate such as 1 Hz carrier phase observation data.

The main interface design view of GNSS_ACS system is divided as two kinds: one is an interface design based on Google Map as shown in Fig. 7, the other is an interface design based on human-computer interaction monitoring as shown in Fig. 8.

4. Experimental Testing and Analysis

In order to analyze and verify the effectiveness and feasibility of intelligent anti-collision monitoring function of GNSS_ACS system, consists of collision avoidance and early warning, it is applied into intelligent anti-collision monitoring of construction tower crane group. An experimental testing was carried out on two large tower cranes served for the site protection construction project in Beijing. Fig. 9 shows that the two tower cranes are cooperating in hoisting operation. Fig. 10 shows the installation location of the GNSS reference station as shown in (A) and GNSS rover station as shown in (B) and (C).

Fig. 9. Cooperating hoisting operation of two tower cranes.

(A)base (B)rover_1727 (C)rover_1366

Fig. 10. Installation location of GNSS sensors.

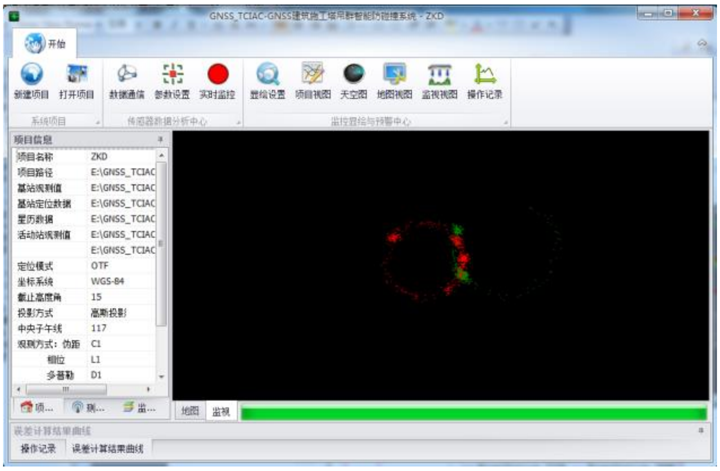


Fig. 11. Monitoring effect in GNSS_ACS system.

When two tower cranes are started, all monitoring equipments is put into working state, for example, high-precision monitoring data can be obtained by sensors consist of the GNSS rover station and the odometer on the tower crane which was send to the central control center such as cloud server in real time and synchronously. And then, the cloud server carry out the space position coordinates of hook of tower crane in real time. According to the position information of hook, collision avoidance and early warning of construction tower crane group was monitored in real time. The real-time monitoring effect is shown in Fig. 11.

From Fig. 11, on the processing experimental testing, with 2 sets of construction tower crane hook test points close and going away for many times including relative movement mode and chasing movement mode. It can realize three kinds of alarm monitoring function in GNSS_ACS system respectively:

$$\text{Alarm monitoring}=\begin{cases}\text{C-level, defined as showing the word "Please pay attention to driving",} \\ \qquad\text{and emitting the sound "ding-ding-ding" from the alarm.} \\ \text{B-level, defined as showing the word "Please give way",} \\ \qquad\text{and emitting the sound "class bell" from the alarm.} \\ \text{A-level, defined as showing the word "please emergency brake",} \\ \qquad\text{and emitting the sound "electronic alarm" from the alarm.}\end{cases} \tag{3}$$

In order to evaluate the accuracy of intelligent anti-collision monitoring of GNSS_ACS system between each other of construction tower crane group. The monitoring data of GNSS rover stations both of rover_1727 and rover_1366 with 600 consecutive epochs form GNSS_ACS system was used for the accuracy analysis, the results show in Fig. 12 and Fig. 13 respectively.

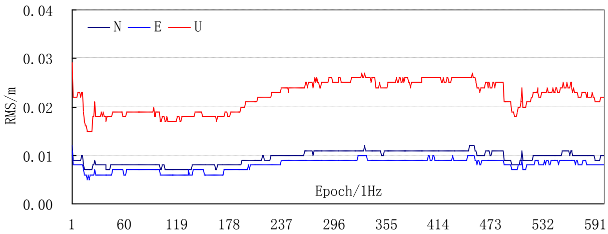


Fig. 12. RMS of rover_1727.

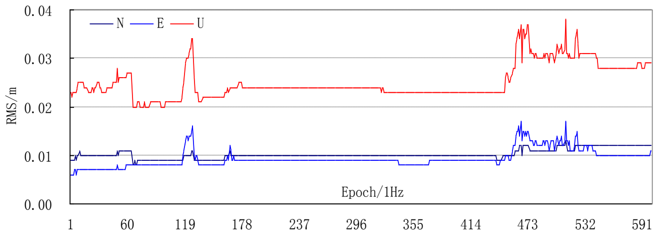


Fig. 13. RMS of rover_1366.

From Fig. 12, for 600 consecutive epochs of rover_1727, the min-error of N-RMS is 0.007m, the max-error of N-RMS is 0.012m and the avg-error of N-RMS is 0.010m; the min- error of E-RMS is 0.005m, the max-error of E-RMS is 0.008m and the avg-error of E-RMS is 0.011m; the min-error of U-RMS is 0.015m, the max-error of U-RMS is 0.029m and the avg-error of U-RMS is 0.022m.

Form Fig. 13, for the 600 consecutive epochs of rover_1366, the min-error of N-RMS is 0.008m, the max-error of N-RMS is 0.013m and the avg-error of N-RMS is 0.010m; the min-error of E-RMS is 0.006m, the max-error of E-RMS is 0.017m and the avg-error of E-RMS is 0.009m; the min-error of U-RMS is 0.020m, the max-error of U-RMS is 0.038m and the avg-error of U-RMS is 0.025m.

The results of numerical analysis from Fig. 12 to Fig. 13 show that the precision of intelligent anti-collision monitoring of GNSS_ACS system is cm-level. It shows that the solutions proposed in this paper can provide a high-precision real-time method for GNSS-based anti-collision monitoring of construction tower crane group.

5. Conclusions

In view of the application with complex working environments of construction tower crane group, in order to improve the positioning accuracy and reliability of anti-collision monitoring application, a novel intelligent method based on GNSS single-epoch positioning technology via high-precision carrier phase observations is proposed. GNSS-based anti-collision monitoring principles are given in detail. C# programming language based on VS2010 development platform is used for establishing the function modules of the proposed principles. A set of GNSS-based anti-collision monitoring auxiliary system for construction tower crane group, named as GNSS_ACS, is designed and developed. It can realize three kinds of alarm monitoring function consist of C-level, B-level and A-level respectively. And then, the effectiveness of intelligent anti-collision of GNSS_ACS system is verified in the process of experimental testing and results analysis during the cooperating hoisting operation of two large tower cranes at the site protection construction project in Beijing. Finally, the anti-collision monitoring accuracy of GNSS_ACS system, for 600 consecutive epochs of the rover station such as rover_1727, the min-error of N-RMS is 0.007m, the max-error of N-RMS is 0.012m and the avg-error of N-RMS is 0.010m; the min- error of E-RMS is 0.005m, the max-error of E-RMS is 0.008m and the avg-error of E-RMS is 0.011m; the min-error of U-RMS is 0.015m, the max-error of U-RMS is 0.029m and the avg-error of U-RMS is 0.022m, is obtained in cm-level which verifies the effectiveness and feasibility of the proposed solutions in this paper. It is worth mentioning that the solutions proposed in this paper have been granted two China invention patents listed as ZL201710683912.7 and ZL201710683918.4, which can provide effective technical support for GNSS-based intelligent anti-collision monitoring applications for construction tower crane group.

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