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无线无源预应力传感器的研究

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摘要: 无线无源预应力传感器可以有效地监测混凝土中钢筋预应力的变化情况, 在建筑结构的健康性检测中有重要作用。首先, 介绍无线无源预应力传感器的整体工作流程框架, 主要由外部读取器和介质内预应力传感器组成。具体介绍了各个工作模块的实现原理和实现方案。随后, 对该无线无源预应力传感器进行实物测试, 验证该传感器在空气和混凝土介质中的工作性能, 并分析了误差来源。所设计的无线无源预应力传感器的工作距离在 30cm 以上。

关键词: 建筑健康性检测; 无线无源预应力传感器; 耦合谐振距离

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0 引言

目前建筑结构的健康性监测是一个较新的领域^[1]。实时地检测桥梁、房屋、道路内部结构的预应力变化, 能提前了解建筑的安全性, 预防发生建筑倒塌等安全事故^[2]。但是, 现有的健康性检测设备都是有源有线的预应力传感器, 有线使传感器在建筑中的部署变得困难, 特别是要置于建筑内部的传感器; 而有源使得传感器的应用时间变得有限, 维护需要较大成本, 同时, 建筑内部的传感器一旦能量耗尽, 将无法重用, 造成浪费^[3]。

为了克服现有建筑健康性监测传感器有线、有源的不足, 本文提出一种无线无源预应力传感器, 该无线无源预应力传感器能吸收外部的无线能量为自身供电, 同时, 采用低频无线信号将收集到的数据发送给外部的数据采集设备。该预应力传感器部署将减少对建筑结构本身的破坏, 使用时间长久, 维护方便。

本文首先介绍无线无源预应力传感器的整体工作流程框架, 然后对各个模块进行实现原理的介绍, 包括能量传输模块、电源模块、调制模块、数据采集和处理模块, 再对该传感系统进行实物测试和分析, 最后对该无线无源预应力传感器的作进一步展望。

1 整体框架

无线无源预应力传感系统主要分为外部模块和内部模块 2 大部分, 具体见图 1 所示:

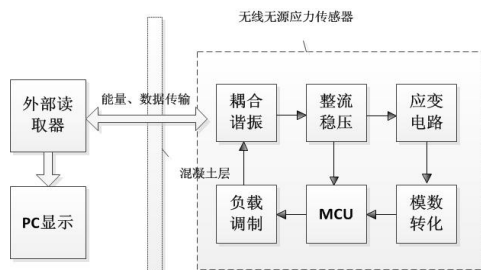


图 1 无线无源预应力传感系统的整体示意图

外部读取器主要用于能量的供给和数据的接收, 并在 PC 端显示结果。内部模块主要分为能量接收、应变电路、

数据处理和发送 3 大部分。谐振电路与整流稳压电路进行能量的接收, 将 125kHz 的交流射频信号转化为 3.3V 的直流稳定电源。应变电路将钢筋中的预应力转化为微小电压信号, 是预应力传感模块。而模数转化、MCU 和负载调制 3 个模块将模拟电压信号转化为数字信号, 并且加载到 125kHz 的射频信号上, 由谐振模块将数据反馈到外部读取器上。

整个系统操作简单方便, 极为节省能源, 在需要检测数据时, 传感器才会消耗能量

进行工作。而在数据传输方面, 相较于其他无线数据模块例如蓝牙、ZIGBEE 模块等, 125kHz 信号对固体介质有良好的穿透性, 虽然数据的速率较低, 但是对于采集预应力数据而言已经足够了^[4]。另外由于采用的是负载调制的方式反馈数据, 传感器不需要特殊的信号发射设备, 既减低了能量消耗, 同时也降低了成本。

因此, 低能量消耗和信号良好穿透能力是本预应力传感器的最大优势。

2 具体模块介绍

外部读取器的发射部分和整个预应力传感器的详细电路图如图 2 所示:

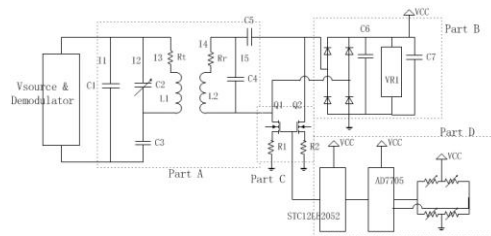


图 2 预应力传感器的整体电路设计

主要由 Part A 能量传输模块、Part B 电源模块、Part C 调制模块和 Part D 数据采集处理模块组成。下文将对各个模块进行具体的介绍。

2.1 能量传输模块

图 2 中 Part A 部分是能量传输模块, 该模块主要将发送端的交流能量传输到传感器端。传输模型为带负载匹配的谐振耦合电路。通过 MATLAB 的仿真实验和实际电路的微调,

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可以将传输效率调整至最大。MATLAB 调试基于频率分裂原理^[5-6],在固定天线参数的情况下,调整耦合电容的大小,即达到负载匹配来取得效率最大值。在实际的电路调试过程中,可根据仿真得到的理论值通过可调电容来调整电容 C4 和 C5 的值,通过检测电源模块输入端的电压值的大小来判断是否处于能量传输的极大值^[7]。

2.2 电源模块

图 2 中 Part B 部分是电源模块,该模块主要保证后端数据处理模块以及应变模块的正常工作,提供稳定的直流电源。该模块主要包括整流电路、3.3v 稳压器以及滤波电容,将能量传输模块获取的交流能量转化为较为稳定的直流能量。

2.3 调制模块

图 2 中 Part C 为信号调制模块,所采用的原理是电阻式负载调制原理。利用负载端电阻值的大小变化,来影响反射电压的大小,从而让发射端解析到反馈信号。具体实现由两个三级管带两个电阻完成,输入 0 或者 1 数字信号,打开或者关闭电阻电路,实现负载端电阻值的有效变化。电阻阻值需要配合耦合谐振电路传输极值来选取,因为对于耦合谐振电路来说,负载电阻也会对传输效率产生较大影响。

2.4 数据采集处理模块

图 2 中 Part D 为数据采集和处理模块,负责将预应力值从检测对象中采集出来并进行数字化处理。该部分主要由应变电路、模数转换电路和 MCU 控制电路组成。另外,应变电路和检测对象之间的连接由一个应变转换装置完成,具体如图 3 所示:

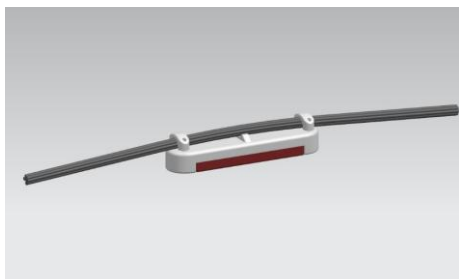


图 3 预应力转换装置模型图

在图 3 中,钢筋穿过该装置时,会产生微小变形,对下方感应块产生一定的挤压,迫使其也产生变形,将应变片贴于感应块下感应。由于这里的预应力是线性转换的,故只需要在测算时做一个线性的转换即可。

应变电路将检测到的毫伏级的电压输入到 AD 转换器中,MCU 将 AD 转换器输出的数字信号进行编码和加密,并以一定的频率输出到调制模块。整个数据采集和处理即完成。

3 传感器实测

根据本文之前的设计方案,购买相应的电子元件,制作成无线无源预应力传感器,并对该传感器在实验室环境下,进行数据采集和数据传输测试,验证该无线无源预应力传感器的工作性能。

3.1 测试方案设计

本次实测的目的在于验证无线无源预应力传感器工作稳定性、最大工作距离以及在固体介质下的工作性能。基于

上述目的,制定如下测试方案:

1) 在空气介质中,保持预应力传感器和读取器之间的距离,测量预应力传感器的工作电压和应变电压的数值;不断增加两者之间的距离,看工作电压和应变电压数值的变化情况。验证预应力传感器在空气介质下的工作性能。

2) 更换带负载匹配耦合谐振电路为普通串联型电路,验证优化电路的性能。

3) 介质改为固体介质,验证此环境下的预应力传感器的工作性能。

具体的测试过程为:在每一距离下,测定优化电路在空气介质和固体介质下的应变电压值和传感器工作电压值,测定普通串联电路在空气介质同一距离下的应变电压值和传感器工作电压值。其中,应变电压值采用测五次取平均的方法,保留 3 位小数。

3.2 测试环境搭建

整个测试环境包括:上位机数据显示程序、外部读取器、无线无源预应力传感器和应力模拟装置。具体的测试参数如表 1 所示:

表 1 测试环境参数

部件名	具体测试参数
上位机数据显示程序	笔记本 PC、RS232 转 USB 数据线
外部读取器	发射功率: 2w 发射线圈: 17uH 电源: 12v 移动电源
无线无源预应力传感器	接收线圈: 1350uH 工作电压: 大于 2.4v
混凝土墙壁	厚度 31.5cm
应力模拟装置	螺丝钉、弹性刚体

测试环境主要分为空气介质测试和穿透混凝土墙体测试两种环境。具体的测试环境示意图如图 4 和图 5 所示:



图 4 无线无源预应力传感器测试环境搭建——空气介质



图 5 无线无源预应力传感器测试环境搭建——混凝土墙体介质

图 4 和 5 中应力模拟装置由螺丝钉和弹性刚体组成。旋转螺丝钉对刚体产生挤压,使刚体产生不同程度的变形,进而预应力传感系统也可以采集到不同的应变电压数值。

而对于上位机数据显示程序,将 AD 转换公式对采集到的数据进行计算,保留 4 位小数对数据进行显示。

3 测试结果分析

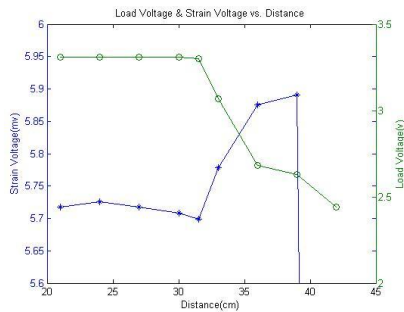
在应力转换装置施加一定力的情况下, 在不同距离下, 3 个测试组测得的应变电压数据如表 2 所示:

表 2 无线无源预应力传感器实测数据

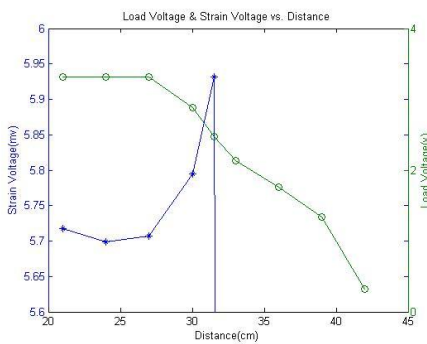
距离 (cm)	优化电路、空气 介质 左应变电压、右 工作电压		串联电路、空气 介质		优化电路、介质 墙壁	
21	5.717	3.31	5.718	3.31	\	\
24	5.726	3.31	5.699	3.31	\	\
27	5.718	3.31	5.707	3.31	\	\
30	5.708	3.31	5.795	2.88	\	\
31.5	5.699	3.30	5.931	2.47	5.727	3.26
33	5.778	3.07	0	2.14	5.760	3.06
36	5.876	2.68	0	1.76	5.821	2.88
39	5.891	2.63	0	1.34	5.902	2.62
42	0	2.44	0	0.32	0	2.32

其中, 应变电压的单位为 mv, 工作电压的单位为 v。

根据上述数据对空气介质下的应变电压和工作电压进行曲线图展示如图 6 所示:



(a)



(b)

(a) 预应力传感器的耦合谐振模块带负载匹配; (b) 耦合谐振模块为普通串联电路。其中, 圈代表工作电压, 星代表应变电压

图 6 预应力传感器应变电压和工作电压随距离的变化关系。

通过图 6 的对比图可以看出, 耦合谐振电路经过优化后的预应力传感器的最大工作距离更大, 从 31cm 提高至 38cm, 性能提高了 20% 以上。而通过对比表 2 中第一组和第三组的数据可以发现: 空气介质与混凝土介质条件下, 预应力传感器的工作性能几乎不受影响。

另外, 对比 3 组数据可以发现一个共同点是: 随着工作

电压降低时, 检测到的应变电压值有相应的升高。假设当前电压为 $V = kV_0$, V_0 为正常工作电压。此时, 应变电路的灵敏度变为 $2kV_0(\text{mv})$, 即相同应变下, 当前应变电压变为 $k\Delta V$ 。而 AD 的参考电压此时变为 kV_{ref} , 因此根据 AD 转换公式可知, 当前的计算结果将不会随着 k 的改变而改变。可以推断, 当工作电压低于 3.3v 时, 会影响到 AD 的模数转换性能, 导致数字数据产生一定的偏差, 而本身的计算模型不会带来误差值。

从上述分析可知, 当工作电压低于 3.3v 时, 预应力传感器仍然可以顺利将数据传回来, 但是由于模数转换器的工作性能限制, 会产生一定的误差, 随着工作距离的增加误差逐渐增大, 此测试条件下最大误差为 $\varepsilon = 0.2/5.7 \approx 3.5\%$ 。

上述误差的规避主要通过保证预应力传感器的工作距离保证在一定范围之内。若不得已而超出该范围时, 应尽量减少超出距离, 同时相应地减少预应力的合格范围, 保证预应力监测的有效性。另外, 当由于监测操作不规范 (例如不小心在范围外进行了若干组数据检测) 而产生误差数据时, 应该采用多次测量, 去掉明显误差数据, 再取平均的方法来降低误差。

4 总结

本文简单介绍了建筑结构安全性检测中, 传统预应力传感器的不足, 设计并实现了在 30cm 以上工作距离下的无线无源预应力传感器, 详细介绍了各个模块的工作原理和实现方案, 并对传感器在实验室环境下, 进行了模拟测试, 验证了无线无源预应力传感器在谐振电路优化后的工作距离有了一定的提升, 同时, 混凝土介质并不影响该传感器的工作性能。另外对应变电压检测误差来源进行了分析, 提出了降低测量误差的方法。

未来可以在建筑结构中网络化部署该类传感器, 以实现统一化管理与监测, 具体的规划与设计方案的下一步研究的重点。

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Abstract: For the issue of node energy and network lifetime in wireless sensor network (WSN), an improved LEACH-C protocol is proposed. Firstly, the network is deployed into clustering and cluster head is selected by using LEACH-C clustering algorithm. Secondly, a multi-hop optimal path from source cluster head to the base station is searched, considering transmission distance and node energy of cluster head, by using ant colony algorithm, which helps to avoid the cluster head far away from the base station in single-hop way dying early due to a lot of energy consumption during its message transmission. The experimental results show, compared with LEACH and LEACH-C, the proposed protocol can make node energy more balanced and prolong the network lifetime.

Key words: Wireless Sensor Network; LEACH-C Protocol; Ant Colony Algorithm; Multi-hop Transmission; Network Lifetime

WiFi Wireless Access Network Planning Study..... (33)

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Abstract: As the demand of the wireless business gradually strengthens, wireless broadband Wi-Fi is attracted extensive attention. To solve the problems such as Wi-Fi single mode of construction, existing deficiency of backward operation in management and lack of bandwidth, it proposes the correlative strategy and network planning of Wi-Fi wireless access. And it also studies and analyzes the Wi-Fi access network planning to guarantee the bandwidth, management and security of the current Wi-Fi wireless access in network effectively.

Key words: Wi-Fi; Network Planning; 802.11; AP

Statechart Diagram of UML Steps Design Research in Software Engineering.....(36)

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Abstract: Statechart diagram as a modeling diagram of UML is widely used in the development process of object-oriented software system. This paper mainly studies the difference between the state diagram and activity diagram, the method of drawing the state diagram and the detailed drawing of the two kinds of objects.

Key words: UML; State Chart Diagram; Activity Diagram; Securities Trading Systems

An Agent-based Cache Consistence Maintenance Strategy in Mobile Cloud Environment..... (38)

Zhang Yili¹, Yang Wankou² (1.School of Computer and Software, Nanjing Institute of Industry Technology, Nanjing 210023,China; 2.College of Automation, Southeast University, Nanjing 211189, China)

Abstract: Broadcasting timestamps strategy is widely used in consistent maintenance of mobile cache. Aiming at the problems of write latencies and disconnection operation in the traditional strategy, the mobile cloud computing is combined with agent and caching technique, and the three-layer structure in mobile cloud platform, and the data caches are constructed in middle layer. The server is coordinated with the client by the middle layer. Meanwhile, the implement strategies are given. The simulation results show that the problems of write latencies and disconnection operation can be solved. The response speed of client request is improved, and network transfer cost is decreased.

Key words: Cache Consistency; Mobile Agent; Mobile Cloud Computing; Transaction; Transmission Cost

RESEARCH AND DESIGN

Research and Design of High Availability Framework for Domain Name System..... (42)

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Abstract: Domestic generic DNS architecture mostly using Windows, Linux built-in service and obsolete hardware, so the degree of security, intelligence is not enough. This paper is based on DNS operating principle. It analyzes the characteristics and defects of existing DNS infrastructure, researches and applies the distributed deployment technology, efficient data synchronization technology and smart DHCP technology to build a DNS architecture model which is safe, simple and easy to expand. Thereby it enhances the DNS response service capabilities and users' experience.

Key words: Domain Name Resolution; High-Availability; Distributed

Design and Implement of Multi-antenna High Power LF RFID Reader..... (45)

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Abstract: Radio Frequency Identification (RFID) is a kind of automatic identification technology. Low-frequency RFID signals can penetrate through most objects. Thus, LF RFID System works well in the environment which requires good field penetration. According to the shortcomings of existing LF RFID readers, a kind of multi-antenna high power LF RFID reader is presented. By using multi-antenna technique and high power radio frequency technique, the identification range of LF reader can be expanded and the performance and function of LF RFID system can be promoted. It introduces the overall structure of this reader and analyzes the concrete implement both in hardware and software. The final functional test tells that this reader works quite well.

Key words: RFID; Low-Frequency; Multi-antenna; High Power

Super-pixel and Characteristic Improvement Based Foreground Segmentation Algorithm Using Grab Cut..... (48)

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Abstract: Grab cut segments images precisely with less interaction, but its efficiency is low. Using the SLIC super pixel algorithm as pretreatment can significantly improve the efficiency of Grab cut, but the precision will be bad on condition that the color features of foreground and background were similar. This paper presents an improved Grab cut algorithm based on super pixel and modified features. First, the original image is pre-segmented into super-pixel image, and then it calculates the color features and texture features of super pixels. Finally, it gets a new boundary term by combining the two features with different weights. The minimum cut can be calculated by the new energy function. Experimental results show that this algorithm performs well on accuracy and efficiency.

Key words: Grab Cut; SLIC; Super-pixel; LBP Texture Feature

Analysis of Wireless and Powerless Pre-stressed Force Sensor..... (51)

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Abstract: Wireless and powerless stress sensor will play an important role in structure health monitoring, because it can detect pre-stressed force of concrete. This article introduces the framework and workflow of this wireless and powerless stress sensor. It is mainly composed of outside reader-writer and inside stress sensor. Then this article will introduce implementation rationale and solution of every module. Then this sensor is tested in the environment of air and concrete to verify its performance. And the cause of error is analyzed. This wireless and powerless sensor gets stress value well with working distance of 30cm.

Key words: Structure Health Monitoring; Wireless and Powerless Stress Sensor; Resonant Coupling Distance

Research and Implementation of Incremental Data Synchronization Strategy in Mobile Network..... (54)

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Abstract: The new generation of anti-fake currency propaganda system combines database and mobile network to support data online update. It can synchronize information online, which will be managed orderly and displayed rapidly. Means of wireless communication used in mobile network is vulnerable to outside interference and leads to unstable connection speed. Meanwhile, telecom operators usually charge according to the flow. So, higher fault-tolerant ability in data synchronization and lower operation cost by minimizing the amount of communication are requisite. This paper presents an incremental data synchronization strategy suitable to the scene which implemented by using WCF technology on dotNET platform. After testing, the strategy achieves the original design goals, and has been used in actual production.

Key words: Incremental Data Synchronization Strategy; Mobile Network; Anti-Fake Currency Propaganda

Vert.x Enterprise Web Application Designing and Implementing..... (57)

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Abstract: In this paper, it uses the latest Vert.x server framework to design and implement the college student course attendance management system based on the WeChat common platform with the asynchronous, non-blocking, real-time, highly concurrent working mode. It solves the problem that traditional server platform can not meet the requirement of real-time connection request of large customers, and it also achieves the enterprise level Web application of high performance and high concurrency.

Key words: Vert.x; Node.js; Enterprise Application; Architecture Design

Architecture Design of Application Data Subsystem for Grid Planning Simulation..... (60)

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Abstract: In order to meet the demand of structure and function in applying data management for grid plan research simulation laboratory, this paper proposes a set of applying data subsystem, which serves for grid plan research simulation laboratory, combined with the actual requirement in grid plan simulation. This paper