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Design and Implementation Technique of the Specific Embedded System for an Instantaneous Wireless Image Observation

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Abstract

For an instantaneous wireless image observation service, the specific embedded system design and implementation technique which has the instantaneous maximum 1 fps (frame per second) rate for a 160x128 size image is proposed by applying the intelligent sensing concept based on the IoT (Internet of Things) technique to the wireless remote observation, and embodied in prototypes, which are consisted of the intelligent remote monitoring node based on the Zigbee embedded modules with a small digital camera, the provisional ad-hoc wireless network channel, and the main node for system control in this work. Through of the real wireless remote observation experiment, the proposed technique is more proper for the instantaneous and provisional observation situation of the fast start and high successes rate since the observation speed enhancement over three times is attained by the proposed methodology than the conventional observation technique.

***Keywords**: Internet of Things, embedded system, instantaneous wireless image observation, provisional ad-hoc wireless network, Zigbee, methodology, implementation.*

1. Introduction

For the security or protection service required at home or in society, the necessity of the remote monitoring service based on the IoT technique [1-3] has been recently increased [4-6]. As the IoT techniques based on the wired and wireless networks are developed, the studies to apply the developed technology to the security area are actively in progress at various fields. There have been some previous studies [7-8] that the ad-hoc wireless network technique which is widely accepted as a small range, low power, and bidirectional digital wireless communication technique is applied to the wireless remote observation system.

The wireless remote observation technique is to transfer the observed images, voices, or data from sensors by using wireless delivery tools into the observation service point, and then displays its information on the observation system [9]. If the wireless remote observation service is embodied by use of the permanent or *fixed* wireless networking (*e.g.*, WiFi scheme), the cost for the wireless observation service must be *expensive* because of its high installation cost. And so the temporary wireless networking (*e.g.*, Zigbee or Bluetooth scheme) is more preferable to the fixed wireless network because of its low cost and easy installation. However, the wireless remote monitoring based on the temporary ad-hoc wireless networking has usually the *low data transfer* capability as follows. If the wireless remote observation for a 160x128 image (*i.e.*, 20,480 pixels) is executed through ad-hoc wireless network and the 16 bit conversion scheme for one pixel is used, then the observation time for just one image has at least the lone time over three seconds because total data is 327,680 bits and the data speed except payload control bit is

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approximately 100 kbps within the maximum 250 kbps specification of the packet speed [10]. And so the conventional wireless remote observation meets a failure because of the long time interval between two successive observed images. In order to capture the instantaneous and important situation during wireless remote observation, the high speed wireless observation technique is absolutely needed under the environment of the provisional ad-hoc wireless networking.

In this work, we consider the optimal methodology and the implementation method for the *instantaneous* and *provisional* wireless remote observation service. As the extension work of the previous study [11], the specific embedded system design technique which provides the instantaneous high speed wireless image transmission with temporary ad-hoc wireless networking is proposed by combining the intelligent sensing concept based on the IoT technique with the wireless remote observation. The proposed system is composed of the intelligent remote monitoring node with camera processing function, the main node, the system controller with the 1 fps wireless image transmission capability for a 160x128 size image, and the provisional ad-hoc wireless network channel.

In Section 1, we described the challenges of the conventional wireless remote observation technique and the motivation of this work. In Section 2, we propose the methodology of the specific embedded system design that provides the high speed transmission with temporary ad-hoc wireless network for the instantaneous wireless remote observation service. In Section 3, we present the system design and implementation of the proposed techniques. In Section 4, we describe an experiment and analysis study with the implemented prototype. Conclusions are described in Section 5.

2. An Instantaneous Wireless Image Observation

There has been made use of the fixed wireless network transmission or the unidirectional analog transmission scheme in the conventional wireless remote image observation so far. The methodology considered in this work exploits the instantaneous wireless image observation by use of the intelligent sensing concept based on the IoT technique and the ad-hoc wireless network which has the provisional, bidirectional, easy implementation, and low installation cost characteristics. The methodology and the system architecture design of the proposed idea are described in this section.

2.1. Methodology

The key task of the proposed concept in this paper is the embodiment of the instantaneous wireless image transmission, where the camera image packets recorded the remote real situation are quickly delivered by use of the temporary ad-hoc wireless network transmission into the observation point instead of the conventional slow packet transmission or the limited survey of sensing information. In this work we apply the *intelligent sensing* concept based on the IoT technique into the instantaneous wireless image observation technique in order to increase the observation speed for instantaneous observation. To embody the proposed idea, we consider the methodology of the specific embedded system design for the instantaneous and provisional wireless image observation as shown in Figure 1, where the specific embedded system is constructed by the PC based system controller with the main node, the provisional ad-hoc wireless network channel, and the intelligent remote monitoring node built in the camera control function instead of the monitoring node of the conventional wireless observation.

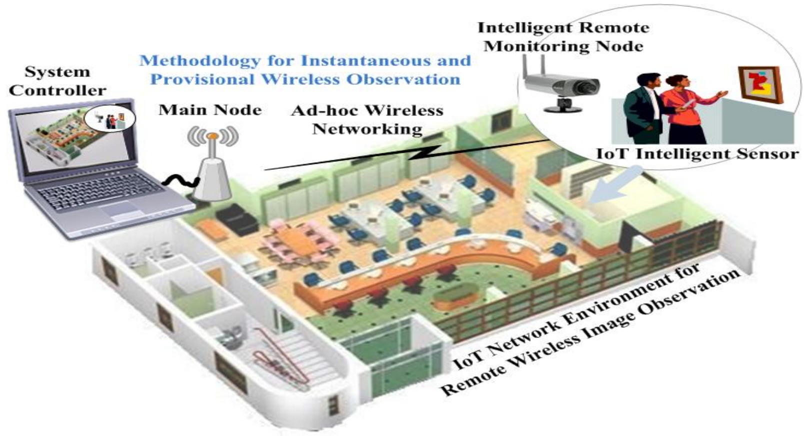

Figure 1. The Methodology of the Specific Embedded System Design for the Instantaneous Wireless Image Observation

The proposed methodology of Figure 1 is executed as follows: when the user wants to observe instantaneously the real situation around the specific observation point of the building for security reason or remote monitoring (*e.g.*, the instantaneous observation around the man and woman who are enjoying a picture in the specific area of the building), the system controller of the proposed observation system commands the intelligent remote monitoring node around target to execute the instantaneous observation by use of the provisional ad-hoc wireless networking. Then the remote intelligent monitoring node captures and collects the target's image for several seconds by the built-in camera, converts the observed image into the compressed image data (*e.g.*, the JPEG encoded data), and formats the compressed image data into the wireless image packets of the provisional ad-hoc wireless network frame. The wireless image packets are moved from the intelligent remote monitoring node into the main node according to the ad-hoc wireless network (*e.g.*, Zigbee) protocol. Finally, the system controller reconstructs the compressed image data and displays the observed image on the screen of the system controller.

In the conventional wireless observation system, it is natural that the wireless image transmission has the *low* transfer rate because all the camera operation inside the remote monitoring node is directly controlled *one by one* by the *far away* PC based system controller around the main node, and the wireless transmission data between the system controller and the observation camera includes the original image plus the camera control data together. However the instantaneous wireless image transmission in the proposed methodology has the high transfer speed since all the camera operation is perfectly ruled and controlled by the *nearby* intelligent *remote* monitoring node around the target, and the wireless transmission data between the system controller and camera includes the only pure image data except control bit. Here the intelligent remote monitoring node of the proposed methodology can be regarded as the *intelligent sensor* on the IoT network.

The major specification of the specific embedded system considered according to the proposed methodology is listed as shown in Table 1. The ad-hoc wireless network technique (*i.e.*, Zigbee scheme) of the proposed methodology has the hierarchical architecture similar to the general wireless communication technique as follows. The PHY and MAC layers (*i.e.*, the lower layers of hardware and firmware respectively) are specified by the IEEE 802.15.4 standard for the low data rate wireless personal network. The NWK, APS, ZDO, and AF layers (*i.e.*, the higher layers of software) are ruled by the Zigbee specification [10]. The Zigbee scheme has the advantages of the lower power consumption than the other scheme (*e.g.*, Bluetooth or UWB) and the good wireless networking capability among the short range wireless communication schemes.

Table 1. Major Specification of the Designed Specific Embedded System

Specification	Description
overall transfer speed image acquisition speed	115 kbps serial data communication 1 fps image observation
observed image size	Normal 160x128 (20,480pixels) Max 328x240 (78,720pixels)
wireless networking protocol	IEEE 802.15.4(PHY/MAC layers) Zigbee (NWK/ZDO/AF layers)
physical link	2.4 GHz carrier frequency/16 channel modulation DSSS-QPSK data rate 250 kbps/chip rate 2 Mcps

The specification of the PHY and MAC layers has something to do with the wireless modem and its application. The wireless modem used in this work has the following features: the carrier frequency is about 2.4 GHz, the number of channel is 16, the frequency bandwidth between channels is 5 MHz, the spreading technique is direct sequence spreading spectrum (DSSS), the modulation is offset QPSK scheme, and the maximum data speed is 100 kbps except the payload within frame while the maximum packet speed is 250 kbps. Also, the carrier sense multiple access-collision avoidance (CSMA-CA) and slotted-CSMA with beacon signal techniques are applied in the MAC layer.

2.2. System Architecture Design

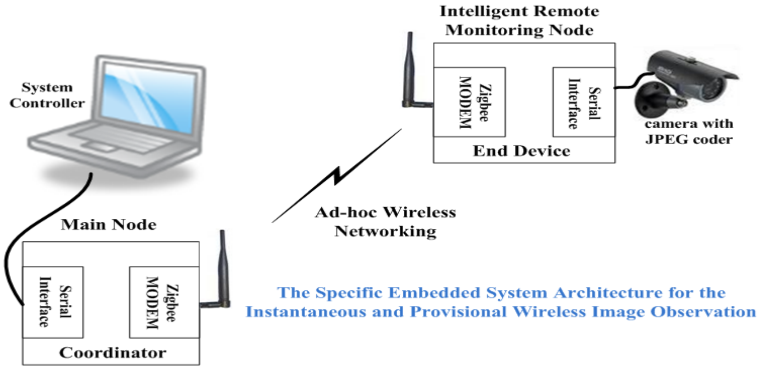

Figure 2. The Specific Embedded System Architecture Designed by the Proposed Methodology for the Instantaneous Wireless Observation

In order to embody the specific embedded system with the major specification of Table 1 for the instantaneous and provisional wireless image observation, we propose the system architecture for the specific embedded system as shown in Figure 2, where the PC-based system controller inside the specific embedded system is connected to the main node by the serial data communication scheme, and the main node has the role of coordinator in the temporary ad-hoc wireless network transmission. The main node has the functions of the serial interface, and the transmission and reception of packet by wireless modem, and also the main node commutes the maximum 10 mw output power into the intelligent remote monitoring node.

The intelligent remote monitoring node within the specific embedded system architecture of Figure 2 is connected to the system controller by the serial data communication scheme, plays a role of router or end device, and holds the same network address of the coordinator (*i.e.*, main node). The camera module inside the intelligent remote monitoring node converts the observed image into compressed packet data using the image compression scheme, and transfers the compressed packet data into the intelligent remote monitoring node.

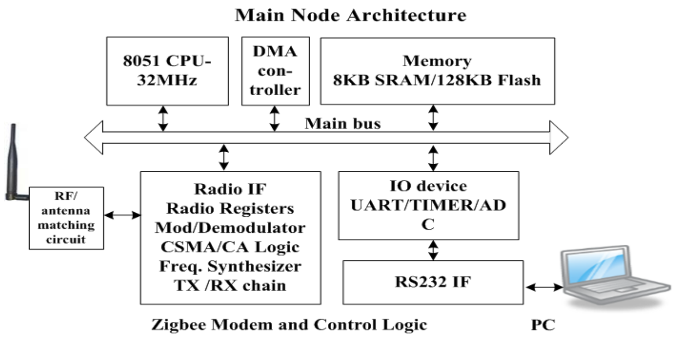

Figure 3. Architecture of the Main Node inside the Proposed Observation System Designed for the Instantaneous Wireless Image Observation

Figure 3 shows the detailed description of the main node architecture inside the proposed observation system of Figure 2. The main node is implemented on the basis of the commercial develop board and the serial data communication scheme. The internal architecture of the main node is divided into the four blocks as follows. The CPU block is composed of the 8051 CPU core using a 32 MHz clock, the DMA controller capable of moving a couple of data without CPU, and its peripheral circuits. The memory block has 8 kB SRAM and 128 kB flash memory, where the SRAM is used as the program memory for system operation and the flash memory is utilized as data memory. The radio block as a key module of the ad-hoc wireless network communication has a modulator and demodulator, the algorithm logic of CSMA-CA MAC layer for channel arbitration, a frequency synthesizer, and its peripheral logic. The *radio block* plays a role of transmitting the 2.4 GHz signal, where the data is transferred into the ad-hoc wireless network channel by whip antenna after the frame formatting, the modulation, and the channel allocation. The I/O port block has a timer, an ADC, and UART. And it is connected to the system controller by the serial data communication interface. All the blocks are connected through the eight bits main bus.

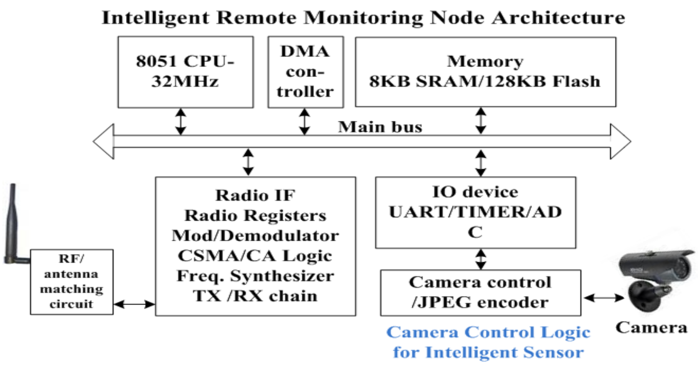

Figure 4. The Intelligent Monitoring Node Architecture Inside the Proposed Observation System Designed for the Instantaneous Wireless Observation

Figure 4 shows the detailed view of the intelligent remote monitoring node inside the specific embedded system of Figure 2. The intelligent remote monitoring node is implemented on the basis of the commercial developed board, a small camera module, and its serial communication scheme. The intelligent remote monitoring node is also composed of the four blocks similar to the main node of Figure 3.

3. Design and Implementation of the Specific Embedded System

The specific embedded system considered in this work for the instantaneous wireless image observation as shown in Figure 1 is designed and implemented according to the proposed methodology in this section. The specific embedded system is designed on the basis of the two commercial embedded developed boards, where one is the embedded board for the system controller with prototype as a role of the main node, and the other is the embedded board for the remote observation device with prototype as a role of the intelligent remote monitoring node. The designed specific embedded system has the two main operations as follows: One is the instantaneous wireless transmission of the observed image packet except the camera control data from the intelligent remote monitoring node into the main node through the provisional ad-hoc wireless networking. The other is the display of the received image packet on the user interface (UI) screen of the system controller connected to the main node.

The designed specific embedded system is carried out as follows. The provisional ad-hoc wireless networking between the nodes is first constructed by the request command of the end device as a role of the intelligent remote monitoring node and the coordinator as a role of the main node. However the camera initialization step and the collection process of the observed image packet are only executed by the request of the end device (*i.e.*, the intelligent remote monitoring node) unlike the conventional wireless observation scheme that the camera operation is *entirely* enforced by the system controller within the main node. The collected image packet within the end device is transferred into the main node by ad-hoc wireless network transmission, and so the transferred image packet is displayed on the screen of the system controller.

As it is seen in Table 1, the image acquisition speed by the intelligent remote monitoring node within the designed specific embedded system has the instantaneous maximum 1 fps rate for a 160x128 image. The overall speed of the proposed observation system is *completely* dependent of the wireless transmission capability, *i.e.*, the data transfer speed between the modules. Both the local interface between the camera module and the intelligent remote monitoring node, and the main interface between the main node and the PC-based system controller are utilized by the general serial data communication scheme, and so the maximum data transfer speed of the proposed observation system has the approximately 100 kbps for a 160x128 image.

The embedded software architecture and its signal flow for the intelligent remote monitoring node inside the proposed observation system is designed as shown in Figure 5, where the embedded software of the intelligent remote monitoring node for the instantaneous wireless image observation is operated as follows. When the power of the proposed observation system becomes ON state, the main program (*i.e.*, Zmain.c of Figure 5) starts to be executed. And the hardware board, the internal memory, the hardware driver, and its operating system are initialized, and the stack pointer indicates the program of Osal.c which checks whether any event is present or not.

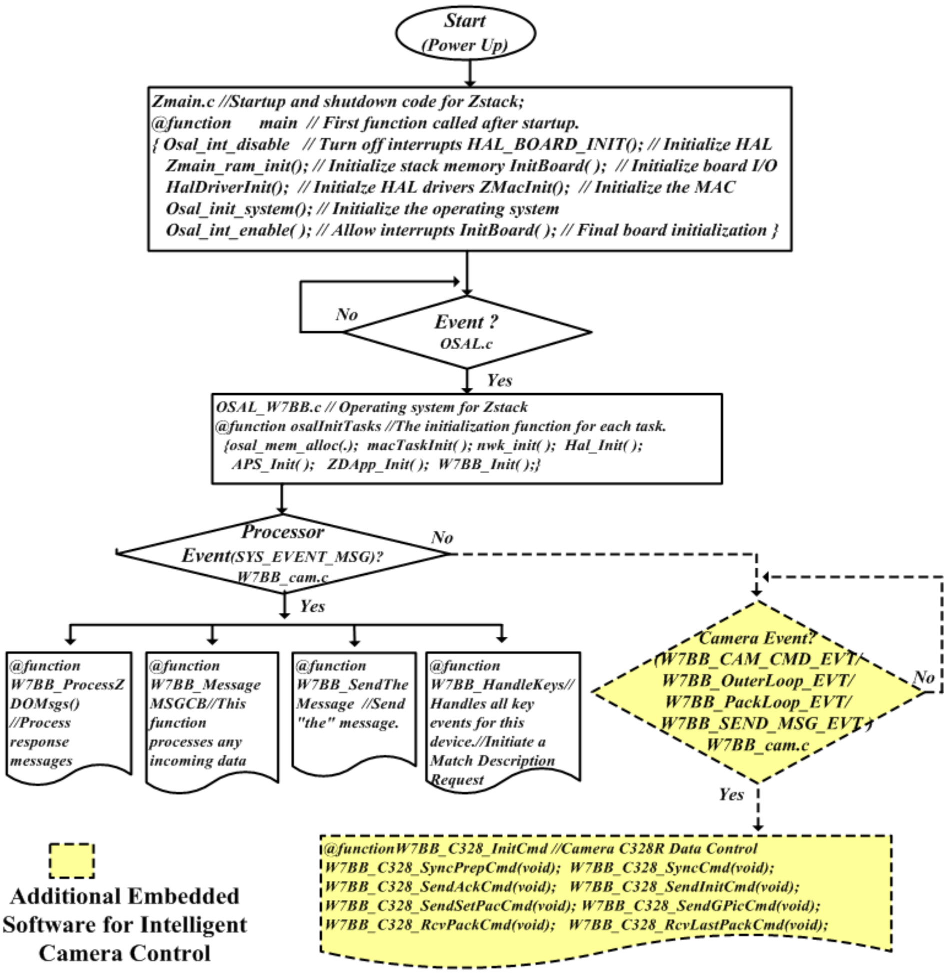

Figure 5. The Embedded Software Architecture for the Intelligent Remote Monitoring Node within the Proposed Observation System

If the event is occurred, then the stack point indicates the program of Osal-W7BB.c, where the memory allocation and the initialization of each layer are made. And the stack point indicates the program of W7BB-Cam.c, where various processor events are tested. When the network binding process for temporary ad-hoc wireless networking is executed by the request of the intelligent remote monitoring node, the function of W7BB-HandleKeys is activated according to the network binding protocol. The compressed packet data is transmitted from the intelligent remote monitoring node to the main node through ad-hoc wireless network transmission, and the function of W7BB-ProcessMSGCmd of the program W7BB-Cam.c within the main node is activated, and the image packet is stored into the internal memory. Then the received image data is transferred to the system controller through serial data communication scheme, and the UI program recovers the compressed packet data and displays them onto the screen of the system controller. Unlike the conventional wireless observation, the camera initialization and the reception of image packet data are accomplished by activating the various functions (*e.g.*, W7BB-CAM-CMD-VT) of the program of W7BB-Cam.c within the intelligent remote monitoring node, and the system controller of the proposed observation system is *not directly* related with the camera operation *at all*.

4. Experiment and Performance Analysis

4.1. Implemented Prototype

The prototypes of the proposed observation system for the instantaneous and provisional wireless image observation are implemented as shown in Figure 6.

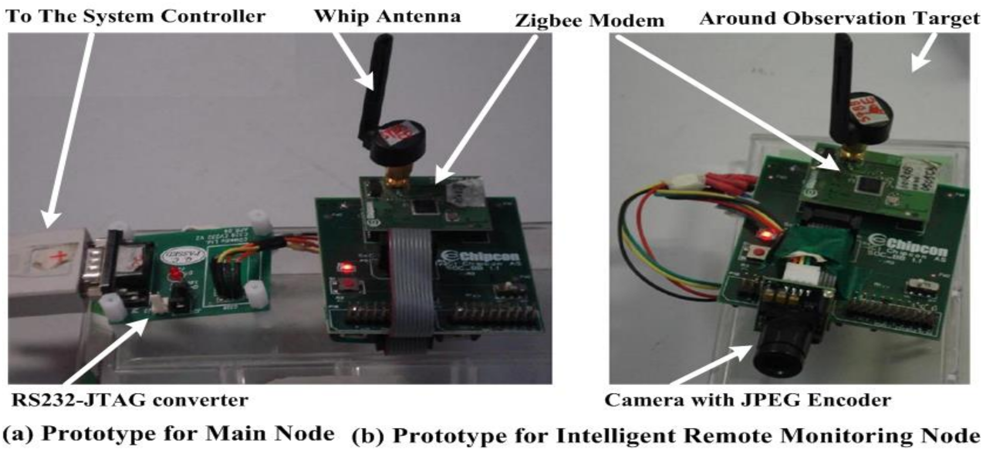

Figure 6. The Implemented Prototypes of the Proposed Observation System for the Instantaneous Wireless Image Observation

Figures 6(a) and 6(b) show the implemented prototypes of the main node and the intelligent remote monitoring node inside the proposed observation system for the instantaneous and provisional wireless image observation. With the proposed methodology of Figure 1 and the major specification of Table 1, the observation system is implemented as follows. Each node are developed by combining the modified commercial develop board with ad-hoc wireless networking (*e.g.*, TI's CC2xxx series), and the main node has the hardware architecture of Figure 3. The hardware architecture and the embedded software architecture of the intelligent remote monitoring node are the same as shown in Figure 4 and Figure 5 respectively. The camera module inside the intelligent remote monitoring node is the small camera built-in the functions of the JPEG image coding algorithm and the serial data communication scheme, where the part name of the camera module is the C328-3xxx kit with the specifications of 20x28 mm size, 3.6 mm focal length, 660 FOV, VGA resolution. The main interface between the PC based system controller and the prototype for the main node uses the serial data communication scheme, which are also applied to display the observed image on the screen of the system controller.

The embedded software for the intelligent remote monitoring node built-in all the functions of the Figure 5 including the intelligent camera control function is implemented by the software coding work based on the TI's Zigbee stack, and the embedded software for the main node built-in the function of the Figure 5 except the intelligent camera control function part is also embodied by the software coding work based on the TI's developing tool.

4.2. Experiment

The experiment was carried out as shown in Figure 7 with the implemented prototypes of Figure 6 under the wireless image observation environment of the line-of-sight channel and the temporary ad-hoc wireless networking for verifying the implemented prototypes of the proposed observation system.

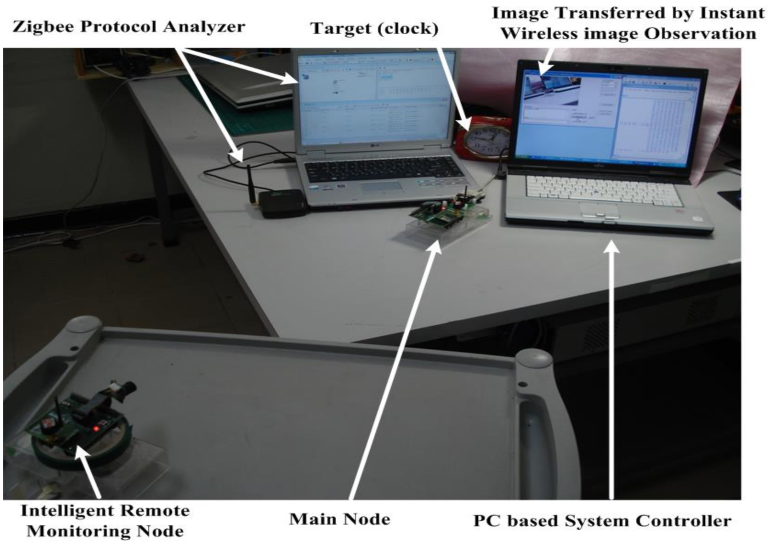

Figure 7. The Instantaneous Wireless Image Observation Test with the Implemented Prototypes for Verifying the Proposed Observation System

The test environment for the instantaneous wireless image observation is constructed as follows: a target (clock object) is located at 127 cm away with line-of-sight condition from the intelligent remote monitoring node, and the distance between the main node and the intelligent remote monitoring node is approximately 100 cm away. Zigbee protocol analyzer is utilized for analyzing the provisional ad-hoc wireless networking and its channel characteristic, and the PC based system controller is operated for displaying the result of the instantaneous wireless image observation test as shown in Figure 7.

After constructing the provisional ad-hoc wireless networking between the intelligent remote monitoring node and the main node, the intelligent remote monitoring node *orders* the camera to execute the initialization operation and the image acquisition. Then the intelligent remote monitoring node starts to transfer the collected image to the main node. In other words, the JPEG encoded compressed image packet except control bit is transferred from the intelligent remote monitoring node to the ad-hoc wireless network channel. During the wireless image observation experiment of Figure 7, the intelligent remote monitoring node transfers the captured clock image from the camera inside the intelligent remote monitoring node to the main mode through temporary ad-hoc wireless networking, and the main node displays the transferred image on the screen of the system controller at a speed of 1 fps wireless transmission for a 160x128 image.

In order to verify the implemented prototypes for the instantaneous and provisional wireless image observation, the ad-hoc wireless network protocol analyzer is utilized for the instantaneous and provisional observation test as shown in Figure 7 and Figure 8, where the ad-hoc wireless network channel and the wireless image transmission are fully analyzed. The test result on the screen of the Zigbee protocol analyzer from the experiment of Figure 7 was represented in Figure 8, where the ad-hoc wireless networking result between the intelligent remote monitoring node and the main node (*i.e.*, the result of wireless image observation test of Figure 7) was shown in the top of the left side, the image packet data captured by Zigbee protocol analyzer was described in the bottom side, the ad-hoc wireless network protocol communicated between nodes was represented in the middle side, and the packet (*i.e.*, image plus control data) captured by Zigbee protocol analyzer was shown in the top of the right side.

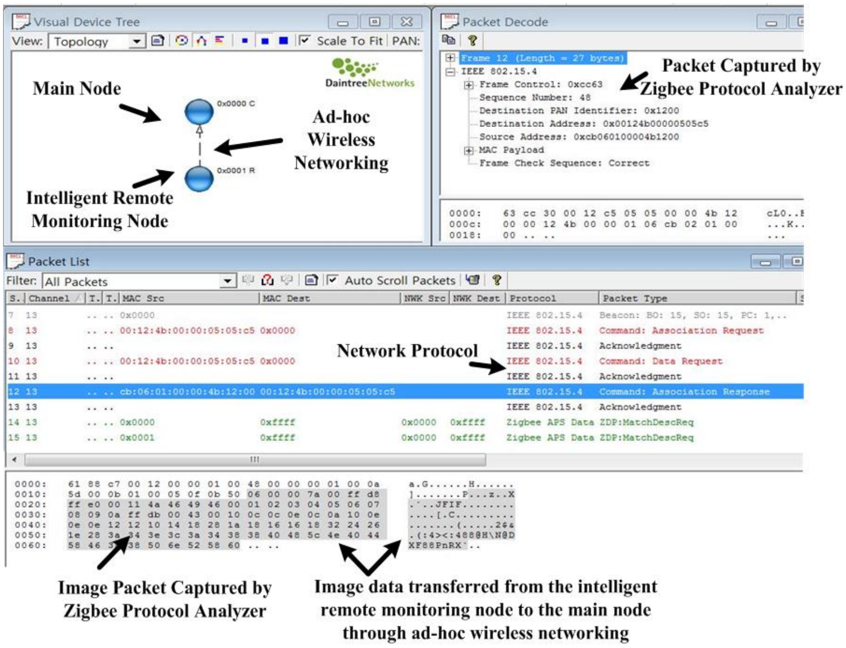

Figure 8. The Analyzed Result of Zigbee Protocol Analyzer Obtained from the Instantaneous and Provisional Wireless Observation Test of Figure 7

The provisional ad-hoc wireless network binding process is executed in order to bind the layers of the main node and the intelligent remote monitoring node as shown in Figure 8. The process of building up the ad-hoc wireless networking in the wireless channel is fully described in the middle side of Figure 8, where the main node as a role of the pan coordinator that the network address is randomly assigned send the “Beacon Request” signal several times by broadcast transmission scheme in order to construct the network binding with the other nodes, and so the nearby router (*i.e.*, the intelligent remote monitoring node) sends the “Associate Request” and “Data Request” signals to the main node for its response by unicast transmission scheme. The main node sends “Associate Response” signal to the responding nearby router again, and then the network binding of the physical and MAC layers between the two nodes has been completed. During network binding, the unique physical addresses of the main node and the intelligent remote monitoring node (*e.g.*, the 64bit addresses as 0X00 12 4B 00 00 05 05 C5 and 0X00 12 4B 00 00 01 06) are interchanged as shown in the middle side of Figure 8. The ad-hoc wireless network binding process is competed if the coordinator and the router commute the “MatchDescReq” messages. The logical network address (*e.g.*, the 16 bit addresses as 0X0000 and 0X0001 shown in the middle side of Figure 8) are interchanged similar to the interchanging case of the physical address.

4.3. Performance Analysis

The performance experiment for the instantaneous and provisional wireless observation speed comparison between the proposed and the conventional techniques was carried out under the condition that the implemented prototypes for the proposed observation system of Figure 7 are utilized for the speed comparison, and the proposed technique is based on the intelligent remote monitoring node. The comparison result was represented in Figure 9, where the proposed technique preserves the 1 fps observation speed within the instantaneous observation region, however the conventional technique has the low 0.3 fps speed within the full range of the instantaneous observation.

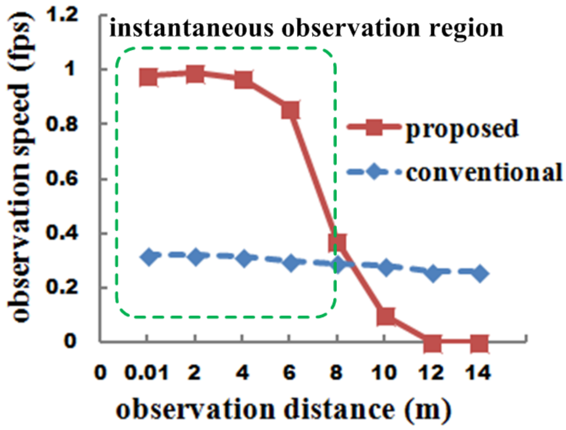

Figure 9. Observation Speed Comparison between the Proposed Technique based on the Intelligent Remote Monitoring Node and the Conventional Technique

We could know from the test result of Figure 9 that the proposed technique based on the intelligent remote monitoring node is more preferable to the conventional technique in order for the instantaneous and provisional wireless image observation, and the observation speed enhancement over three times is attained by the proposed technique in the short or mid-range of the 0.01~6 m observation distance.

The success rate comparison test between the proposed and the conventional techniques was accomplished under the condition that the implemented prototypes of Figure 7 are utilized for the success rate comparison, the proposed technique is operated with the intelligent remote monitoring node, and the conventional technique is managed with the ordinary monitoring node. The test result was shown in Figure 10, where the proposed technique has the error-free wireless image observation within the instantaneous observation region (*i.e.*, 0.016~0.6 minute observation time), but the conventional technique meets to a failure during the instantaneous observation region and the error-free observation after the instantaneous observation range.

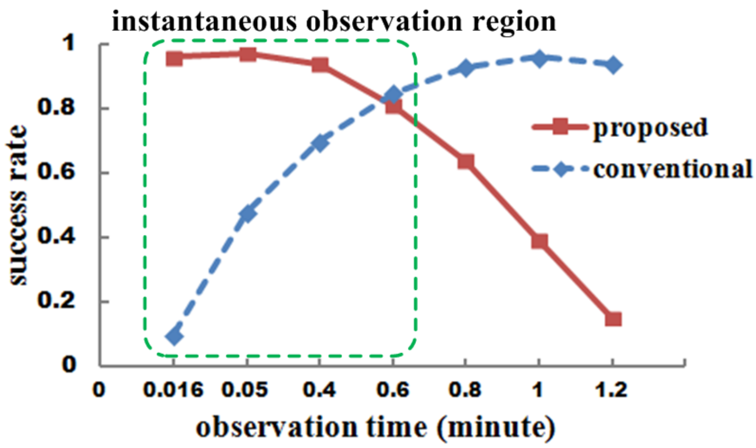

Figure 10. Success Rate Comparison between the Proposed Technique based on the Intelligent Remote Monitoring Node and the Conventional Technique in the Instantaneous Observation Region

We could see from the result of Figure 10 that the proposed technique is more proper for the wireless image observation than the conventional technique under the real environment of the instantaneous and provisional observation situation of the fast start and high successes rate. On the other hand, the conventional technique is suitable to the slow start and long range observation.

5. Conclusions

For the instantaneous wireless remote observation, the provisional wireless network is more preferable to the fixed or permanent network because of its easy installation and low cost. However, the conventional wireless remote observation meets a failure because of the long time interval of the image acquisition and the low rate transfer capability.

In order to capture the observed image at the instantaneous and important situation during wireless remote observation, combining the wireless image observation technique with the *intelligent sensor* based on IoT technique was considered to increase the observation speed for the instantaneous and provisional wireless image observation, and the optimal methodology and the implementation method was studied. And then the specific embedded system design technique which provides the instantaneous high speed wireless image transmission with temporary ad-hoc wireless networking was proposed. The implemented system is consisted of the intelligent remote monitoring node, the main node, the system controller with the 1 fps wireless image transmission capability for a 160x128 size image, and the temporary ad-hoc wireless network channel.

We could see from the real observation experiments that the observation speed enhancement over three times is attained by the proposed methodology in the mid-range of the 0.01~6 m observation distance, and then the proposed technique is more proper for the instantaneous and provisional observation situation of the fast start and high successes rate.

Acknowledgments

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