Data transmission system of networked digital voice room based on Internet of Things technology

Jian Du

1 Nanjing Xiaozhuang College, Nanjing, Jiangsu 211171, China

Abstract. In order to solve the problem of poor transmission performance caused by data congestion in network digital language lab, its data transmission system is designed based on the technology of internet of things. In the hardware part, the main control circuit and transmission interface circuit are designed to reduce the signal reflection caused by the change of line width and angle. In the software part, the data transmission compression algorithm is designed to reduce the communication overhead. The internet of things technology is used to set data transmission nodes, and the weighted fairness data transmission protocol is set to control the energy efficiency of transmission. The random key pre-distribution scheme based on the hash key chain is used to construct the data security transmission model. The experimental results show that, compared with the data transmission system based on data mining and cloud computing, the designed system achieves the lowest word error rate and sentence error rate, and has better data transmission performance.

1. Introduction

With the deep development of multimedia teaching technology, many colleges and universities have offered multimedia classrooms to show students digital, information and network teaching classes. By combined with network teaching technology, the network digital language lab is provided to students. Students can gain autonomous feedback in such an interactive teaching lab. The main feature is the introduction of autonomous learning mode into teaching and the specific analysis of extracurricular learning mode. As a classroom aid, the introduction of dynamic content in teacher's explanation can improve students' understanding of knowledge, and also provide students with an autonomous listening teaching form. Network digital language lab is based on the content of network data. The standardized network protocol transforms A/S into voice resources or audio data resources. When it is sent to the user terminal, the sound quality is excellent. It can meet the rich needs of users, and has the function of autonomous learning and interaction. Voice room equipment consists of teacher console, computer, language control system, DVD and so on. For example, it can provide students with calls and control the volume. In teaching foreign language, it can realize multi-functional display and provide students with various forms of English resources and content, which is convenient for students to learn. Network digital language lab has powerful functions, for example, audio and video transmission has high fidelity features, the whole system can eliminate noise, sound quality is clearer. In addition, there are expansionary features, such as, very rich resources in its internal structure, higher degree of freedom. Therefore, when teaching foreign language, teachers are no longer limited to play back tapes. And such lab can be used widely.
In the most of the application scenarios of network digital language lab, there are high requirements on the quality of voice or audio and video, so it is necessary to collect audio and video signals with high standards. However, the amount of original data obtained is often large, which brings great pressure to the subsequent audio and video transmission and storage. With the continuous growth of data, the requirement on transmission speed is also increasing. In order to realize the high-speed acquisition and transmission of enormous data information, it is necessary to design a data transmission system with an efficient transmission function [1]. By applying Internet of things technology, we can use terminal devices with sensors to collect data information in real-time and build a wireless transmission network to complete data transmission. Therefore, this paper designs a data transmission system of network digital language lab based on the Internet of Things technology. What’s more, it can further promote the development of interactive dynamic teaching, and then improve the quality of multimedia teaching.

2. Hardware design of data transmission system in network digital language lab

Hardware circuit design is the foundation of system construction. According to the performance index and the design scheme, this chapter discusses the hardware architecture corresponding to the system function, and analyzes and designs the hardware circuits of each part of the system. The following is a detailed description of the main control circuit and transmission interface circuit. The main control circuit is the core of the system control, and it is the key to the normal operation of the hardware function of the whole system. Before the circuit design, the main control chip is selected. Considering the variety of choice, as well as the technical support and reliability in practical application, this paper selects FPGA of Xilinx Company as the core of system control. We mainly consider the number of internal basic resources when selecting FPGA such as high-speed serial transceiver, BRAM logic block, internal logic unit, and the maximum line rate of serial transceiver. And Xilinx 28 nanometer FPGA Series 7 is a generation of products, which is in line with the requirements of transmission system [2]. The XC7K325TFFG900-2 of Kintex-7 series is considered as the main control chip. FPGA is based on SRAM structure to realize programmable characteristics, so it needs external memory and corresponding configuration circuit to ensure the loading of logic program after being powered on. The common configuration modes of FPGA are JTAG mode, mainly SPI and BPI. The configuration is carried out through M0, M1 and M2 signal pins of CONTG Bank on FPGA. JTAG mode is online debugging mode. After power on, logic program can be written to FPGA by computer. The main SPI mode is that FPGA reads configuration data from the corresponding SPI FLASH chip through traditional SPI interface. The main BPI mode is that FPGA can read configuration data from the corresponding NOR FLASH in parallel, which is the fastest configuration mode in chip design. The system is designed to interconnect with the computer through PCI Express bus. According to the protocol, PCI Express equipment must be started and initialized within 100ms after power on. Therefore, the main BPI and JTAG mode are used as the configuration mode of FPGA.

Transmission interface circuit is the key for data transmission system. The ADC 16DX370 of TI company is selected as the ADC of the system. The converter can carry out two channel sampling at the same time, and the integrated input buffer can eliminate the charge feedback noise of switched capacitor sampling circuit. The JEDS204B interface can be configured with one or two channels per channel to cope with the link transmission of different line rates. Since the external analog input signal is a single ended signal, it is necessary to convert the single ended input signal into a differential signal input converter in order to reduce the signal imbalance distortion as much as possible. JESD204b interface mainly includes synchronous request input interface SYNCb and serial data output interface. As a part of JESD204B interface, SYNCb signal is used to send synchronization request from FPGA to converter. The internal circuit structure of SYNCb signal input terminal is shown in Figure 1.
Two differential terminating resistors provide 100Ω differential impedance, and the voltage divider at the back makes it have a wide common mode voltage input range, which can be compatible with common logic levels, including LVDS and LVPECL. Since SYNCh is not a high-speed signal, it is designed to be connected to the HR Bank of FPGA. HR Bank supports a wide range of logic level standards, including 2.5V IO level matching with the reference voltage of SYNCh internal voltage divider structure. In PCB routing, the differential impedance of the transmission line is 100Ω to match the impedance of the receiver. The serial data output interface is the main functional part of JESD204B interface, and its physical link rate can reach up to 7.4Gbps [3]. In view of the high signal frequency of the interface, signal integrity should be considered in PCB design. Specifically, the circular arc routing is adopted in the serial data differential transmission line to ensure the same length and layer, and minimize the characteristic impedance inconsistency and signal reflection caused by the change of line width and angle. The distance between the serial channels should be 3 times or more than that of the differential transmission line to reduce the crosstalk. The characteristic impedance of the differential transmission line is controlled to 100Ω to ensure the impedance matching of the high-speed transmission line.

3. Software design of data transmission system in networked digital voice room

3.1. Design of data transmission compression algorithm

A large number of network nodes with short-range wireless communication monitor a geographical area cooperatively, and transmit the sensing data to the sink node through self-organizing hop by hop forwarding. In order to obtain real-time, accurate and continuous information data, the transmission system adopts the method of high-frequency sampling, and obtains the detailed and accurate basic data distribution, but this will lead to excess data [4]. Even if each transmission node records several bytes per second, it will generate several GB of data in a short time, which will bring great communication overhead to nodes with limited energy. Data compression is a popular method to reduce communication overhead. Due to the high complexity of wavelet transform and the need for high computing and storage requirements, it is not suitable for the transmission system software design in this paper [5]. In this paper, the piecewise linear approximation method is used to design data transmission compression algorithm. The piecewise linear approximation method divides the time series into some segments, and each segment data point is approximately described by a line segment. The data transmission compression algorithm designed in this paper can approximately describe a time series with unconnected line segments in linear time and ensure the accuracy of the error. The main idea is briefly described below. Given a time series, a maximum error bound is made. Starting from the first data point, the algorithm greedily scans the data points in the sequence in order until a data point is scanned, so that all the data points before the data point can be approximately described by a line segment, and the accuracy is guaranteed. But if this data point is added, there is no line segment
that can approximately describe all the data points that are not approximately described. The approximate value of data points can be calculated by the following formula:

\[ u(t_i) = v(t_a) + \frac{v(t_p) - v(t_a)}{t_p - t_a} (t_i - t_a) \]  \hspace{1cm} (1)

In formula (1), \( u \) represents the approximate value of the data point; \( t \) represents finite time series; \( i \) represents the serial number of the data point; \( v \) represents the actual monitoring value of the node; \( \alpha \) represents the beginning and end of time series; \( \beta \) represents the end point of the time series. In the vertical direction, the maximum distance between the approximate value of the data point and the line segment \([t_p - t_a]\) is less than or equals to the set maximum error. In this way, for the whole time series, we only need to record the start time of the first line segment, the end time of each subsequent line segment, and the slope and intercept of each line segment. In this way, all data points before the last data point are approximated by a line segment, and then greedy scanning is performed from the last data point until the end of the whole time series [6]. By compressing the amount of data transmission, the energy consumption is reduced. It can reduce the communication overhead.

3.2. Setting node transmission protocol based on Internet of Things Technology

Generally speaking, a transmission network is composed of several common nodes and at least one sink node. The nodes form a network through self-organization. In the transmission network, each node can only communicate with a few hop nodes nearby, and the data can only reach the sink node through the intermediate node through multi-hop forwarding. When the packet receiving rate of a node is greater than its forwarding or scheduling rate, it is necessary to cache the excess packets [7]. When the queue of buffered packets is full, the excess packets will be discarded, causing congestion problems in the transmission network. In this regard, the Internet of things technology is used to set data transmission nodes, and the weighted fairness data transmission protocol is set to control the energy efficiency of data transmission. There are two main indicators to measure the effectiveness of congestion control protocol. One is quality of service, including throughput and delay, the other is, weighted fairness. At present, most congestion control protocols mainly consider the quality of service, but seldom consider how to ensure the weighted fairness of data transmission. Ensuring weighted fairness can make sink nodes get more packets from important data sources. In this paper, the transmission node is set based on the Internet of things technology, so that the sink node receives more packets from important transmission nodes [8]. Each node is given a weight. The larger the weight, the more important the data generated by the node. The following formula is used to measure fairness:

\[ g = \left( \frac{\sum_{j=1}^{s} m_{j,} / \chi_j}{s \sum_{j=1}^{s} (m_{j,} / \chi_j)^2} \right)^2 \]  \hspace{1cm} (2)

In formula (2), \( g \) represents transmission fairness; \( s \) is the total number of nodes; \( j \) represents the node serial number; \( t \) represents the transmission time; \( m \) is the number of packets received by sink node from common node; \( \chi \) represents the weight of the node. The congestion measure is the average packet rate of the incoming node divided by the average packet rate of the outgoing node. The calculation formula can be expressed as follows:

\[ y(j) = \frac{t_j(n)}{t_j(n+1)} \]  \hspace{1cm} (3)
In formula (3), \( y \) represents congestion degree; \( t_j(n) \) is the average service time of packets; \( t_j(n + 1) \) represents the average arrival time of packets; \( n \) represents the number of newly received packets. Adjust the packet rate of the incoming node, so that the number of packets received by the common node per unit time is proportional to the weight value size [9]. Therefore, the weighted fairness data transmission protocol can be adjusted adaptively according to the network changes, which provides dynamic indication information for congestion control.

3.3. Construction of data security transmission model
While improving the efficiency of data transmission system, it is also necessary to ensure the security of data transmission. Through the description of data transmission mode, the specific process of data security transmission model is explained. During the data transmission, it may attack a node in the transmission process, or tamper with the data. The anti-attack key distribution scheme based on deployment non-overlapping key pool is used to manage all communication keys between nodes in the process of data transmission. It is guaranteed that the transmission result will not be changed because the adversary tampers with a node. In some applications of data security transmission, the actual location of nodes can be predicted before the actual deployment. The key pre-distribution scheme based on node deployment knowledge improves the local connectivity of nodes and network security. Suppose that the node is statically processed after deployment. The deployment area is a two-dimensional rectangular area, and the node location probability can be regarded as a two-dimensional Gaussian distribution [10]. The sub key pool of each unit is divided into three non-overlapping sub key pools. Random key pre-distribution scheme using hash key chain. The specific implementation process is as follows: (1) key pre-distribution stage. The first step is to select the first key of a group of key chains. The first key is randomly selected in the key pool. The hash function is used to generate a set of fixed length key chains, and then each key in the key chain is assigned a unique ID, which needs to be a continuous sequence. The second step is to generate the key ring of the node. Nodes in the network need to store their own key and identity identifier. (2) Shared key discovery phase. The communication between nodes \( P \) and \( Q \) is illustrated as an example. If a key stored in node \( P \) and node \( Q \) is on the same key chain, the key identity identifier of the two nodes is determined. The communication key of the two can be expressed as:

\[
K_{PQ} = h(K'|P|Q)
\]  

(4)

In formula (4), \( K_{PQ} \) is the communication key of nodes \( P \) and \( Q \); \( h \) is Hash function; \( K'|P|Q \) represents the identity identifier of nodes \( P \) and \( Q \). When calculating the communication key, the key with larger ID is usually used to calculate, so the calculated communication key is the same. (3) Path key establishment phase. After the deployment of the data security transmission model, if there are two nodes in the communication range that can not directly establish a communication connection, then it is necessary to establish a communication key through the intermediate node. In the communication, it is agreed that the communication key of the two nodes is generated by the calculation of the relatively large ID, and transmitted to the node with relatively small ID through the third party. (4) Key enhancement phase. The key used to establish communication with neighboring nodes is from the key ring, which may be captured by the attacker. If there is a node captured by the enemy in the network, the probability of a key leakage in the key pool is:

\[
p = \left(1 - \left(1 - \frac{u}{o}\right)^e\right)^r
\]  

(5)

In formula (5), \( p \) represents the probability of data transmission being destroyed; \( u \) represents the number of keys selected by the node; \( o \) represents the total number of key pools; \( e \) is the total number of nodes. In order to enhance the anti-capture ability of nodes, the key enhancement phase is
added to the model. After establishing the communication key among adjacent nodes, Hash function is used to calculate the identifier of each key stored in each node. After calculation, the original key is deleted. In this way, even if the node is captured, it can not decrypt the original key, so as to ensure the security of data transmission.

4. Experiment

4.1. Experimental preparation
This paper designs the data transmission system of network digital language lab from both hardware and software aspects, and carries out the experimental test below. The data used in this experiment is provided by a domestic educational technology company in an online education platform. The original data is the video course of online education in middle school, including mathematics, physics, chemistry and other main subjects in middle school. Firstly, the audio stream in the video is extracted. The audio data format is single channel, and the sampling frequency is 18000Hz. Secondly, the audio is divided into speech segment and non-speech segment by manual cutting, and the speech segment is retained. The duration of each audio after cutting is between 5s and 30s, which ensures the semantic integrity of the audio content. The voice segment audio data is taken as the test set of this transmission system test, which contains about 1 million Chinese words. The dynamic test method is used to test the operation of the system, and the results are shown in Figure 2.

![Figure 2. Concurrent response test](image)

According to the system performance test results in Figure 2, the concurrent response time is less than 2.5s, which meets the system design requirements. In large concurrency, the system still has good stability and carrying capacity, and can support voice room data transmission. Based on the system performance test, the voice data transmission ability of the system is further verified.

4.2. Experimental result
This experiment selects word error rate and sentence error rate as evaluation indexes to evaluate the system's voice data transmission ability. The word error rate and sentence error rate are compared under the labeled speech of the test set after word segmentation and the speech data transmitted by the system, and the minimum editing distance is calculated for the word error rate. The calculation formula is as follows:

\[
\begin{align*}
\lambda_1 &= \frac{r + f_1 + I_1}{S} \\
\lambda_2 &= \frac{f_2}{I_2}
\end{align*}
\]  

In formula (6), \( \lambda_1 \) and \( \lambda_2 \) are the error rate of word and expressing sentences; \( r \) is the number of wrong words inserted; \( f_1 \) and \( f_2 \) are the number of words and sentences with deletion errors; \( I_1 \)
represents the number of words that are replaced incorrectly; $S$ refers to the number of manually labelled words after word segmentation; $l_2$ is the number of all sentences in the test set. The lower the above two evaluation indexes, the better the performance of voice data transmission. We firstly select the data transmission system based on data mining and cloud computing as the control group, and then compare it with the system based on the Internet of things. The experimental results are shown in Table 1.

| Size (GB) |
|---|
| 258 |
| 296 |
| 182 |
| 157 |
| 163 |
| 172 |

Table 1. Test results

| Size (GB) | Data transmission system based on Internet of things technology | Data transmission system based on data mining | Data transmission system based on cloud computing |
|---|---|---|---|
| | Word error rate (%) | Sentence error rate (%) | Word error rate (%) | Sentence error rate (%) | Word error rate (%) | Sentence error rate (%) |
| 258 | 18.56 | 28.62 | 26.23 | 36.24 | 29.04 | 40.09 |
| 296 | 20.21 | 28.14 | 28.14 | 38.37 | 29.61 | 39.62 |
| 182 | 17.94 | 28.48 | 29.56 | 37.52 | 29.32 | 40.34 |
| 157 | 18.36 | 27.72 | 28.87 | 38.85 | 29.23 | 40.27 |
| 163 | 19.29 | 28.23 | 27.62 | 38.28 | 29.58 | 40.55 |
| 172 | 20.06 | 27.65 | 28.28 | 39.62 | 28.81 | 39.86 |

According to the comparison results in Table 1, the word error rate of the data transmission system based on Internet of things technology is 19.07%, which is 9.05% and 10.2% lower than that of the data transmission system based on data mining and cloud computing. The sentence error rate of data transmission system based on Internet of things technology is 19.07%, which is 10.01% and 11.98% lower than that based on data mining and cloud computing. There are differences in the performance of voice data transmission among the three systems. The system achieves the lowest word error rate and sentence error rate in the test set. Therefore, the design system has good data transmission performance, and can output and input voice data more accurately.

5. Conclusion

Based on the Internet of things technology, this paper designs the data transmission system of network digital language lab. The experimental results show that the system reduces the word error rate and the sentence error rate of voice data, and achieves accurate data transmission. The research work of this paper is only a part of many data transmission systems, and the work done is very limited. We will further study and improve its data transmission system in the following work and make an in-depth study of the relationship between other swarm intelligence optimization algorithms and data transmission mode. This paper aims to find a key management scheme with good network scalability and low resource overhead, and explore the relationship between the node density and attack probability of nodes deployed in real-time application in the transmission network.

References
[1] Li L, Liu L, Peng H, et al.(2019) Flexible and Secure Data Transmission System based on Semi-Tensor Compressive Sensing in Wireless Body Area Networks[J]. IEEE Internet of Things Journal, 6(2):3212-3227.
[2] Wanchun, Liu, Petar, et al.(2019) Wireless Networked Control Systems With Coding-Free Data Transmission for Industrial IoT[J]. IEEE Internet of Things Journal, 7(3):1788-1801.
[3] Sargolzaei A, Yazdani K, Abbaspour A R, et al.(2019) Detection and Mitigation of False Data Injection Attacks in Networked Control Systems[J]. IEEE Transactions on Industrial Informatics, (99):1-1.
[4] Bansal K, Mukhija P.(2020) Aperiodic sampled-data control of distributed networked control systems under stochastic cyber-attacks[J]. IEEE/CAA Journal of Automatica Sinica, 7(4):1064-1073.

[5] Dmitriev A S, Mokhseni T I.(2021) Multiple Access in Relative Information Transmission Systems with Chaotic Radio Pulses[J]. Journal of Communications Technology and Electronics, 66(5):599-605.

[6] Elhoseny M, K Shankar.(2020) Reliable Data Transmission Model for Mobile Ad Hoc Network Using Signcryption Technique[J]. IEEE Transactions on Reliability, 69(3):1077-1086.

[7] Y Harbi, Aliouat Z, Refoufi A, et al.(2019) Enhanced authentication and key management scheme for securing data transmission in the internet of things[J]. AD Hoc Networks, 94(Nov.):101948.1-101948.13.

[8] Anh-Huy, NGUYEN, Yosuke, et al.(2019) Adaptive Channel Access Control Solving Compound Problem of Hidden Nodes and Continuous Collisions among Periodic Data Flows[J]. IEICE Transactions on Communications, E102. B(11):2113-2125.

[9] Tai W L, Chang Y F, Hou P L.(2019) Security Analysis of a Three-factor Anonymous Authentication Scheme for Wireless Sensor Networks in Internet of Things Environments[J]. International Journal of Network Security, 21(6):1014-1020.

[10] Bulfone A, Drioli C, Ferrin G, et al. (2020) A scalable system for the monitoring of video transmission components in delay-sensitive networked applications[J]. Multimedia Tools and Applications, 79(25):18727-18745.