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On ZigBee location technology in football training

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Abstract. ZigBee location technology was applied to football training system to achieve a practical wireless sensor training system with low cost. The studied football training system was mainly made up of mobile node, reference node, coordinate and monitoring software of upper computer, and their installation methods and functions were elaborated. Node hardware, based on CC2430 and CC2431 chips which integrated radio frequency (RF) and 8051 controller, was an interacting platform for RF module, debugging module, functional module and indication circuit. Specific algorithm was developed based on ZStack protocol stack and specific methods to achieve functions of various nodes were provided. Finally, test was made accordingly and data relevant to football training were recorded, such as total running distance, start reaction and movements of all football players and their intentions to execute coach's strategies. Besides, the studied system met requirements of low cost and high performance.

Key words. ZigBee technology, wireless location system, football training, movements, node
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1. Introduction

With the rising competitiveness level, requirement of coach for players were more strict than used to be, which means that physical states and capabilities of all athletes should be measured [1]. In recent years, wireless communication technology and sensor technology were developed, which can be used to measure physical states and capabilities of all athletes. Generally, wireless sensor network (WSN) was made up of small sensor nodes with functions of data calculating and communication. Those nodes are communicating and collaborating with radio wave formed an interconnected network system which was used to upload data to PC terminal server. Thus, it is easier to process and fed back data of surroundings and tested object. ZigBee network technique was used to build hardware platform for new WSN which

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was used to collect and transmit information within the monitored range in football field continuously and stably.

2. Literature review

ZigBee WSN, which is a wireless data transmission network, is designed based on IEEE802.15.4 technical standard and ZigBee network protocol [2, 3]. Zigbee technology, featuring low cost, high efficiency, low power consumption and position function, is more and more widely used in fields such as smart home, industrial control and medical care because more and more people need the relative position of specific object in some specific situations. In other word, more and more people are eager to have access to ZigBee WSN with real time position technology and tracking technique [4]. Thus, monitoring system for football running position is researched and developed based on Zigbee technique.

Compared with other wireless communication technology, terminal of Zigbee wireless sensor network technology can be represented by an ad hoc network that is launched by coordinator and with which special requirements of WiFi to fields is avoided. Because transmission distance of traditional Bluetooth technology is within 10 m and football players run on field randomly and their distance cannot be limited by 10 m, Zigbee wireless sensor network technology with transmission distance of 100 m is more suitable. Thus, location technique of Zigbee wireless sensor network is applied to monitoring system of football positioning and its location performance is studied.

3. Research method

3.1. Overall design

Football players should not only have a good physical fitness but also have a well understand of tactic running position. ZigBee locating technology applied in football training was to be studied and running positions of players were selected as main objects of study. Each parts of system will be analyzed briefly. Figure 1 represents the principal simulation for whole system.

It is obvious from Fig. 1 that the system is mainly made up of controlling host PC, reference node, mobile node and coordinator. Controlling host PC is also called upper computer. Relevant control and monitoring software were built in the upper computer for coach to observe players' running position and evaluate players' understanding of tactics. CC2430 was used as coordinator to build ZigBee network, which was used to transmit coordinate of location node (mobile node) and parameters of external environment to controlling host PC during communication. Besides, CC2430 was also used as reference node in order to serve as a router [5] and provide coordinate of mobile node and RSSI average value because each player needs to be located. Moreover, coordinate of reference node was fixed by users. CC2431 was used as mobile coordinate because CC2431 was internal integrated location engine

while CC2430 was not. CC2431 can be used to provide reference coordinate and average value of RSSI of reference node. Thus, relative position coordinates of a mobile node compared with the reference node can be calculated. Then, wireless network was used to transmit node identity and coordinate to coordinator.

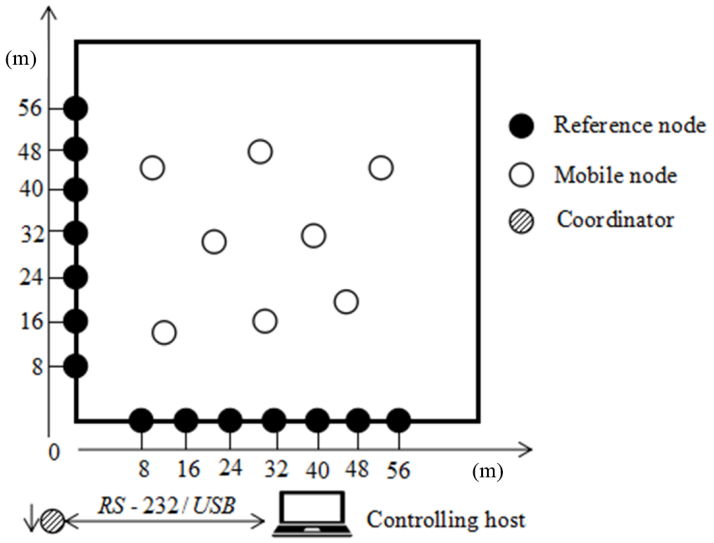

Fig. 1. System principle simulation

Inference for core algorithm of locating: given transmitted power of transmitting module was Pf; receiving power of receiving module was Ps; straight-line distance between those two modules was L and propagation factor was n. According to RSSI ranging principle that strength of transmitting signal decreases regularly with the increase of distance, the relations between transmitted power and receiving can be shown as $Ps = Pf/Ln$. Long-distance Path Loss Model was adopted and the logarithm was taken as $10 \lg Ps = 10 \lg Pf - 10n \lg L$. Transmitted power Pf of transmitting module was given as A because it is a constant; thus $10 \lg Ps = A - 10n \lg L$. Received signal strength was RSSI, thus, it can be interference that RSSI $= A - 10n \lg L$ (units: dB m). Through equivalent variation of mathematical formula, the range formula can be shown as $L = 10(A - \text{RSSI})/(10n)$.

3.2. Hardware platform design and implementation

Hardware circuit was mainly made up of two modules, wireless communication interface module and function module. Wireless communication interface module can receive and send information data among modules, which was the core component of the hardware platform. Function module was mainly made up of power circuit, serial circuit, indicating circuit and keying circuit.

3.2.1. CPU module: An enhanced 8051 CPU kernel of 8 bytes was integrated by CC2430, whose instruction execution speed was faster than that of standard

8051. There was a wireless module in CC2430. Position module was involved, for which Received Signal Strength Indicator (RSSI) of inserted CC2430 was intensively studied. Value of RSSI was a signed binary complement of 8 bytes, which can be read in registers such as RSSIL and RSSI_VAL. Within 8 symbol periods of 128 us, expected values equals to value of RSSI. Gain P of RSSI register value such as RSSIL and RSSI_VAL in RF can be calculated using the formula

$$P = RSSI\_VAL + RSSI\_OFFSET \text{ [dbm]} \tag{1}$$

RSSI_OFFSET was estimated value of pre-gain based on practical situation during system developments. Generally, RSSI_OFFSET was approximate to -45. Given RSSI register was read as -20. Then, actual input power of RF was approximate to -65 dBm. Figure 2 shows a typical relation graph of input power and RSSI_VAL. Thus, linear performance of RSSI value read in CC2430 was well and its dynamic range was about 100 dB.

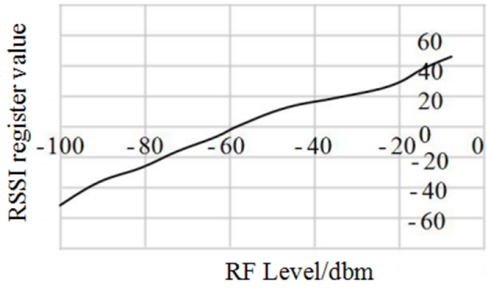

Fig. 2. Relation between RSSI value and input power

3.2.2. Design of backstepping controller: A two-line interface was provided by debugging interface of CC2430 to system on chip debugging. Through this debugging interface, on-chip Flash can be programmed and memorizer and register can be read [6]. In the debugging mode, Pin P2_1 of I/O was changed into debugging data cable and P2_2 was changed into clock line of debugging. Figure 3 shows sequence diagram of debugging interface.

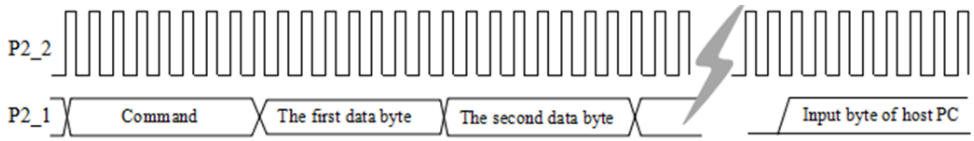

Fig. 3. Sequence diagram of debugging interface

It can be seen from Fig. 3 that SPI of two-line interface was used by debugging interface and data was driven onto pin of two-way debugging data in order to sampling on positive and negative edge of debugging clock. Debugging time was determined by debug command sent by external PC which command was made up of 1 to 4 input bytes (includes command byte) and an optional input byte read by host PC.

The first byte of debug command was command byte whose coding scheme is:

1. 7–3 bytes were instruction code;
2. 2–1 bytes were return input bytes to host PC;
3. 1–0 bytes were number of bytes of command bytes of host PC.

Debugging interface would be limited under certain circumstance though it can operate under all power modes. Under certain power mode, power consumption would be much higher than expected value because system was operating under normal mode with digital voltage regulator in operation. When debugging power mode was in 2 and 3 states, chip would stop operation when the system awoke. Thus, command of HALT and RESUME was need to make sure software would work continuously. When chip was awaken in power mode 1, system will continuously to work.

3.2.3. CC2430 peripheral equipment:

1) Power management clock

Power management controller (PMC) of CC2430 was studied. Power module was closed to avoid static power loss and achieve Ultra lower power run (VLPR). In the other hand, the lowest dynamic consumption can be achieved by clock gating and closed oscillator. Table 1 can be used to analysis influence of power mode to system operation and relations between power conditioner and oscillator.

Table 1. Power modes

Power mode	High-frequency oscillator	Low-frequency oscillator	Digital power regulator
Configuration	A: NO, B:32MHz crystal oscillator, C:16MHz RC oscillator	A:no, B:32.753kHz RC oscillator, C:32.768kHz crystal oscillator	NO
PM0	B,C	B or C	Open
PM1	A	B or C	Open
PM2	A	B or C	Closed
PM3	A	A	Closed

2) CC2430 Reset

There are four reset reasons for CC2430, including entry pin RESET_N into low level forcibly, power-on reset, Brown-out restoration, watchdog reset [7]. There are 4 initial states after restoration:

- Set I/O pin as input and pull up.
- Counter of CPU program was set as 0x0000 at which position program starts operation.
- All peripheral registers were initialized as restoration value.
- Watchdog timer was forbidden to work.

When equipment is on, there is a power on reset (POR) providing properly ini-

tialization in CC2430. In the meanwhile, Brown-out detection (BOD) working with adjusting 1.8 V digital power supply can ensure memorizer was integrated though changing supply voltage would cause adjusting 1.8 V power lower than that of Flash memorizer and the lowest level regulated by SRAM [8]. For CC2430, before starting power-on initialization, power-on reset and brown-out detection will keep equipment in reset state until supply voltage was higher than that of power on reset and brown-out detection.

In Fig. 4, working state of POR/BOD of typical 1.8 V adjusting power supply voltage with positive reset signal BOD_RESET and BOD_RESET can be observed. Reset cause for system's last can be read in register SLEEP.RST.

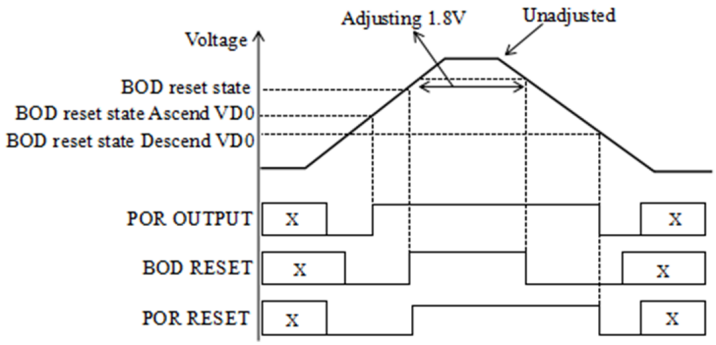

Fig. 4. Relations between power-on reset and brown-out detection

3) Others

There are 21 digital I/O pin, which can be configured as GPIO interface or used as external I/O signal to connect peripherals such as ADC, UART or timer by configuring register.

Direct memorizer access (DMA) controller was inserted in CC2430, with which CPU was basically not involved in data processing such as transmit data from ADC and RF to peripheral. DMA controller had to coordinate all DMA data transfer task to ensure DMA request and CPU access were working according to priority sequence. Data of memorizer was transferred by programming DMA path with software under DMA control. Actually, DMA controller also controlled other data transfer besides data in external data memory space.

There are two serial communication interfaces (SCI) in CC2430, T0 and USART1. Those two interfaces have two modes with some same functions, one was asynchronous serial mode and the other was synchronous serial peripheral interface.

There are two low voltage stabilizers those mainly for providing 1.8 V voltage and using as analog and digital power source. Besides, voltage stabilizers should not be used to supply power to external circuit because capacitance of power supply was limited and voltage stabilizers would produce noise which would influence stability of electric circuit.

3.2.4. Design of circuit schematic diagram: Figure 5 shows specific circuit schematic diagram.

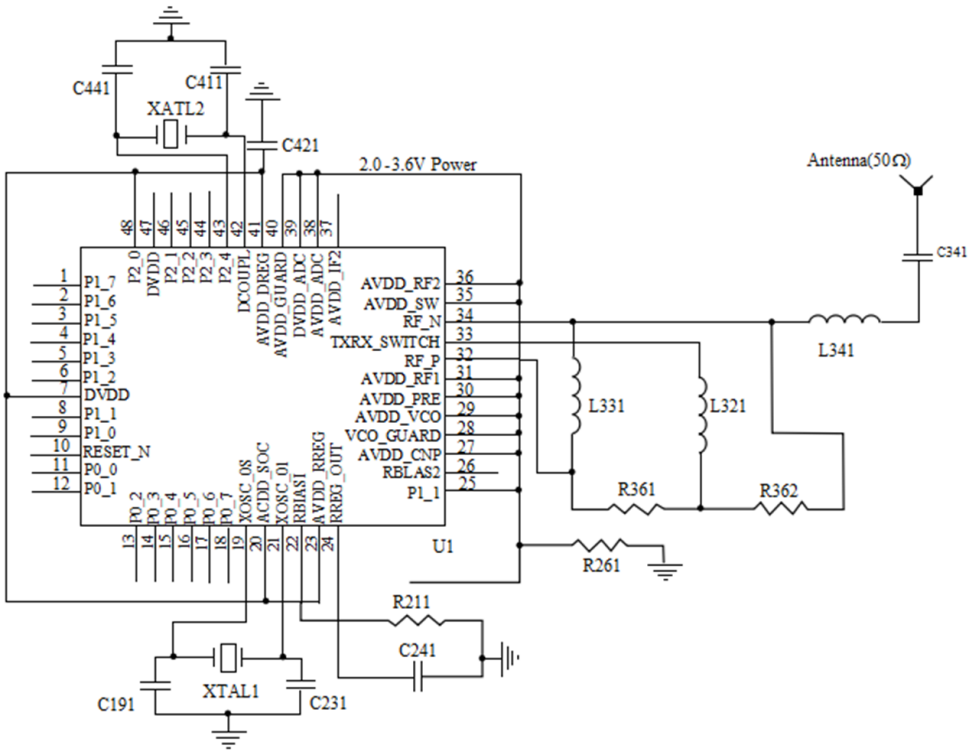

Fig. 5. Design of typical circuit schematic diagram

However, for the layout of PCB, size of decoupling capacitor of power supply, circuit layout and filtering of power supply should be well designed in order to achieve well performance. Decoupling capacitor should be close to pin for power supply and via hole should be designed separately for connecting ground plane of PCB panel. When designing external digital facilities of high speed, it should avoid disturbing RF circuit. Figure 6 shows specific PDB graph.

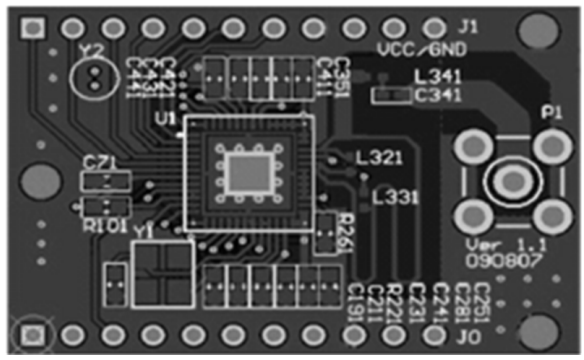

Fig. 6. PCB graph of CC2430

3.3. Software design

Software development platform IAR of ZigBee and ZStack protocol stack were used to develop software. OSAL was used to allocate tasks, which will form a simple and practical multi-task operating system through certain ways. In original state, OSAL will initialize system software and system resources. Objects of study have to be located, thus detailed analysis and study about it to be made. Code of ZigBee wireless position was based on Profile document that involves three parts, reference node, location node and coordinator. Those three parts represents three equipments and certain application range and serial ID function for equipments were identified.

XY-RSSI request: a response message will be triggered after sending serial ID 0x0011. Accepting equipment would return this XY-RSSI response message after receiving it. Location node would send this respond to reference node. Expected value calculated using collected signal strength and coordinate of X and Y will be sent by reference node to location node.

XY-RSSI response: serial ID 0x0012 was used to answer request of XY RSSI. RSSI of request information was included in expected value of RSSI. Those receipt response signal that made up of 5 bits would be stored for calculating coordinate, see Table 2 below.

Table 2. XY-RSSI information

Bit	Function
0, 1	X coordinate of reference node
2, 3	Y coordinate of reference node
4	Broadcast average value of RSSI value to itself of all reference nodes

Discovery request of location node: serial ID 0x0013 was used to locate with location node forcibly. When sending this ID, few of irrelevant content should be included. This ID can be read at location node and then coordinate of location node was achieved with a calculation. Answer to location node discovery: serial ID 0x0014. Table 3 shows ID information.

Table 3. Discovery requests of location node

Bit	Function	Value	Bit	Function	Value
0	State	0or1	6,7	Short URL of recent reference node	NO
1, 2	X coordinate calculated by location node	NO	8, 9	X coordinate of recent reference node	NO
3, 4	Y coordinate calculated by location node	NO	10, 11	Y coordinate of recent reference node	NO
5	Number of reference nodes	0∼8	12	RSSI value of recent reference node	NO

Unicast of reference node configuration: serial ID 0x0015 was sent to reference node configuration and answer request of reference node configuration. This information was obtained from PC. After this step, coordinate of reference nodes X and Y were set. Table 4 shows the configuration information.

Table 4. Configuration information of reference node

Bit	Function
0,1	X coordinate of reference node
2,3	Y coordinate of reference node

Unicast of location node configuration: serial ID 0x0016 can be used to configure location node which include A-parameter, A-parameter, running mode, information collecting time and cycle length. This information was gained from PC upper computer. Table 5 shows specific configuration information.

Table 5. Configuration information of mobile node

Bit	Function	Remark
0	A-parameter of mobile node	Intensity of electrical signal within the circumstance of 1 m around emission node was sampled
1	N-parameter of mobile node	Intensity of electrical signal within the circumstance of 1 m around emission node was sampled
2	Running mode	0: Waiting for discovery or response of information request; 1: Discover information or response automatically
3, 4	Waiting time before collection	Waiting time (ms) after sending request information
5, 6	Period	Time for one discovery under Automatic mode
7, 8	Short URL	Destination address of automatic mode to location node response. In contrast, request address.
9	Ref.end	NO
10	The minimum number of reference node	The minimum node involved in calculation

Reference node request configuration broadcast: serial ID 0x0017 was sent to the reference node to be configured. Through this command, all configuration information about position in reference node can be got and configuration broadcast of request in location node can be known whose main content was about serial ID 0x0018 which can be sent to mobile node to request node configuration information. Thus, all parameters about location node were obtained. Serial ID 0x0019 was sent several times to reference node within a given distance. Expected level of

RSSI information can be obtained with reference node. After configuring location information, software was built through hardware platform.

4. Result and analysis

A test area of 16×16 was set in basketball court (see Figs. 7 and 8) in which 6 reference nodes were set. Coordinates of these 6 reference nodes are A(0,4), B(0,8), C(0,12), D(4,0), E(8,0) and F(12,0). Three mobile nodes (a, b, c) were moving randomly in the test area and upper computer monitoring software was used to locating, tracking and analyzing theses three mobile nodes. Meanwhile, estimated positions were shown in software and marked as a1, b1 and c1.

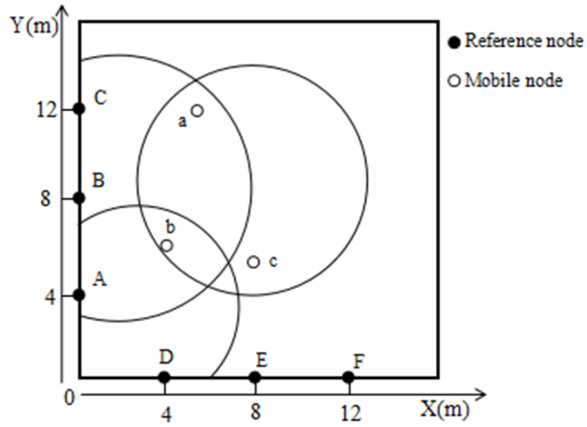

Fig. 7. Practical distribution map of mobile node at time T

Practical and estimated distribution maps of mobile node were shown in Figs. 7 and 8. Table 6 shows comparison of nodes' practical and estimated coordinates. For test result, precision analysis on location error was made, whose equation is

$$\text{error} = \sqrt{(x - x1)^2 + (y - y1)^2}\,, \tag{2}$$

where x, y are the practical coordinates and $x1$, $y1$ are the location coordinates of a point.

Table 6. Comparison between nodes' practical and estimated coordinates at time T

Type	A	B	C
Practical coordinate (m)	(6.00,12.00)	(4.00,6.00)	(8.00,5.00)
Location coordinate (m)	(6.18,11.78)	(4.13,6.35)	(8.23,4.88)
Location error (m)	0.284	0.373	0.259

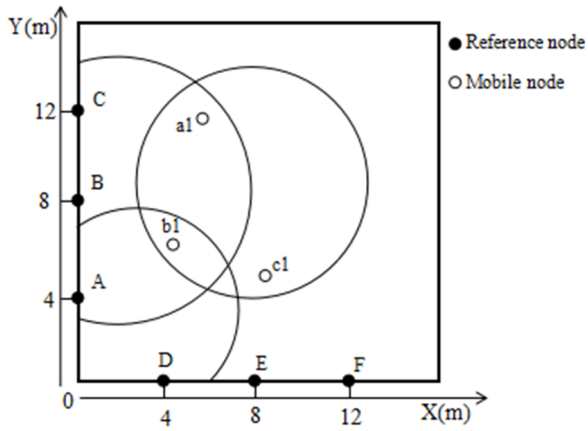

Fig. 8. Estimated distribution map of mobile node at time T

In practical, short URL of two nodes sometimes would be the same, which was tackled through repeated experiments. To sum up, method studied was proved to be feasible and effective by experimental testing.

5. Result and analysis

After analyzing existing wireless location technology, some classic location techniques of wireless local area network and specific functions provided by ZigBee technique, design scheme was put forwarded whose hardware was based on core chip of CC2430 and CC2431 and software was using Z-Stack protocol stack. Running position of football players on court were objects for study location technology based on ZigBee network. Study method that used was proved to be feasible and effective by experimental testing. There are many obstacles in this study, some of which were tackled by repeated experiments while some need further improvement.

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