CYCLIST TRAINING MONITORING SYSTEM BASED ON WIRELESS SENSOR NETWORK

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To my beloved mother and father,

to my lecturers, for their guidance and encouragement.

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ABSTRACT

Recent innovation of technology in wireless sensor network (WSN) has eased the deployment of WSN in many applications such as health monitoring system. This research presents a cyclist training monitoring system that is equipped with a set of sensors using the WSN technology. This enables continuous monitoring process of cyclist training that can be done anytime and anywhere. A stable and reliable wireless cyclist monitoring system with minimum data loss is vital to establish a smart and efficient sports management program that can lead to better quality outcomes of cyclist training. This cyclist training monitoring system has been developed and tested in real cyclist training environment in velodrome. The system is designed based on WSN that is linked to the cloud network on the Internet. Using TelG node as the basis, customized transceiver nodes are developed to establish the WSN. These nodes have been built with 30% reduction in size from the existing nodes. Seven measurements were conducted to investigate several factors that affect the packet loss rate before the system architecture was constructed. The factors that were taken into account during the measurements are the distance between the transmitter and the receiver, the height and angle of the receiver, the mobility of the transmitter, the transmission power of the transmitter, as well as the packet size and transmission rate. The results from the measurements correspond to the wireless communication theory. Based on the seven measurements, the system architecture was constructed. Several experiments were conducted in a real scenario in velodrome to measure the reliability of the system architecture. It was shown from the experiments that the proposed system is reliable even when the cyclist is moving at high speed which is 30km/h constantly. The packet loss in all experiments conducted is less than 2%, which does not give huge impact to the sensor data transmission. In addition, the results have shown that the proposed system can produce minimum end-to-end delay which is at 11ms when packet size is below 20 bytes which can be neglected.

ABSTRAK

Inovasi terbaru dalam jaringan penderia tanpa wayar (WSN) telah memudahkan penggunaan WSN dalam banyak aplikasi seperti sistem pemantauan kesihatan. Kajian ini mempersembahkan sistem pemantauan berterusan untuk latihan pelumba basikal yang dilengkapi dengan penderia yang menggunakan teknologi WSN. Ini membolehkan proses pemantauan latihan berbasikal dapat dilakukan pada bila-bila masa dan di mana-mana sahaja. Sistem pemantauan latihan pelumba tanpa wayar yang stabil dan boleh diharap adalah perlu untuk membina program pengurusan sukan yang pintar dan berkesan yang boleh menghasilkan hasil latihan berbasikal yang lebih berkualiti. Sistem pemantauan latihan pelumba ini telah dibangunkan dan diuji dalam persekitaran sebenar latihan pelumba di velodrom. Sistem ini telah direka khusus berdasarkan WSN yang dihubungkan dengan pangkalan data awan di Internet. Menggunakan peranti TelG sebagai asas, peranti penghantar terima telah dibina untuk membentuk WSN. Saiz peranti penghantar terima tersebut telah dikurangkan sebanyak 30% dari nod asal. Tujuh pengukuran telah dijalankan untuk mengenalpasti faktor-faktor yang mempengaruhi kadar kehilangan paket sebelum seni bina sistem dibina. Faktor-faktor yang di ambil kira ketika pengukuran itu adalah jarak antara pemancar dan penerima, tinggi dan sudut penerima, pergerakan peranti pemancar, kuasa pancaran dari peranti pemancar, serta saiz dan kadar paket. Hasil dari pengukuran didapati bertepatan dengan teori komunikasi tanpa wayar. Berdasarkan tujuh pengukuran tersebut, seni bina sistem dibina. Beberapa pengukuran dilakukan dalam keadaan sebenar dalam velodrom untuk mengukur kebolehpercayaan seni bina sistem tersebut. Hasil daripada eksperimen menunjukkan kebolehpercayaan sistem yang dicadangkan termasuk ketika pelumba sedang mengayuh pada kelajuan yang tinggi iaitu 30km/h secara tetap. Kehilangan paket dalam semua pengukuran adalah kurang daripada 2%, dimana ianya tidak memberikan kesan besar kepada penghantaran data penderia. Tambahan lagi, hasil pengukuran menunjukan sistem yang dicadangkan menghasilkan lengah hujung-ke-hujung yang minima iaitu 11ms apabila saiz paket kurang daripada 20 bait dan boleh diabaikan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

API	-	Application Programming Interface
APL	-	Application Layer
APS	-	Application Service
BER	-	Bit Error Rate
BPSK	-	Binary Phase Shift Keying
CAP	-	Carrierless Amplitude Phase
DOD	-	Delay of Frame
DOF	-	Degree of Freedom
FCS	-	Frame Check Sequence
GTS	-	Guaranted Time Slot
HRM	-	Heart Rate monitor
MAC	-	Media Access Control
MHR	-	Multi Hop Relay
MSDU	-	Media Access Control Service Data Unit
NWL	-	Network Layer
OQPSK	-	Offset Quadrature Phase Shift Keying
PAN	-	Personal Area Network
PC	-	Personal Computer
PER	-	Packet Error Rate
PHY	-	Physical Layer
QoS	-	Quality of Service
RFD	-	Reduce Function Device
RSSI	-	Receive Signal Strength Indicator
RTC	-	Real Time Clock
SCMA-CA	-	Carrier Sense Multiple Access along with Collision Avoidance

SDK	-	Software Development Kit
SEMS	-	Smart Energy Management System
SHAAL	-	Smart Home and Ambient Assisted Living
SRM	-	Schoberer Rad Messtechnik
USB	-	Universal Serial Bus
WMSN	-	Wireless Multimedia Sensor Network
WPAN	-	Wireless Personal Area Networks
WSN	-	Wireless Sensor Network

LIST OF SYMBOLS

μA	-	Microampere
m	-	Meter
Ms	-	Millisecond
P_{corr}	-	Total number of packet loss
P_{total}	-	Total of transmit packet

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Wireless sensor networks (WSN) encompass of a number of cheap low-power devices that are small in size and typically powered by battery [1]. These sensor devices work together to establish a smart environment that gathers important data and information to be accessed by human anytime and anywhere. Owing to their simplicity and ad hoc deployment features, WSNs have been applied to various fields of science and technology such as health care, military surveillance, highway traffic, environment monitoring and sport monitoring [2]. Recent state-of-the-art technology of WSNs has enabled the integration of these interconnected sensor nodes in the Internet-of-Things (IoT) area [3]. Using the WSNs as the basis, these smart sensors in IoT collaborate directly without any human intervention to deliver a new class of applications that further contributes to the quality of life.

One of the main tasks of WSNs is data gathering at the sensor field where sensed data are continuously collected. These data can be processed first by sensor nodes before they are being forwarded through wireless communications to a base station for further processing. A base station can be centrally located within the sensor field, or somewhere outside the sensing field. In the latter case, a gateway is required to link the sensor network with the base station since the sensor nodes have limited transmission range. Meanwhile, sensor nodes are often deployed at the specific locations as required by the application. Since the size of a sensor node is small, the node can be attached at any location with minimal disturbance to the surrounding environment. The flexibility offered by WSNs have reduced the costs and efforts for deployment and maintenance. Consequently, this had made WSNs a competitive approach for data collection compared to its wired counterpart with infrastructure-based network [2].

1.2 Background of the Research

In recent years, wireless communication technology have greatly reduced the dependency of connecting wires to collect the data and power the measurement equipment. As a result, the ability to take multiple measurements over the human body or other apparatus have been improved tremendously [4]. Moreover, with the advancement of smaller, less intrusive communication and sensing technologies, bulky and obtrusive apparatus can be substituted with lighter equipment. There are a wide range of WSNs applications that would benefit enormously from the sensing technologies. Among the applications is sport and health monitoring in which the capability of sensor nodes to collect data unobtrusively and without hindering movement or performance would enable its implementation to improve an athlete's performance in sports. The data collected by sensor nodes could relate information about the body and its relative movement, besides any other performance-related data that is desirable. In addition, new wireless connectivity radio standards could facilitate the data collection process and enable the data from different sensor nodes at multiple points to be collected synchronously [4]. The data fusion process that takes over after the data collection process will compress the information collected, before they are being sent to the base station for further interpretation of data.

Cycling is one of the most popular sports in Malaysia and significant interests are given for this sport recently with the winning of a bronze medal by Malaysia team in the 2016 Olympic tournament in Rio, Brazil. The success of this sport is due to the elite level support provided by the Malaysia government with strong recreational and developmental programs. However, there is still room for improvement in which latest technology can be exploited in order to achieve superior performance in the future. For instance, sports management wireless remote monitoring system has an important role in observing athlete’s performance in his/her daily training. When monitoring the performance of athletes in the field, an applicable method of data transport must be determined in order to get the athlete’s performance characteristics back to the coach. Therefore, the development of a stable and efficient wireless sports monitoring system is vital to establish a smart and efficient sports management program that can lead to quality outcomes.

The cyclist training monitoring system is important during cyclist training to avoid over training and to have a high quality of training. Before advances in WSN technologies, the normal practice to measure the performance of athletes in cycling training program is by using conventional stopwatch [5]. The results acquired from the training by using stopwatch is imprecise and uninformative. In addition, this method also has insufficient scientific supports that proves training by using stopwatch can actually improve the performance of an athlete [6]. Hence, this research presents a cyclist training monitoring system that is developed to enhance the sports management program. The general diagram for the cyclist training monitoring system is shown in Figure 1.1. The system consists of hardware components such as server, gateway, sensor nodes and sensor devices. There are four types of nodes used in this research: sensors node, forwarder node, relay node and base station node. Based on the environment in a real cycling track in velodrome, data from the cyclist are collected and sent to the forwarder node. Then, data from the forwarder node is delivered to the base station through multiple hops of relay nodes to be sent to the server. Once the data have been uploaded to the server, it can be accessed by the trainers or coaches at anytime and anywhere.

From a networking perspective, packet delivery performance is the most crucial aspect of wireless communication. Packet delivery performance can be defined as the ability of the packet transmits to reach their destination. Packet delivery performance can be said as unsuccessful if there are a lot of packet losses during the transmission process. Hence, our work aims to develop a reliable real-time monitoring system that takes into account factors that can affect the packet delivery during packet transmission from the forwarder nodes or gateway to the base station.

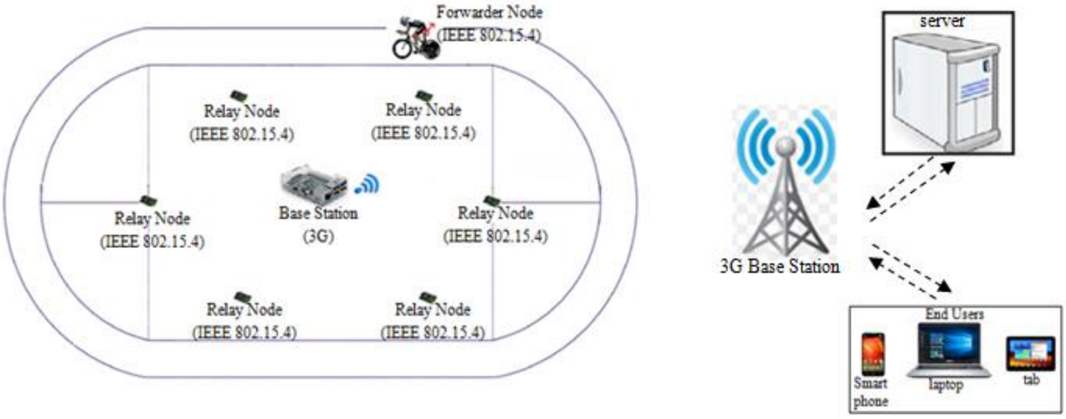

Figure 1.1 General Diagram of Cyclist Training Monitoring System.

1.3 Problem Statement

Cycling is a highly competitive sport that requires a very high level of strength supported by a high fitness level. An appropriate training program and sport management system is necessary in order to improve team skills and consequently increase competitiveness in international tournaments. In addition, statistical data collected during cyclist training sessions can be used to measure an athlete's performance and to produce athlete performance profiles. Ubiquitous and versatile mobile devices can be applied to cyclist activity monitoring, offering a cost-effective ways of widespread performance analysis. The ability to collect data remotely enables the coach or trainer to incorporate feedback into their training regimen and hence, enhance their skills and moderate their activities to meet health outcomes [7].

The current device used by the national cycling team to measure the speed, cadence, heart rate and power of the athletes during the training sessions is SRM (Schoberer Rad Messtechnik). The SRM is a battery power monitoring system that has been widely used to provide an accurate measurement of cycling power [8]. Another device such as Heart Rate Monitor (HRM) is also used to monitor the performance of the athletes. Besides monitoring the performance of the athletes, these devices are also able to monitor their health condition [9]. The data produced by SRM and HRM devices are reliable and accurate data. However, the data produced are stored first and must be transferred to a laptop or personal computer (PC) through a universal serial bus (USB) cable to enable the coach to observe and analyze the data. Hence, this process is quite time consuming and inefficient for the coach to monitor their athletes performances continuously. Therefore, a wireless cyclist training monitoring system with low power consumption, long communication range between transmitter (cyclist) and receiver (coach) with minimum delay is really desirable in order for the national cycling team to improve their performance as well as to prevent over training.

As WSN forms the basis of cyclist training monitoring system, sensor nodes are required to control the WSN configurations. Such configurations encompass various tasks to ensure reliable network connection that is able to deliver real time data. Moreover, the monitored parameters of the bicycle or cyclist must be real time and accurate so that instant feedback can be given by the coach to improve the performance of cyclists. Due to this reason, packet delivery performance is the most crucial aspect in the developed system [10]. The data delivered will not be accurate if a lot of data is dropped during the transmission process. Packet loss rate around one percent is acceptable [11]. Hence, the transmission ability of sensor nodes is highly depended on the transceivers used in the wireless module. In addition, the issue of end to end delay is also really important when it comes to real time monitoring [12]. It can be elaborated as time taken for a packet to be delivered to the destination. A system with minimum delay is favourable since data can be accessed faster by the end user.

In this research, XBee module is used as transceiver while IEEE 802.15.4 (Institute of Electrical and Electronics Engineers) standard is utilized as transmission protocol. The transmission ability of Xbee module differs according to certain conditions such as distance between transmitter and receiver, height and angle of receiver, the mobility of the receiver, transmission power of transmitter, as well as packet size and rate. Since the training sessions of athletes are held in velodrome, the real size of velodrome as well as its shape must be taken into account when designing the whole system. The velodrome is 330m lengths and the track is banked with a certain degree of angle. The distance and the banked track of the velodrome are among factors that affect packets received rate during the transmission process. Therefore, it is important to consider these factors during the transmission process and design the system architecture for a wireless cyclist monitoring system that have minimum packet loss rate as well as end to end delay.

1.4 Objectives

This research is a part of wireless cyclist monitoring system project that aims to have a reliable wireless cyclist monitoring system. In order to achieve the main goal of the work, the specific objectives of this research are listed as below:

i. To design and develop a wireless cyclist monitoring system in a real test bed environment based on customized TelG node with reduced size.

ii. To study the factors that affect the packet loss rate and analyze as well as justify the factors based on propagation model using 330 meter Velodrome tracks as the environment of the study and IEEE 802.15.4 as wireless standard.

iii. To measure and evaluate the performance of the developed wireless cyclist monitoring system in terms of packet loss rate and end to end delay.

1.5 Scope of Study

The scope of this research is to design a reliable system architecture with acceptable packet loss rate for cyclist training monitoring system in a real experimental test bed. The work includes the hardware design of sensor node and software development for sensor networks. This work is part of the cyclist training monitoring system project developed at Advanced Telecommunication Technology (ATT) laboratory. In this work, a customized wireless sensor node is developed based on the TelG mote and its operating system [13]. TelG mote has been successful developed and used discretely in Wireless Biomedical Sensor Network (WBSN) project [13] and Wireless Multimedia Sensor Network (WMSN) [14] project. The research work in this thesis is limited to:-

i. Design a reliable system architecture for wireless cyclist monitoring by conducting several measurements that affect packet loss rate using standard Xbee as transmission module. The factors that are taken into account during the measurements are distance between transmitter and receiver, height and angle of receiver, the mobility of the transceiver, transmission power of transmitter, as well as packet size and rate. In addition, the experiments focus on track cycling racing in 330m velodrome or banked track.
ii. Develop customized sensor nodes based on TelG mote. These sensor nodes are used as forwarder nodes and relay nodes to deliver the data to the base station. The software used for the design process is SolidWork while C language based on WiseOS operating system is used to program the sensor nodes. The communication standard used is IEEE 802.15.4.
iii. The performance of the proposed architecture is evaluated based on packet loss rate and end to end delay in a real test bed environment. The network scenario used is according to the environment in 330m velodrome cycling track.

1.6 Significance of the Research

The output of this research is a reliable architecture for cyclist training monitoring system using IEEE802.15.4 as the communication standard. The system that is developed based on the proposed architecture is able to achieve low packet loss rate and low end to end delay. The proposed architecture can be utilized efficiently in a banked cycling track or 330m velodrome environment. The benefits of the proposed system can be significant in which it can be implemented in the national sports management program and leads to improved performance of the athletes. Accordingly, the level of competitiveness among athletes in international tournaments can be increased.

1.7 Research Contribution

The contributions achieved in this research are listed as follows:

1. Design and build sensor nodes that are based on the TelG mote.
    - The nodes are designed as transceivers to be used in the cyclist training monitoring system as a forwarder node and relay nodes. The process involved are circuit design, printed circuit board (PCB) layout design, fabrication and electronic component installation. The built sensor nodes are small in size so that they can be attached on the bicycles. The total number of sensor nodes that is built for this research is 10.
2. Programming the nodes to operate as a transceiver to be used for the packet loss measurement.
    - There are seven types of measurements conducted which involved varied distance of transmitter and receiver, varied heights of receiver, the movement of transmitter, different packet size, varied transmitter power, data transmission from multiple nodes, and varied angles of transmitter.
    - The results from these measurements are analysed in terms of packet loss rate to determine the best system architecture for cyclist monitoring system.
3. Reliable architecture for cyclist training monitoring system.
    - With regards to the results from the measurements above, a system architecture for cyclist training monitoring is designed. The location of sensor nodes such as forwarder node and relay nodes are specified in a way that data delivery at the base station is optimum. In other words, packet loss rate performance is considered when placing the sensor nodes in a 330m velodrome cycling track.

1.8 Thesis Structure and Organization

This thesis consists of six chapters. Introduction of this research that has been described in Chapter 1 focuses on the problem statement, research objectives, scope of the work, significance of the research, and thesis contributions. The remainder of this thesis is organized as the following.

Chapter 2 elaborates on the wireless technology such as WSN, IEEE 802.15.4 and WiFi network that are used in the development of cyclist monitoring system. The structure of monitoring system within the focus research area is also highlighted. In addition, related works in this area which motivates the research work presented in this thesis is discussed.

Chapter 3 describes the general methodology for this research. Specifically, this chapter explains on the hardware work involved in this research. The development of the sensor nodes as forwarder nodes and relay node is elaborated in this chapter. Moreover, a performance metrics used to evaluate the system performance will be explained.

Chapter 4 specifies the programming work for sensor nodes design. The details flow of sensor nodes as transmitters and receivers are explained in this chapter. The details setup and methodology during the measurements process are also described.

Chapter 5 presents the performance study of the cyclist monitoring system based on the measurements and experiments conducted in a real test-bed 33m velodrome cycling track. The results obtained in terms of packet loss rate and end to end delay are also justified in this chapter.

Chapter 6 expresses the conclusion of this research work. The contributions achieved are also highlighted. In addition, possible strategies for future work are suggested in this chapter.

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