Research on Communication and Monitoring of Construction Machinery under the Framework of Wireless Sensor Network

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Abstract. Aiming at the problem that the current wireless sensor network performance is low and cannot meet the requirements of high-precision synchronous acquisition of mechanical vibration signals, this paper proposes a synchronous acquisition method (SACD) based on cross-layer design. Based on this monitoring mode, an experimental platform is constructed to conduct a vibration signal measurement experiment, and compared with the wired vibration signal test and analysis method. The results show that the vibration monitoring mode based on the wireless sensor network can meet the basic requirements of mechanical vibration monitoring applications.

Keywords: Wireless sensor network, construction machinery, communication and monitoring, machinery vibration monitoring.

1. Introduction

Wireless sensor networks (WSNs) are a new type of information acquisition technology that can perceive and collect information about various environments or monitored objects in real time. It has huge applications in military, industrial, medical, environmental monitoring, traffic management, emergency rescue and disaster relief and other fields. Value and potential application prospects. However, due to the physical dispersion, each independent collection node can only control the collection by maintaining a local clock, and it is difficult to ensure synchronous collection between the nodes [1]. The accuracy of synchronization acquisition directly affects the effectiveness of signal acquisition and the quality of state analysis results. For example, the time difference in the acquisition of vibration data at each measuring point in the experimental modal analysis will cause serious phase errors. In addition, different applications require different sampling frequencies, and high-frequency sampling requires higher synchronization accuracy than low-frequency sampling. According to the characteristics of mechanical vibration monitoring applications, this paper optimizes the wireless sensor network structure and transmission mechanism, and uses the wireless sensor network structure as a breakthrough point to realize mechanical vibration monitoring on the current universal wireless sensor network hardware platform.

2. Cluster tree star hybrid topology

The high sampling frequency of mechanical vibration monitoring will generate a large amount of raw data in a short time, and a too low network data transmission rate will lead to extremely poor timeliness. For this reason, a multi-channel transmission method based on cluster tree star hybrid topology is proposed. After adopting the multi-hop network synchronization acquisition trigger method based on cross-layer design and beacon timing compensation proposed in the previous research to complete the synchronous acquisition of mechanical vibration signals, the gateway sends a data aggregation command beacon [2]. After each routing node receives the convergence command, it first inherits the content of the beacon and forwards it downward, and then uses the distribution channel to build a network. After each collection node receives the aggregation command, it joins the network with its parent routing node channel to construct a single-hop star network as shown in Figure 1.

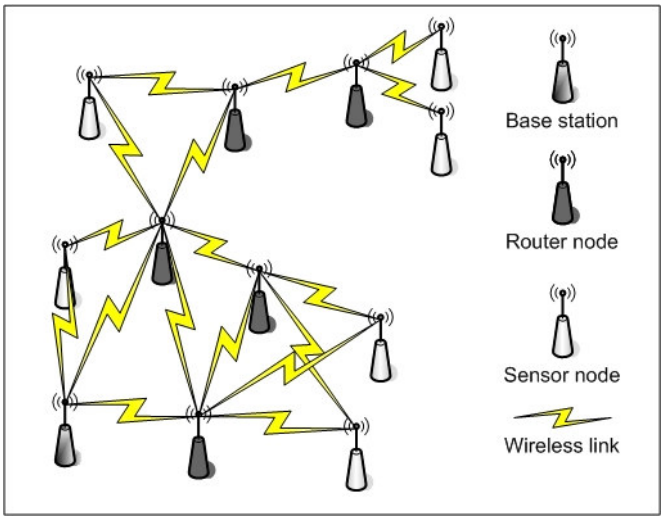


Figure 1. Cluster tree star hybrid topology

The wireless sensor network based on IEEE802.15.4 protocol supports three topological structures: star, peer and tree. The multi-channel transmission method based on cluster tree and star hybrid topology can effectively combine the advantages of tree topology and star topology. On the one hand, the network routing algorithm can be simplified by using the distinct characteristics of the tree topology hierarchy; on the other hand, in the star topology, the underlying TIMAC protocol stack provides periodic synchronization of the entire network under the beacon mode, which is a physical Distributed node provide basic time synchronization conditions to facilitate transmission scheduling of nodes in the tree. In addition, since each routing node uses different channels to establish a network, there is no need to consider how to avoid beacon collisions.

3. Design of wireless network mode for mechanical vibration monitoring

3.1 Design of the collection mode of mechanical vibration signals

In the measurement and collection of mechanical vibration signals, due to the small size of the wireless sensor nodes, the power supply capacity is very limited. The existing MEMS vibration measurement sensors have relatively narrow pick-up frequency bands and are difficult to apply to mechanical vibration measurement. At the same time, the front end of the signal is amplified, Filtering and other reprocessing links require a set of signal reprocessing circuits with low power consumption, low sensitivity to passive components, high gain amplification, and strong denoising capabilities [3]. However, there is no mechanical vibration signal sensor collection suitable for wireless sensor network nodes. According to the characteristics of small mechanical vibration monitoring range and relatively fixed measuring points, the monitoring mode combining the existing vibration measuring sensors, signal reprocessing circuit and wireless network node can be adopted, and the vibration signal can be connected to the front-end circuit after reprocessing. The wireless node performs A/D conversion to complete the collection of vibration data, ensuring high vibration signal quality and collection reliability.

3.2 Mechanical vibration monitoring wireless sensor network system model

The mechanical vibration monitoring wireless sensor network system consists of three parts: mechanical vibration signal collection, data transmission, and data management, as shown in Figure 2 (picture quoted in Wireless Sensor Networks for Condition Monitoring in the Railway Industry: A Survey). The entire monitoring system is a wireless sensor network composed of multiple relatively independent micro monitoring subnets. In the mechanical vibration signal collection part, a certain number of monitoring nodes are distributed in the monitoring area for data collection, and a wireless

sensor network is formed through a certain networking method. Each monitoring node completes the collection of vibration data, and the collected data is sent to the gateway node [4]. The gateway node functions as a data collection point in the network, and is finally transmitted to the data terminal for the next step of data processing, and at the same time, the monitoring terminal receives it through analysis the obtained vibration data can monitor the vibration of mechanical equipment and diagnose the failure of mechanical equipment.

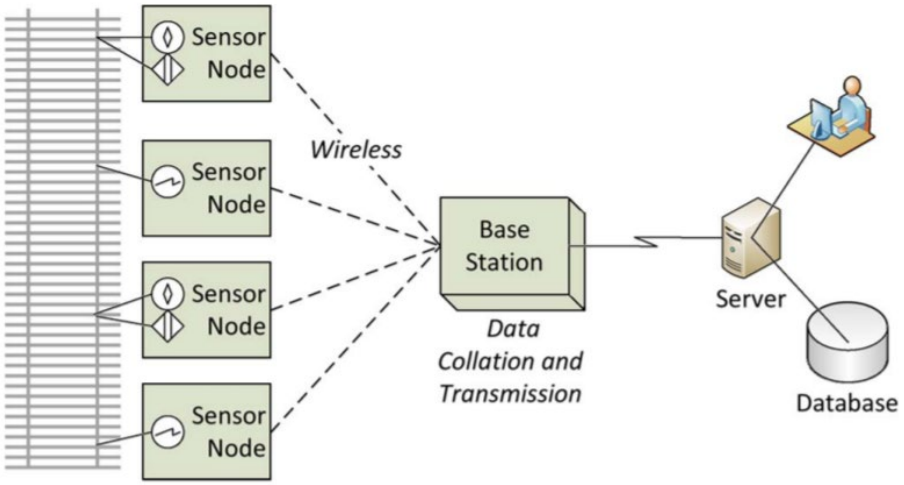


Figure 2. Mechanical vibration monitoring wireless sensor network system model

3.3 Monitoring node hardware design

In a mechanical vibration monitoring system, timely and accurate acquisition of vibration signals is a prerequisite for monitoring and diagnosis. In order to ensure high vibration signal quality and collection reliability, a monitoring mode combining the existing vibration sensor and signal reprocessing circuit with wireless network nodes is adopted, and the collected vibration signals of mechanical parts are reprocessed by the front-end circuit. Access to the wireless network node to perform A/D conversion, and finally complete data transmission through the wireless communication module. The hardware composition of the monitoring node is shown in Figure 3 (the picture is quoted from SLEWS-A Prototype System for Flexible Real Time Monitoring of Landslides Using an Open Spatial Data Infrastructure and Wireless Sensor Networks).

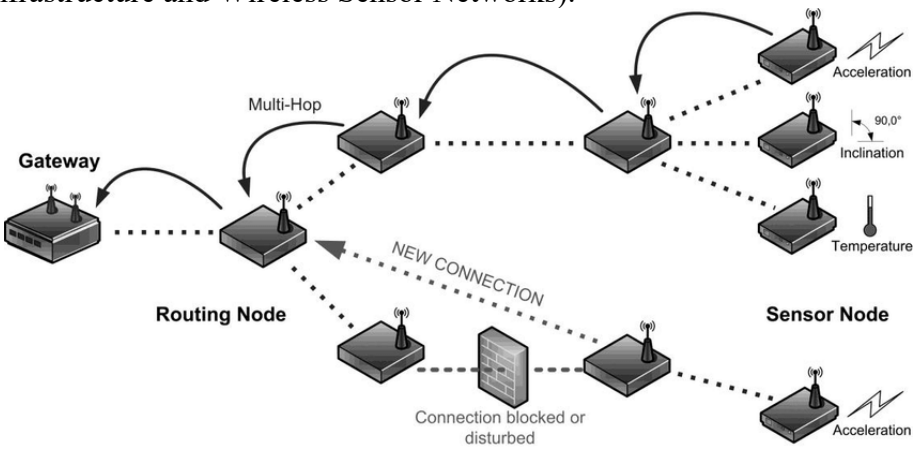


Figure 3. The hardware composition of the monitoring node

4. Dynamic compensation of crystal frequency offset

The synchronization error between the acquisition nodes gradually increases with the acquisition time. The maximum synchronization error at the 10th second is 1260.66 μs (between node 6 and node 2), and the minimum synchronization error is 51.16 μs. However, the synchronization cumulative

error has an almost linear relationship with the acquisition duration, that is, the crystal oscillator frequency offset can be assumed to be a fixed value in a short time. When the node 6 and the node 2 continuously collect for 10s, the relative synchronization cumulative error is 1260.66μs, and the average error of the sampling interval is about 9.85ns. The Timer clock used by the WSNs acquisition node for sampling trigger is 8MHz, and the counting interval is 125ns. The synchronization error will only exceed one counting interval after node 6 and node 2 are collected 13 times [5]. Therefore, the compensation of crystal frequency offset cannot be solved by adjusting the Timer overflow value at one time. The overflow value of the counter needs to be dynamically adjusted during the acquisition process. First, estimate the frequency offset of the crystal oscillator. The sink node periodically sends a beacon frame every 2s. The acquisition node starts the Timer when the first SFD interrupt is detected, and stops the Timer when the sixth SFD interrupt is detected, and records this period of time (10s) the count number of Timer C within. The Sink node sends the standard count number C_0 calculated at the ideal count interval t_0 (here 125ns) during this period to the node, namely:

$$C_t = C_0 t_0 \tag{1}$$

In the formula: t is the actual counting interval of the node Timer, the offset $d_0 = t_0 - t$ that should be compensated for each count, the number of counts h corresponding to each sampling is obtained after the acquisition parameter configuration, and the compensation offset for each sampling is calculated as:

$$d = hd_0 = \frac{C - C_0}{C_0} ht \tag{2}$$

That is, the compensation count value for each sampling is:

$$C_d = \frac{C - C_0}{C_0} h \tag{3}$$

In order to improve the compensation accuracy, the absolute value of the compensation count value of each sampling should be as close to 0 as possible, and the overflow value of the count and the compensation value should be adjusted:

$$\begin{aligned} H &= h + round(C_d) \\ D &= C_d - round(C_d) \end{aligned} \tag{4}$$

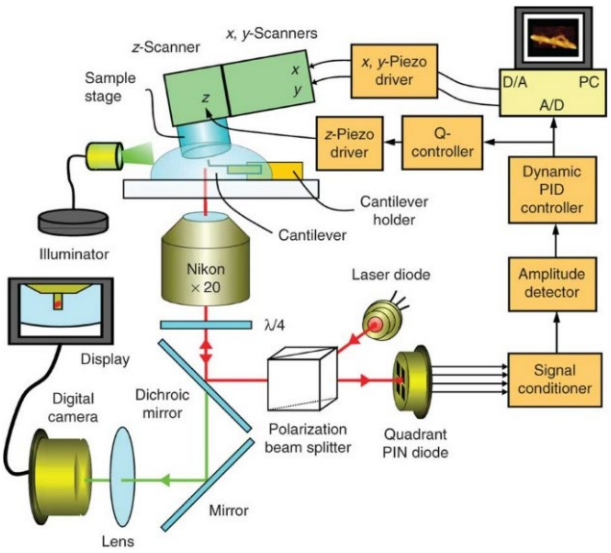


Figure 4. Crystal frequency dynamic compensation process

During continuous acquisition, use R to record the sum of the compensation counts, and update $R_i = R_{i-1} + D$ each time it is sampled, where i represents the i-th sample and the initial value $R_0 = 0$. According to R_i dynamically adjust the sampling trigger count overflow value, the process is shown in Figure 4 (picture quoted in Guide to video recording of structure dynamics and dynamic processes of proteins by high-speed atomic force microscopy). Since the value of the counter in the Timer is

compared with the value of the shadow register, and the count overflow value in the preload register is copied to the shadow register after the next count overflow, it is necessary to update the count overflow value 1 cycle in advance [6]. That is, when $R_i \succ 0.5-D$ (D>0), or when $R_i \leq 0.5-D$ (D≦0), update the overflow value of the count, and restore it in the next sampling.

5. System Test

In order to test the transmission performance of the multi-data gathering point network structure in the wireless sensor network mechanical vibration monitoring system. We deployed 15 measurement points and cooperated with 4 base station nodes to test the vibration signal of a motorcycle frame, evaluate the transmission performance of the network structure of multiple data collection points, and set the sampling frequency of the sensor nodes to 1kHz.

When the data reliability transmission mechanism is not used, the statistical data of the success rate of wireless sensor network data packet transmission is shown in Figure 5. It can be seen that the one-time transmission success rate of data packets is higher than that of the conventional network structure, which is above 90%. After adopting the reliable data packet transmission mechanism, no data packet loss was found in the whole data collection process, indicating that the network transmission mechanism implemented for the multi-data gathering point network structure can meet the data transmission requirements of the vibration signal obtained by 1kHz sampling. Our research found that the time delay of the data packet is low, the maximum data packet time delay is 10.13ms, and the average time delay is 6.35ms, showing good real-time performance [7]. Due to the complex radio frequency environment of the mechanical equipment site, the Micaz node used in this article works in the 2.4GHz wireless transmission frequency band. By comparing with the Mica2 node (working in the 868MHz frequency band), it is found that the wireless signal transmission and reception quality of the Micaz node is higher under the same environment. The wireless signal quality of other frequency bands needs further research. At the same time, node energy limiting factors have a greater impact on field applications. The wireless sensor node uses two ordinary AA batteries for power supply. When the power supply voltage of the node is less than 2.7V, it will cause excessive sampling error. Therefore, during the test, the node is under continuous sampling working conditions. The voltage will drop below 2.7V. In the future system development, the monitoring time can be extended by some technical means such as data compression.

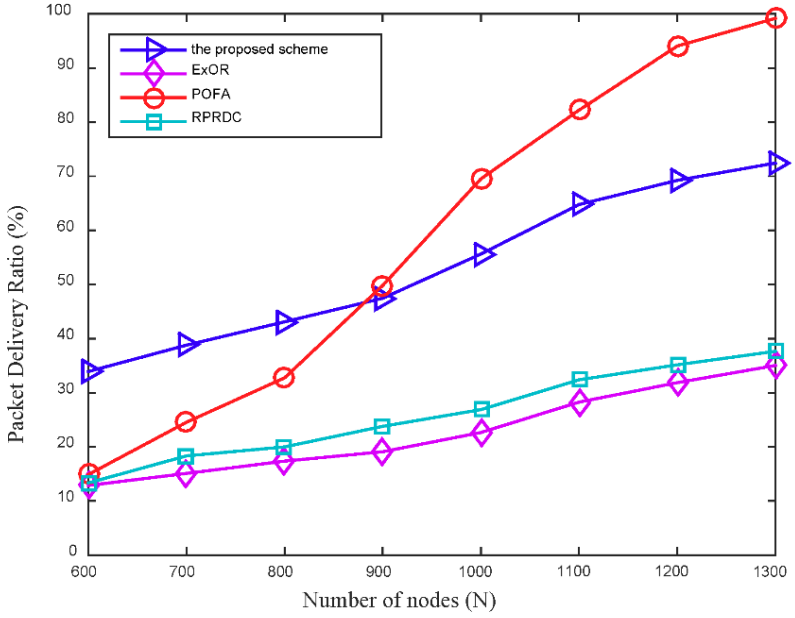


Figure 5. The statistical data curve of the success rate of data packet transmission in the wireless sensor network

6. Conclusion

Based on the detailed analysis of the key technologies of the wireless sensor network in the application of mechanical vibration monitoring, a mechanical vibration monitoring model based on the wireless sensor network was designed, and a comparative analysis was carried out through the construction of an experimental platform, which showed that the wireless sensor network model is in the existing The mechanical vibration test task can be completed under hardware conditions, and the network transmission characterized by multiple data collection points has high reliability and real-time performance.

Acknowledgments

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References

[1] Miao Mingming, Wu Jian. Research on Wireless Sensor Network System for Gun Sound Location. Electronic Design Engineering, 27(1) (2019) 55-62.

[2] Sun Yujia, Yu Jiyan, Wang Xiaoming. Adaptive temperature compensation wireless sensor network time synchronization method. Chinese Journal of Scientific Instrument, 5(1) (2019) 105-112.

[3] Wang Jun, Du Zhuangzhuang, He Zhitao, et al. Construction of a quantitative index system for the invulnerability of a cobweb-like farmland wireless sensor network. Transactions of the Chinese Society of Agricultural Engineering, 35(14) (2019) 95-99.

[4] Cui Yong, Zhang Qian, Fu Li. Experimental teaching exploration of wireless sensor network based on cloud experimental platform. Experimental Technology and Management, 36(9) (2019) 32-34.

[5] Peng Duo, Wang Weizhi, Yun Qi. OSFL-TLBO localization algorithm for wireless sensor network nodes. Journal of Sensor Technology, 33(3) (2020) 75-77.

[6] Zhang Tie, Hong Jingdong, Liu Xiaogang. Demonstration method of robot torque-free sensor drag based on elastic friction model. Transactions of the Chinese Society of Agricultural Machinery, 50(1) (2019) 91-100.

[7] Hong Lin, Li Xu, Wang Shengli, et al. Research on intelligent construction system of construction machinery based on multi-sensor fusion. Modern Manufacturing Engineering, 5(5) (2019) 132-138.