Low power consumption Internet of Things and its core sensor package technology in underground pipe gallery

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Abstract: Underground pipeline corridor is a part of the construction of Smart City. There are many kinds of pipelines in it. Because of the complex air composition and special space structure, it is impossible to carry out high-frequency manual maintenance. Therefore, in order to ensure the safe operation of pipeline corridor, it is necessary to monitor its working environment in real time. In this paper, a low-power Internet of Things (IOT) system is designed for the special environment of underground pipeline gallery. The system’s network is built by low-power ZigBee module. Cooperated with micro-sensors, it can monitor the environment of pipeline gallery in real time, and the low-power of the system can make up for the long-term unattended situation of pipeline gallery. This paper also designs a sensor packaging technology for this environment, which protects the sensor from corrosion in the corridor environment without affecting the smooth network. Finally, the material is tested.

1. Introduction
Underground pipeline corridor is one of the key points in the recent development of Smart City in our country[1]. Because there are many kinds of pipelines in the underground pipeline gallery, once an accident occurs, it can easily lead to collapse of each supply system. Therefore it is necessary to establish a wireless sensor network to monitor the operation of the pipeline gallery in real time[2,3]. However, because of the complex environment of underground pipeline gallery, it is impossible to carry out frequent equipment maintenance, so the low power consumption of the system is highly required. And the environment is destructive to sensors, so special sensor encapsulation technology is needed to ensure that sensors are not eroded by the corridor environment and the IoT system can communicate normally. At present, the low power consumption IoT system for underground pipeline galleries is not mature enough, and the nodes and power consumption can not be reduced, which leads to high operating costs. The unique environment also makes frequent maintenance difficult to implement, and it is difficult to balance equipment protection and communication quality.
In order to reduce the power consumption of a large number of nodes in the IoT operation, the system uses ZigBee protocol as the network support, and combines various sensors to form a low-power ZigBee IoT system. The system contains many terminal nodes. The various types of sensors built in the nodes can measure the temperature, humidity, acoustooptic, gas, pressure and other physical parameters in the surrounding environment in a full period of time[4]. Each node in the system is equipped with ZigBee module, which provides wireless communication. Through its own self-organizing network technology, a ZigBee IoT system is formed. The sensor completes some data acquisition work on time, then transmits information to the main node by different nodes of ZigBee network, and finally summarizes it to the data monitoring center[5]. Through the data monitoring center, we can understand the changes and trends of various environmental factors, their temporal changes and spatial distribution, so that we can prevent potential accidents and deal with them in time[6,7].

2. System structure and function realization
The whole system is divided into three parts: perception layer, transmission layer and application layer.

2.1. Perception layer

2.1.1. The sensors. To make sure we can accurately know about the underground pipe gallery in the actual environment as much as possible. It is needed to use a variety of miniature sensors, such as gas sensors, combustible/toxic gas sensors, pressure sensors, temperature and humidity sensors, etc. to detect the gas pipeline, transmission pipeline, communication pipelines, water supply and drainage pipelines on temperature, humidity, light, gas, pressure and so on. Due to its special environment, the underground pipe gallery will be unmanned for a long time, which is difficult to maintain the devices. And there are a large number of sensors at each terminal node. So we need to reduce the power consumption by using microsensors, and then we can supply the power by batteries[8].

2.1.2. The encapsulation of terminal nodes. The underground pipe gallery has complex environment, various air components and high humidity. The long-term exposure of the sensor to this environment will cause corrosion to the circuit. It will seriously affect the operation of the sensor and the ZigBee module and reduce its service life and system stability. The manpower and financial costs will be indirectly increased in the meanwhile. Therefore, it is necessary to adopt appropriate packaging technology to protect the sensor from external erosion, and at the same time, it is necessary to ensure that the ZigBee module has good communication capability without increasing power consumption under this package.

2.2. Transmission layer

2.2.1. ZigBee. Among the three wireless data transmission technologies of wifi, bluetooth and ZigBee, ZigBee is a low-power personal area network protocol based on the IEEE802.15.4 standard[9]. It is characterized by close proximity, low complexity, self-organization, low power consumption, support for a large number of nodes, and support for multiple network topologies[10,11,12]. Therefore, using the ZigBee technology of the IoT wireless data terminal module, the self-organizing network function of the multi-data module can be realized, and then the wireless network data technology such as multi-point parallel monitoring, data parallel transmission and network intelligent assembly can be realized in the underground pipe corridor monitoring process[13].

In order to achieve low power consumption of the network, the ZigBee module can be designed with CC2530 chip. It can work in dormancy mode with very low power consumption, so the dormancy time of ZigBee module can be set reasonably through the design of software level, which not only ensures its normal operation, but also maximizes the reduction of power consumption. Of course, the network power consumption can also be reduced by optimizing the time synchronization algorithm.
2.2.2. System networking. Devices in a ZigBee network can be divided into three parts: a coordinator node, a routing node, and a terminal node. The coordinator node is the key to the node’s access to the network, and is also the control center of the entire network, responsible for the establishment of the network and the allocation of PAN_ID. The routing node has a routing function, which can be connected to the network through the coordinator node, and is mainly used to transmit data and function as a transit station. The terminal node is composed of sensors and wireless devices. It accesses the network through the coordinator node, and is mainly responsible for the collection of terminal data[14].

First, to build a ZigBee network, we need to find a coordinator node, then scan the channel, set PAN_ID, and initialize the network. When the coordinator initializes the network, the nodes that want to join the network can establish a connection with the coordinator [15]. The steps are as follows: (1) searching the coordinator node; (2) requesting connection; (3) waiting for connection response; (4) requesting data; (5) entering the network.

2.3. The application layer
The application layer is to analysis the data collected by the sensor network and display it by using the humanized interactive interface. It is convenient for staff to understand the real-time environment of underground pipeline gallery [16], understand the trend and change trend of environmental data, and help to predict the occurrence of accidents in advance and deal with them in time.

3. Experiment

3.1. Testing of encapsulation material’s wave transmission performance
Because of the complex environment of underground pipeline gallery and the strong corrosiveness of air, in order to ensure the normal operation of sensors and ZigBee modules, it is necessary to encapsulate each terminal node. When choosing packaging materials, the influence of materials on the communication performance of ZigBee module must be considered. Polytetrafluoroethylene (PTFE), polyethylene terephthalate (PET), polyvinyl chloride (PVC) and acrylonitrile-butadiene-styrene copolymer (ABS) with anticorrosive properties can be selected.

3.1.1. Method. The coaxial transmission/reflection method is used in this test. The coaxial transmission/reflection method is to process the sample to be measured into a circular ring of a certain size and put it into the cavity formed by the coaxial connector to form the S parameter measurement system. According to the transmission line theory, the whole coaxial line is equivalent to a two-port network with reciprocal symmetry. The network parameters of the two ports are measured by vector network analyzer. The complex permittivity and permeability of the material are inverted according to the reflection and transmission parameters and the NRW algorithm. The test scheme is as follows:
Table 1. Coaxial waveguide test scheme

| Existing equipment          | ROHDE&SCHWARZ ZVA24 10mhz-24ghz                     |
|-----------------------------|----------------------------------------------------|
| Add equipment               | SMA-type coaxial connector to N-type coaxial connector |
| Sample size                 | The outer diameter is 7 mm, the inner diameter is 3.04 mm, and the ring (the sample conforms to the size of N-joint). The thickness is 1 mm, 1.5 mm, 2 mm, 2.5 mm and 3 mm. |
| Sample material             | PTFE, ABS, PVC                                      |
| Number of samples           | 5 sizes for each material, total 5*3=15 samples     |
| The position of the sample  | The cavity formed in the inner part of the coaxial connector of the male head and the coaxial connector of the female head. |
| Parameters to be measured   | Parameter S (S11, S21)                              |
| Test power                  | 0.5 W (if the actual situation cannot be reached, it can be adjusted appropriately) |
| Test frequency              | 2.4 GHz frequency point                            |

The test steps are as follows:
A. Preheating VNA for half an hour, connecting coaxial line during preheating;
B. The test frequency is 2.4 GHz point frequency and the power is 27 dBm.
C. Using TRL method to calibrate VNA;
D. Connect the SMA to N coaxial joint with the original SMA coaxial connector (i.e. connect the coaxial line of VNA port 1 to port A of the test fixture shown in Figure 1 and the coaxial line of VNA port 2 to port B of the test fixture shown in Figure 1)
E. The PTFE shown in Figure 2 is marked as PTFE_10; PTFE_15; PTFE_20; PTFE_25; PTFE_30 according to thickness.
1. Put PTFE_10 into the test fixture, tighten the fixture, and measure S parameter, which is recorded as S_PTFE_10_1.
2. Loosen the clamp screw, tighten the screw, and measure S parameter, which is recorded as S_PTFE_10_2.
3. Loosen the clamp screw, tighten the screw, and measure S parameter, which is recorded as S_PTFE_10_3.
4. Remove PTFE_10.
Repeat the above operations on PTFE_15, PTFE_20, PTFE_25 and PTFE_30 and record the corresponding data.
Continue to measure ABS and PVC with the above methods.
3.1.2. Test results. The coaxial waveguide test system is composed of ROHDE&SCHWARZ ZVA24 10MHz-24GHz vector network analyzer and N-type coaxial test fixture. The sample is placed in the cavity formed by N-type coaxial test fixture. The transmission parameters S21 and reflection parameters S11 of the sample are measured. The results of the samples with different thickness are as follows:
3.2. The conclusion of experiment

From Figure 3 to Figure 5, it can be seen that the transmission coefficients of the three materials are getting lower and lower with the increasing of the frequency of electromagnetic wave, and the transmission coefficients will also decrease with the increasing of the thickness of the samples. The reflection coefficients will increase roughly at the same frequency. From Figure 6, it can be seen that PTFE has the best transmission coefficient at the same frequency, followed by ABS sample and PVC sample, and the reflection coefficient of three samples with 1 cm thickness will have a peak at about 1.5 GHz, but it is basically the same at 2.4 GHz.

Sensor packaging materials should be guaranteed to reduce the thickness as much as possible under a certain mechanical strength. It is necessary not only to ensure that the protective enclosure can resist certain impact, but also to minimize the impact of the enclosure on wireless signal transmission. The experimental results show that the PTFE with 1 mm thickness is the most ideal. Under the protection of this shield, the ZigBee module can achieve normal communication without increasing power, and the external environment will not damage the structure of the module, the working status will not be affected, so as to ensure the normal operation of the low-power IoT system of underground pipeline gallery.
4. Conclusion
Using wireless sensor network to construct underground pipe gallery environment stereoscopic monitoring system is one of the hot research directions in the construction of underground pipe gallery nowadays. It integrates sensor technology, embedded processor technology, distributed information integration technology and communication technology. It can monitor, perceive and collect information of various environmental monitoring objects in the distribution area of network remotely and in real time, which is helpful for the establishment of underground pipe gallery. So it is of great significance for intelligent environmental monitoring system of underground pipeline galleries.

The system uses ZigBee technology and sensors to form a low-power sensor network. Using the self-organizing network capability of ZigBee technology, the network topology structure is formed. ZigBee module is composed of designated chips. It combines with reasonable dormancy time setting, small low-power sensors and appropriate packaging technology to solve the problem of high power consumption of nodes, and also ensures the stability and efficiency of data transmission. It can realize all-round and real-time monitoring of underground pipe gallery environment, effectively avoid accidents and ensure the stability of underground pipe gallery.

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