Optimized Design of Mechanical Chain Drive Based on a Wireless Sensor Network Data Algorithm

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Received 11 August 2021; Accepted 28 August 2021; Published 14 September 2021

Academic Editor: Guolong Shi

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In this paper, we use a wireless sensor network data algorithm to optimize the design of mechanical chain drive by conducting an in-depth study of the mechanical chain drive optimization. We utilize the crowdsourcing feature of the swarm-wise sensing network for assisted wireless sensor networking to achieve crowdsourcing-assisted localization. We consider a framework for crowdsourcing-assisted GPS localization of wireless sensor networks and propose two recruitment participant optimization objectives, namely, minimum participants and time efficiency, respectively. A model and theoretical basis are provided for the subsequent trusted data-driven participant selection problem in swarm-wise sensing networks. The sprocket-chain engagement frequency has the greatest influence on the horizontal bending-vertical bending composite in different terrain conditions. The dynamic characteristics under working conditions are most influenced, while the scraping of the scraper and the central groove significantly influenced horizontal bending and vertical bending. Under load conditions, the amplitude of the scraper and central groove scraping increases significantly, which harm the dynamics of the scraper conveyor. By monitoring the speed difference between the head and tail sprockets and the overhang of the scraper, the tensioning status of the scraper conveyor chain can be effectively monitored to avoid chain jamming and chain breakage caused by the loose chain, thus improving the reliability and stability of the scraper conveyor.

1. Introduction

The development of wireless sensor networks and group intelligence-aware networks has been carried out relatively independently, and no research has been conducted to converge the two. Network convergence originally means that with the development of technology, the telephone network and data network gradually merge into one; that is, voice signal transmission through data networks has become a reality and continues to spread. The merging of telephone and data networks will greatly reduce the operating costs of communication networks and simplify the management of the network for users; the biggest benefit is the cost savings. The meaning behind this is that the emergence of new technologies can enhance the original technology, which is often very mature, and preapplication has built a huge system with huge investment [1]. In wireless sensor network monitoring applications that require high reliability of data collection, the ability of the nodes to collect complete data from the monitoring area and transmit them to the user center in a reliable and timely manner is directly related to the effectiveness of the network application [2]. For example, in wireless sensor network data collection based on applications such as soil site monitoring, to accurately predict and identify risk factors, it is not only required that the sensor network can collect data reflecting the complete status of the monitoring area but also required that these data are reliably transmitted to the user within a specified delay [3]. However, random deployment of nodes or coverage voids created during network operation degrades the network coverage quality of service, resulting in the network not being able to collect complete data from the monitoring area.

There are also a variety of factors that affect reliable data collection during the data transmission phase; for example, sensor nodes are battery-powered; once the nodes die due to energy exhaustion, data transmission will be interrupted.
and cannot continue, affecting the continuous data collection; data collection delays caused by factors such as congestion, waiting, dormant scheduling, and unreliable links are too large to meet the data of delay-sensitive wireless sensor network application collection performance requirements; data overflow generated by insufficient node storage space and packet loss due to unreliable links degrade data collection rate performance [4]. From the working principle of the scraper conveyor, the scraper chain is the key component of the scraper conveyor, which is the traction mechanism of the scraper conveyor and is the component that transmits traction force and directly scrapes and transports materials. The chain operates under sliding friction conditions and is not only subjected to large static and dynamic loads but also eroded by mine water, so it usually has a high failure rate. Often, the original technology is already very mature and the early application has established a huge system, with huge investment. The original system does not completely lose its value but can also be used by advanced new technologies. Therefore, a fusion mechanism is needed to enable the new technology and the original technology to be combined into one and function together. Typical failure forms of scraper chains include chain jamming, chain skipping, chain breaking, etc. Some studies show that the reliability of the scraper conveyor decreases exponentially as the working time increases [5]. Although this method can effectively detect the occurrence of faults, it has a certain lag; i.e., it cannot predict and avoid faults in advance.

Wireless sensor networks inevitably face the problems of incomplete data collection in the monitoring area due to coverage voids: the problem of data collection rate degradation due to unreliable link packet loss, the problem of mobile sink data collection techniques not meeting the low latency collection of event monitoring data, and the problem of sink not reliably collecting complete data in the monitoring area due to limited node resources. Unlike the existing message detection-based hole detection algorithm, the hole detection algorithm in this paper can rely on the information of incomplete coverage intersection for concurrent detection of multiple connected holes, which reduces the energy consumption and time of hole detection. In addition, the hole repair algorithm in this paper reduces the number of mobile nodes required for hole repair by optimizing the hole repair drive nodes and can achieve low redundancy and complete repair of covered holes. Considering the dynamic change of node energy and data collection, the minimum dwell time and maximum waiting time of the mobile device are predicted based on the Markov model to avoid its large-span movement in the monitoring area. Compared with existing methods, PPAGS can largely increase the data collection rate with a small number of mobile devices while reducing the data collection delay.

2. Current Status of Research

Considering the operating characteristics of the scraper conveyor, based on the existing advanced sensing technologies, relevant experts and scholars have overcome the problems in assessing the operating condition of the scraper conveyor, and a certain research base has been established, but it is still limited to the system platform design, wireless sensing technology development, and data processing algorithm optimization [6]. The current research mostly uses sensors and measurement devices to measure different parameters of the chain drive system, and the main measurement tools include tension sensors, angle sensors, electromagnetic sensors, Hall elements, and electromagnetic detection devices [7]. In turn, a wireless sensor network is designed for data transmission, and data analysis of different parameters is used to assess the operating status of the equipment for condition monitoring and fault determination of the scraper conveyor [8]. To improve data transmission efficiency, in wireless sensing technology development, Cunningham designed a remote monitoring system for a scraper conveyor combining an RFID wireless sensor network, CAN bus, and industrial Ethernet [9]. Sadeeq and Zeebaree designed a wireless detection system for scraper conveyor drive based on RFID technology [10]. Amutha et al. developed a remote monitoring system based on industrial Ethernet and a wireless mesh switching network-based remote monitoring communication platform to realize remote on-board monitoring of the scraper conveyor [11]. However, although the efficiency of data acquisition was improved to some extent through the design of the network structure, it still failed to apply the measured data to the monitoring of the operation status of the equipment.

When random coverage is performed, there will be several uncovered areas, often called coverage holes, despite the dense network as a guarantee of coverage. For this reason, mobile nodes are added to the sensor network and allowed to move after random deployment to compensate for the uncovered areas. This is an important class of research problems, which is called the coverage problem of mobile wireless sensor networks. In this paper, we will study this type of problem with the main goal of obtaining $K$-recoveries at minimal movement cost [12]. The coverage problem for mobile sensors is the initial version of mobile swarm intelligence sensing, where sensors can only be controlled centrally or are given very limited control strategies. The study of how mobile swarm intelligence perception can provide location information for the mobile sensor coverage problem is one of the research areas in this paper [13]. The BikeNet system uses various sensors and smartphones equipped on cyclists’ bikes to sense and share the air quality and road conditions around the cycling path so that cyclists have real-time knowledge of the environment for path selection and optimal cycling experience [14]. The CrowdAtlas system addresses the current problem of untimely and costly updates of electronic maps by using sensory data from GPS sensors of cell phones and cars of many users in the city to build a real-time updated map of urban roads. The monitoring system includes an electromagnetic sound emitter and an electromagnetic sound sensor [15]. The electromagnetic sound emitted by the electromagnetic sound emitter is reflected when it meets the scraper chain of the scraper conveyor. The electromagnetic sound sensor determines the degree of surface damage to the scraper chain by analyzing the reflected electromagnetic sound. This monitoring system
predicts scraper chain failure by directly monitoring the physical form of the scraper chain. The disadvantage is that the working environment of the scraper conveyor is harsh and the scraper chain will be covered by coal and other materials during normal operation, which makes monitoring inaccurate or even completely impossible.

The actual working environment of the scraper conveyor is usually harsher, manifested by strong vibration and strong electromagnetic interference. It is also required that these data be reliably transmitted to the user within a specified delay. However, random deployment of nodes or coverage holes generated during network operation reduces the quality of network coverage services, resulting in the inability of the network to collect complete data in the monitoring area. For some coal mines with high water seepage, it is also necessary to pay attention to the fact that mine water may flood the return scraper located below the middle plate. Therefore, the tension monitoring system for the scraper conveyor needs to face the problems of waterproof, antivibration, anti-electromagnetic interference, electromagnetic magnetic shielding, etc. For the problems of mine water and strong vibration, it is necessary to improve the stability of the hardware design of the monitoring system, as well as to design the protection scheme. On the other hand, for the mine water and electromagnetic environment can affect the communication and other functions of the tension monitoring system, there is also a need to conduct in-depth research on wireless communication under the mine. In addition, wireless sensor network data collection technology performance indicators include network throughput, robustness, security, and confidentiality. In addition to energy efficiency, which is the primary performance indicator for all wireless sensor network applications, other network performance indicators vary from one application scenario to another. The application of wireless sensor networks in the military field needs to ensure the security and confidentiality of data collection.

3. Optimized Design Analysis of Mechanical Chain Drive with the Wireless Sensor Network Data Algorithm

3.1. Wireless Sensor Network Data Algorithm Design. Wireless link quality affects the performance of network routing protocols. Wireless links are unreliable due to the external environment and cochannel signals. Evaluating the link quality helps to improve the packet forwarding rate and helps to reduce the energy consumption of the network nodes. Identifying credible real data from group-wise perception, participant perception with noise or even conflicting data is a challenging problem. A part of the research focuses on authentic discovery algorithms, and these studies focus on estimating the data quality of participants and discovering potentially authentic data synchronously by quality-based data fusion. They describe the reliability of participants as the variance of a normal distribution, and the estimated true values are usually computed as a weighted average sum or found using a Bayesian approach through EM algorithms or parameterization [16]. As mentioned in Section 3 for moving sensors to achieve specific coverage requirements, collecting the GPS locations of randomly placed sensors in the network is the first step in computing and planning sensor movements, so it is important to assist mobile wireless sensor networks for GPS localization. It makes sense to set the application scenario within urban centers (urban fields) where many people with smart devices are active. This provides a greater opportunity to provide mobile wireless sensor network GPS information. Of course, recruiting participants for the swarm intelligence sensing task needs to be considered at a certain cost. Firstly, recruiting as few participants as possible is one of the goals, and secondly, those suitable participants need to be selected for the recruitment process.

The wireless sensor network is abstractly represented as \( G = (V, E, Q, W) \), where \( V \) represents the set of network nodes; \( E \) represents the set of wireless links of network nodes; \( Q \) represents the set of network link quality, and the link \( (i, j) \) quality is denoted as \( q_{ij} \), assuming that the link quality between all nodes is known; and \( W \) represents the set of work schedules of network nodes, and the work schedule \( w_i \) of any node \( i \) is represented by a string consisting of 0 and 1 sequences. A work cycle of the network is denoted as \( T \), and a time slot is denoted as \( \pi \). There are \( T \) time slots in a work cycle, and each time slot \( \pi \) completes one data transmission. The state of each time slot is divided into a sleep state and active state, which are represented by 1 and 0, respectively. In period \( T \), the time slot position of the active state of node \( i \) is calculated according to

\[
\begin{align*}
X_{i,n} &= i \mod \left( \frac{T}{\pi} \right), \\
X_{i,n-1} &= (X_{i,n} - C) \mod \left( \frac{T}{\pi} \right).
\end{align*}
\]

The next-hop forwarding node selection considers the residual energy of the nodes as well as the link quality, which balances the energy consumption of the network nodes and increases the network lifetime. The link metric of node \( i \) with neighbor node \( j \) is defined as

\[
SLQ_\text{E}_{ij} = \beta p_{ij} + \frac{(1 - \beta)E_j}{(1 + \beta)W},
\]

Due to other reasons such as load changes, the chain tension of the scraper conveyor will change constantly during the actual coal mining work, making the whole section or local tension of the chain exceed the design value. Too much or too little chain tension will affect the normal operation of the scraper conveyor. If the chain is too loose, the chain will easily break away from the sprocket at the separation point of the head sprocket or the tail sprocket and the chain, causing impact and vibration of the sprocket and causing...
accidents such as chain breakage and chain jamming in serious cases [17]. Data overflow caused by insufficient node storage space and data packet loss caused by unreliable links reduce the performance of the data collection rate. If the chain is too tight, it will increase the friction between the chain and the sprocket and the middle groove, increase the running resistance, make the power consumption of the scraper conveyor increase, and accelerate the wear of the related equipment. The scraper conveyor is not only used as coal transportation equipment in the coal mining working face but also used as a track for the coal mining machine to run. The coal mining machine moves on the scraper conveyor slide and cuts the coal wall, and the coal falls on the scraper conveyor and is pushed to the head by the scraper and scraper chain. Although this method can effectively detect the occurrence of faults, it has a certain hysteresis; that is, it cannot predict and avoid faults in advance. Wireless sensor networks inevitably face the problem of incomplete collection of data in the monitoring area caused by coverage holes and the problem of reduced data collection rate due to packet loss on unreliable links. The function of the scraper conveyor determines that the body of the scraper conveyor is very low, and during operation, there is a large amount of ore impact accompanied by electromagnetic interference from the high-power motor. For some coal mines, large amounts of mine water can seep out of the comprehensive mining face and its presence will also affect the monitoring system, as shown in Figure 1. This principle ensures that the mobile node introduced by the selected cavity driving node has the maximum area for the repair of the cavity region at the cavity repair location. The covered voids consist of boundary arcs of multiple void boundary nodes, and each node has at most two incomplete coverage intersections in the void area.

If each introduced mobile node can only eliminate one void boundary node, the mobile node transforms into a void boundary node and adds a void boundary node in the case of incomplete repair of the coverage void, which is slower in void repair, and when the mobile node introduced by a certain driver node can eliminate more incomplete coverage intersections, it can eliminate more void boundary nodes, which will speed up the void repair. This will speed up the hole repair and help reduce the number of mobile nodes required for hole repair. When the mobile nodes introduced at one time have eliminated all the incomplete coverage intersections, it means that the current hole is repaired.

\[ p(A) = \min t_{ij}. \]  

Based on the introduction of mobile node undivided holes, the nonparallel dichotomous repair strategy ensures that the coverage holes are completely repaired because at least 2 incomplete coverage intersections are eliminated per mobile node introduction during the nonparallel repair of the holes based on the drive node selection principles 1 and 3. Each introduced mobile node produces a maximum of 2 incomplete coverage intersections. The trajectory formed by the blade edge line rotating around the rotary axis is a single-leaf hyperboloid, which can be studied by using the properties of the single-leaf hyperboloid, as shown in Figure 2, which can be regarded as the edge line \(AB\) rotating around the rotary axis \(OZ\).

The contact force between scraper chains is the main cause of chain fatigue and failure. Or use the Bayesian method to find the true value through the EM algorithm or parameterized method. Under the framework of crowdsourcing, assist the mobile wireless sensor network for GPS positioning. The study of the force characteristics of the chain drive system is essentially a study of the change of contact force between scraper chains at different positions. In the transmission process of the scraper conveyor chain drive system, the scraper chain, as the main traction component, includes two types of horizontal circular chain (horizontal chain) and vertical circular chain (vertical chain). The driving chain wheel teeth are circular arc tooth profiles, and there are chain nest grooves and vertical chain grooves distributed between any adjacent teeth. In the process of the chain drive system, the horizontal chain lies flat in the chain nest groove, and the vertical chain is connected with the horizontal chain and distributed in the vertical chain groove. The tooth profile of the driving sprocket is not only the main part of the scraper chain and teeth engagement and disengagement but also the main area of the sprocket bearing force, so the parametric modeling is of great significance to the structure development and optimization design of the sprocket.

\[ D_0 = \sqrt{\left(\frac{p}{\sin \left(60^\circ/N\right)}\right)^2 - \left(\frac{d}{\cos \left(60^\circ/N\right)}\right)^2} \]  

\[ W = (2H + d) \cos \left(\frac{90}{N}\right) + A \sin \left(\frac{90}{N}\right) - d. \]  

The link metric is between node \(i\) and neighbor node \(j\). The Creo2.0 software development platform enables the virtual assembly of different mechanical systems and can be used for the rapid construction of 3D models of scraper conveyor chain drive systems. Among them, the "bottom-up" design method is the most conventional modeling method for virtual assembly, which models each component separately and then assembles each part into a whole in a step-by-step manner from the bottom up according to a certain installation order, constraint relationship, and hierarchy, which requires constant assembly and interference analysis to coordinate the design process to avoid interference errors. The "top-down" assembly design method is adopted for the 3D model of the chain drive system, which can achieve a high degree of coordination between the parametric design of key components and the virtual assembly process. The main principle is as follows: set the overall framework of the assembly or structural assembly scheme, which is used as the installation directory tree of the whole product, and in the assembly process, based on the directory tree, the subordinate assembly relationship and assembly order of different parts can be established from the top-level down to the
bottom-level components and parts for assembly.

\[
\frac{d}{dt} \left( \frac{\partial T}{\partial q} \right)^T + \left( \frac{\partial T}{\partial q} \right)^T - \theta_q^T \mu - \theta_q^T \mu = Q, \tag{5}
\]

where the complete constraint equation of the system satisfies

\[ \varphi(q, t) = 1. \tag{6} \]

The incomplete constraint equations of the system satisfy

\[ \theta(q, q_1, t) = 1. \tag{7} \]

Its basic idea comes from a collective intelligence that includes the contributions of thousands of individuals. And smart devices, such as mobile smartphones, offer a surprisingly diverse range of uses. This flexibility is mainly because these smart devices are often embedded with highly accurate GPS positioning systems. People can easily take these smart devices with them and use them anytime and anywhere, which greatly enhances the mobility of these smart devices. The GPS positioning of mobile wireless sensor networks is assisted in the framework of crowdsourcing. As mentioned in Section 3 for moving sensors to achieve specific coverage requirements, collecting GPS locations of randomly placed sensors in the network is the first step in computing and planning sensor movements, so it is important to assist mobile wireless sensor networks for GPS localization. A virtual prototype model of a double-chain traction chain transmission system considering the movement constraints and force relationships between different components and the dynamic characteristics of the chain transmission system under normal operating conditions, stuck-chain fault conditions, and broken-chain fault conditions is studied. It makes sense to set the application scenario within the urban fields (urban centers), where many people with smart devices are active. This provides a greater opportunity to provide GPS information from mobile wireless sensor networks. Of course, recruiting participants for the swarm intelligence sensing task needs to be considered at a certain cost: firstly recruiting as few participants as possible is one of the goals, and secondly, those suitable participants need to be selected for the recruitment process.

\[
\begin{cases}
F(q, u, \mu, \lambda, t) = 1, \\
G(u, q) = u + q, \\
\phi(q, t) = 1.
\end{cases} \tag{8}
\]

Figure 1: Wireless sensor network framework.
To study the dynamics of the chain drive system, it is necessary to study the complex contact problem between different rigid body surfaces while considering its multibody dynamic characteristics. The contact between different rigid bodies of the chain drive system is a complex nonlinear problem, and the contact collision can be regarded as a time-varying dynamic process, and the most used algorithms to deal with the boundaries of the contact problem are the implicit Lagrange algorithm and the display penalty function method [18]. In this section, the research and analysis of the contact problem between different rigid bodies of the chain drive system mainly involve contact collision detection and contact force solution. The polygonal contact model satisfies the following two characteristics: the surfaces of any rigid bodies in contact with each other can be described by polygons, and the commonly used methods for constructing polygonal surfaces include Bessel curves and NURBS methods; the contact force between any two contacting bodies of the system can be determined based on the elastic base model.

3.2. Experimental Optimization Design of Mechanical Chain Drive. Since the tension acquisition device needs to follow the movement of the scraper to collect the tension of the scraper chain in real time, the tension acquisition device cannot obtain a stable energy source by wired means. The energy source of the tension acquisition device is set as a battery because it relies on the power generation principle such as piezoelectric vibration capturing energy, which leads to the unstable supply voltage. The capacity of the battery and the power consumption of the tension collection device determine the service time of the tension collection device [19]. The capacity of the battery is limited by the size of the battery, and the tension collection device and the battery are encapsulated together in the cavity of the lower pressure plate of the scraper, so there is a great limitation on the size and quantity of the battery. Therefore, to maximize the service time of the tension acquisition device, an energy-saving strategy is designed to reduce the power consumption of the tension acquisition device. The energy-saving strategy requires a proximity switch on the hardware and a dormant program on the software to form in conjunction. As mentioned above, the wireless communication distance is very short, and the data sent by the tension acquisition device can only be received by the data receiving device when the device moves with the squeegee to a position close to the data receiving device installed in the middle plate. Therefore, a proximity switch needs to be designed to notify the tension acquisition device when to start sending data. When the data transmission ends or is no longer within the communication range, the tension acquisition device can turn off the wireless transmitting function and enter the low-power sleep mode to save energy.

The theoretical calculation of the dimensions of each component of the microstrip antenna was carried out above, and to further optimize the performance of the theoretically calculated natures, the length of the radiating patch of the microstrip antenna and the width of the 1/4 wavelength impedance converter were scanned by the simulation software HFSS to seek the dimensions that satisfy the best performance of the antenna. During the actual operation of the chain drive system, there are obvious contact relations...
between the components such as scraper chain, sprocket, and central groove, and contact pairs are formed between two rigid bodies in arbitrary contact, which play an important role in analyzing the interaction relations of the contacting rigid bodies. By analyzing the geometric position of different rigid body polygon contact planes, the contact collision can be detected. The following analysis of the contact between the driving sprocket and scraper chain and the contact relationship between adjacent scraper chains provides an effective basis for studying the contact collision relationship of different rigid bodies of the chain drive system, as shown in Figure 3.

In the actual operation of the chain drive system, there are obvious contact relations between the components such as scraper chain, sprocket, and central groove, and contact pairs are formed between two rigid bodies in arbitrary contact, which play an important role in the analysis of the interaction relations of contacting rigid bodies. By analyzing the geometric position of different rigid body polygon contact planes, the contact collision can be detected. The following analysis of the contact between the driving sprocket and scraper chain and the contact relationship between adjacent scraper chains provides an effective basis for studying the contact collision relationship of different rigid bodies in the chain drive system. By optimizing the driving node, the mobile node for cavity repair and the optimal repair location are determined to ensure that the area of the cavity to be repaired each time reaches the maximum. The experimental results show that compared with the existing methods, CHDARPI has reduced the average detection time and detection energy consumption by 15.2% and 16.7%, respectively.

In actual operation, chain jamming and chain breakage failures are the most common forms of failure in the chain drive system of the scraper conveyor. In this paper, based on the simulation analysis of the virtual prototype model of the chain drive system under normal operating conditions, the dynamics of the chain drive system when the chain jamming fault and chain breakage fault occur are studied by setting the fault conditions. When the chain jamming fault occurs, it shows the jamming and tensing of the scraper chain; when the chain breakage fault occurs, it shows the sudden breakage of a scraper chain, and the scraper chains at the fault location are separated from each other [20]. These two protocols can effectively reduce the average energy consumption of network nodes, and the data collection rate of both exceeds 88%. To simulate the chain jamming fault condition, the sudden tensioning of the chain drive system can be realized by setting the sudden increase in the stiffness coefficient of the contact pair between the horizontal chain and the vertical chain, and the scraper chains forming the contact pair can be separated by releasing the contact pair between the horizontal chain and the vertical chain, thus simulating the chain breakage fault of the chain drive system [21]. Figure 4 depicts the study process of the dynamic characteristics of the chain drive system under the fault condition. The virtual prototype model of the chain drive system under the fault condition can be established quickly by setting the contact stiffness surge and releasing the contact constraints, and the simulation solution can be realized.

To research the monitoring and diagnosis method of the heavy-duty scraper conveyor chain drive system, the dynamic characteristics of the chain drive system need to be fully considered. At present, the study of dynamic characteristics of chain drive systems based on the experimental method is costly and difficult to operate, so most of the research mostly focuses on model simplification and theoretical analysis of the single-chain system, and the reliability of the research method is low [22]. Considering the complexity of the structural composition of the scraper conveyor and the difficulty of the study of the dynamic characteristics, this section establishes a virtual prototype model of the double-chain traction chain drive system based on the multibody dynamic theory and contact collision theory, which integrates the motion constraints and force relationships between different components and studies the dynamic characteristics of the chain drive system under the conditions of normal operation, chain jamming fault operation, and chain breakage fault operation.

4. Analysis of Results

4.1. Wireless Sensor Network Data Algorithm Results

Figure 5 shows the number of anchor points in the monitoring area for the four algorithms with different MCD charging radii. It can be found that the number of anchor points corresponding to all four algorithms decreases as the charging radius of MCD increases, which is because the charging radius of MCD determines the size of each access cell area, and the larger the charging radius, the fewer anchor points in the monitoring area. To address the problems of high detection energy consumption and long detection time of the existing coverage hole detection algorithm based on boundary node message detection, a coverage hole detection algorithm CHDARPI based on the relative position information of link intersection is proposed, and a hole detection message forwarding mechanism based on node orientation angle adaption is designed to achieve the detection of multiple types of coverage holes based on the relative position information of link intersection in the hole detection message.

To achieve low redundancy and complete repair of coverage voids, a dichotomous-based distributed coverage void repair algorithm CHRAND is then proposed to determine the mobile node and the optimal repair location for void repair by optimizing the drive node, which ensures the maximum area of each repaired void. The experimental results show that CHDARPI decreases 15.2% and 16.7% in the average detection time and detection energy consumption, respectively, compared with the existing methods. When the number of mobile nodes in the network is sufficient, the void repair rate of GRAND can reach 100%, and the repair redundancy does not exceed 0.354, as shown in Figure 6.

To address the problem of data collection rate degradation due to unreliable links, an energy-efficient routing protocol for wireless sensor networks is studied, and a dynamic
hierarchical routing protocol EEDRP combined with a dormancy scheduling mechanism is proposed to minimize node energy consumption by making each node in a low-energy operating mode through the dormancy scheduling mechanism. It further combines node residual energy and link quality to determine the next-hop node forwarding set and reduces data transmission delay while improving data transmission reliability through a $k$-packet retransmission mechanism based on active time slot prediction. Specifically, the relationship between unreliable links and the "energy hole"
of the clustering protocol is analyzed, and the fuzzy logic idea is used to decide the network clustering radius. The experimental results show that EEDRP and UCPFLUL protocols can effectively reduce the average energy consumption of network nodes, and the data collection rate of both protocols exceeds 88%.

In the application of mobile sink banded wireless sensor network based on event monitoring, a mobile sink data collection algorithm DCAFAN based on agent node forwarding is proposed to meet the low latency performance requirement of event monitoring data collection, while the existing data collection technique of building to the sink path can
solve the above latency problem but has the problem of unreliable data transmission. Specifically, DCAFAN constructs a queue of agent nodes that identify the moving trajectory of sink and a sequence of line nodes that store tracking agent nodes, and data nodes transmit data to sink by acquiring tracking agent nodes. The sequence of line nodes and the queue of agent nodes are updated with tracking agent nodes to avoid their death due to energy exhaustion. In addition, a wake-up time-lag difference-based routing method is proposed to assist DCAFAN in solving the problem of excessive node data transmission delay under low duty cycle networks. Experimental results show that DCAFAN has good data collection delay performance while balancing network node energy consumption as well as data collection rate performance.

4.2. Mechanical Chain Drive Optimization Results. Figure 7 depicts the Simulink solution module for scraper chain tension estimation. The solution module takes the drive sprocket torque as the system input, provides the known parameters from the state space equations, and uses the state observer constructed in this study as a tool to estimate the scraper chain tension variation for each discrete unit body from the known state parameters. The results of tension estimation at different contact points of the chain drive system during the 1–3 s stable operation phase are described. Combined with equations (7) and (8), the three-dimensional surface plots of the tension variation at different contact position points estimated by the state observer when taking different values are depicted in the figure. The analysis shows that the tension distribution law of the chain drive system is closely related to the spatial location of the contact points.

At the same moment, along the scraper chain running direction, the tension at different contact points of the upper side chain of the chain drive system increases continuously, and the tension at different contact points of the lower side chain also shows an increasing trend, which is consistent with the theoretical analysis of the scraper chain tension distribution mentioned above. When taking different values, the tension changes at different contact points of the upper and lower side chains also meet the above variation law. For the upper side chain, the minimum and maximum values of tension occur at contact points 1 and 73, respectively, and the minimum and maximum values of tension for the lower side chain occur at contact points 74 and 146, which are consistent with the theoretical analysis of the tension distribution of the scraper chain. For the upper side chain and the lower side chain, the tension of the scraper chain is the smallest at the point where the sprocket engages and separates from the scraper chain, and the tension of the scraper chain is the largest when the sprocket engages and meets the scraper chain; when different values are taken, the location distribution of the maximum and minimum points of the contact force of the upper side chain and the lower side chain also meets the above variation law. Therefore, the scraper chain strains at different locations of the single-chain system measured by the scraper chain strain test experiment and the tensions at different contact locations estimated by the state observer have the same variation characteristics, which further verifies the reliability of the proposed tension estimation method.

The chain drive system is prone to chain jamming failure and chain breakage failure so that the working performance of the whole chain drive system is reduced and the safe production of the scraper conveyor is affected, so it is necessary to provide early warning of the occurrence of scraper chain failure in time to avoid malignant accidents. Based on the research of the scraper chain tension distribution law monitoring method, this section proposes a scraper chain fault diagnosis method based on tension estimation. From Figure 8, it can be obtained that the maximum tension values at different contact points of the upper side chain system are significantly higher than those of the lower side chain system, so the upper side chain system is more prone to damage due to stress concentration. Then, the tension distribution state of the chain drive system is analyzed; at the same time, combined with the theoretical calculation results and the virtual prototype simulation results, the error analysis of the estimated results of the tension change of the scraper chain is carried out, and the strain test experiment of the scraper chain is carried out. Experimental verification is performed. In addition, in the actual production environment, the upper side chain system is more likely to be influenced by external factors and scraper chain failure occurs. Therefore, the contact point of the upper side chain system is taken as the research object to start the research of scraper chain fault diagnosis.

In this section, the tension variation of the scraper chain is estimated based on the state observer, and then, the diagnosis of the chain jamming fault and chain breakage fault of the scraper chain is made. The diagnosis effect is not affected by the fault location and the change of the stiffness coefficient, and it can accurately determine whether the scraper chain is faulty and distinguish the fault type. Combined with the aforementioned study on the characteristics of the scraper chain tension change under fault conditions based on the virtual prototype simulation technology and the analysis of the experimental data of the scraper conveyor chain drive system fault test, it can be seen that in the fault stabilization stage, when the chain jamming fault occurs, the contact force between the monitored scraper chains and the strain of the measured scraper chains increases significantly compared with the normal conditions, and when the chain breakage fault occurs, the strain between the monitored scraper chains increases significantly compared with the normal conditions. In the case of chain breakage, the contact force between the monitored scraper chains and the measured strain of the scraper chains decreases compared to the normal condition. The predicted tension variation patterns of the scraper chain at the fault-prone locations under the chain jamming and chain breakage conditions are consistent with the simulation results of the virtual prototype and the experimental analysis results, which verify the effectiveness of the scraper chain fault diagnosis strategy described in this section.

The state-space equations of the discretized model are established, and the design method of the state observer is studied; the matrix dimensionality reduction algorithm is
proposed, and the tension distribution monitoring method of
the chain drive system based on the state observer is studied,
and the scraper chain tension changes at different position
points of the whole chain drive system are estimated by the
scraper chain tension at finite known position points, and then
the tension distribution state of the chain drive system is ana-
lyzed; meanwhile, the error analysis of the scraper chain ten-
sion changes is carried out based on the theoretical
calculation results and the virtual prototype simulation results.

Meanwhile, the error analysis of the estimation results of the
scraper chain tension variation is combined with the theoreti-
cal calculation results and the simulation results of the virtual
prototype, and the experimental verification is carried out
based on the scraper chain strain test experiment. The error
analysis and experimental verification show that the proposed
tension distribution monitoring method can effectively predict
the tension change of the scraper chain with high estimation
accuracy and reliability and can realize comprehensive
monitoring and analysis of tension change at different position points of the chain drive system with the premise of reducing the number of sensors used.

5. Conclusion

A lot of results have been achieved in various aspects of research on coverage voids and data collection techniques for wireless sensor networks, but as the application scope of wireless sensor networks continues to extend, there are still many critical issues to be addressed to meet the ever-changing application requirements. In this paper, we address the impact of node resource constraints, unreliable links, and coverage voids on data collection performance and study data collection techniques in various application scenarios with the goals of low-energy consumption, low latency, and high collection rate. To address the impact of limited node resources on the data collection performance of wireless sensor networks, the existing mobile device path planning algorithm with combined mobile data collection and wireless charging functions cannot simultaneously solve the problems of low data collection rate and high data collection delay under the continuous operation requirements of the network; this paper proposes a greedy policy-based mobile device path planning algorithm PPAGS. The minimum dwell time and maximum wait time of mobile devices in each access unit are predicted using the Markov model for the dynamic change of parameters such as node energy and data collection, which avoids the mobile devices from moving across a large span in the monitoring area. In addition, the PPAGS algorithm has the advantages of low complexity, and there is no need to obtain the actual location information of nodes and anchors during the operation. The experimental results show that the average data collection delay of PPAGS decreases by 25.9%, the average data collection rate increases by 7% to 98.91%, and the average node failure rate does not exceed 3.1% compared with existing methods.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research was supported by the Zhejiang University Visiting Scholar Project: Research and development of intelligent production line “Digital twins” technology (Project number FX2018140), and the National Natural Science Foundation of China project: Research on the design method of rotary Transplanting mechanism facing the requirements of transplanting track and posture (Project number 51375459).

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