High resolution vision sensor transmission control scheme based on 3G and Wi-Fi

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Abstract: Embedded intelligent vision sensor technology has become a research hotspot of wireless vision sensor network (WVSN) due to its low cost and high efficiency image capturing. In earlier research, a low cost and high resolution agricultural vision sensor (HRAVS) was developed based on the platform S3C6410 and OV3640 in South China Agricultural University. In this paper, a vision sensor remote transmission control schema (VSRTC) was developed to enable HRAVS to communicate with each other in various communication technologies (cable, 3G, 4G and Wi-Fi). The combination of HRAVS and VSRTC can be applied in many areas of the Internet of Things (IOT) in Agriculture. This paper introduced design of application architecture, transmission control protocol, and the node's application software of the VSRTC-HRAVS. A WVSN test was conducted for 25 days with 10 camera nodes in experimental fields of South China Agricultural University. Node control stability, the image capturing and encoding performance, the overall average image capturing time and the average frame rate of video capturing under different resolutions were evaluated in a series tests. The results showed that the new camera nodes were able to effectively carry out 3 capture modes (command response/cycle response/video), and under the re-transmission mode, the instruction loss rate was below 1% of all nodes. Given image pixel of 1.3, 2.0 and 3.2 Mpixel, when running without networking, the shortest average overall image processing time of the node were 6.2, 8.2 and 11.1 s respectively, and the largest video frame rates were 58.7, 34.6 and 16.4 frames per second, respectively; When running networking, the shortest average overall image processing time of the node were 17.6, 26.9 and 49.6 s respectively, and the highest video frame rates were 20.2, 16.1 and 9.3 frames per second, respectively. This scheme supported high resolution image and video transmission which can be applied in the field of agriculture where real-time transmission is not highly demanded.

Key words: wireless sensor network; vision; transmission control protocol; high resolution agricultural vision sensor (HRAVS); vision sensor remote transmission control schema (VSRTC)
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0 Introduction

Collecting farmland information is the key and the beginning point to precision agriculture[1-2]. The image information is of intuitive, real-time, informative, and non-destructive performance, etc. It can provide basic data for pest and disease control, crop growth and crop yield estimation and other detection[3-4]. Thus, accurately capturing intuitive images in real-time can help farmers make the right scientific decision. In recent years, Embedded intelligent vision sensor technology has become a research hotspot of wireless vision sensor network (WVSN) due to its low cost and high efficiency image capturing[5-8]. It has been developed for different applications.

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Lloret et al.[7] design an image sensor node with an image processing system for the monitoring of the vineyard, with Atheros AR7161 and Hercules Classic Webcam, but the acquisition of image resolution is only up to 1280 ×1024 pixels. Garcia-Sanchez et al. [8] design an integrated wireless sensor network (WSN) system for crop monitoring, video-surveillance and the process of cultivation control. The sensor nodes are organized to form a ZigBee network through CC2420. But that paper did not mention catching images and the pixel control of images. Guerin et al.[9] present an acquisition system for CMOS (Complementary Metal Oxide Semiconductor) vision sensor with a true 10GBit/s bandwidth, and its resolution of image acquisition by LUSIPHER CMOS is up to the 0.64 Mpixel. Cao et al.[10] design an image sensor node for wireless sensor networks with FPGA(Field-Programmable Gate Array), CMOS LM9628, and CC1000 which is an RF module and power supply unit. LeGall wavelet transform is used in image compression. The resolution of image capture is only 0.3-M pixel. Zhao et al.[11] design an image sensor node and WSN networks with SoC THLK2405 and OV7640 for crop monitoring. The acquisition of image resolution is only 640 ×480 pixels. Liu et al. [12] design a set of farmland image acquisition nodes based on FPGA and 3G transmission system. The transmission time of an image is about 5.42 s. However, video acquisition and pixel effective control are not considered. Xiong et al. [13] design a farmland image acquisition and wireless transmission system based on ZigBee and GPRS. The system camera resolution is up to 1.3 Mpixel, and the image's transmission success rate is 76% in the actual test. Zhao et al. [14] design an image sensor node for the greenhouse environment based on CC2430 and LPC1766 chip. And the system uses ZigBee for transmission of image. The transmitting time for a frame is approximately 135 s. But the camera is just 0.3 Mpixel.

In an earlier published paper by our research group[15], a high resolution agricultural vision sensor (HRAVS) with low cost is developed based on the platform S3C6410 and OV3640 in South China Agricultural University. The HRAVS can capture 3.2 Mpixel images in the farmland, and white balance, brightness, contrast, saturation and other pixel effects of the HRAVS's could be controlled dynamically. In researching above, the GPRS network is usually used for long-distance data transmission, and the Bluetooth or ZigBee technology is used for short-distance data transmission. However, GPRS data transmission is at a low speed and easy to cause data loss. The communication distances of Bluetooth and ZigBee are short. As a result, these network technologies cannot meet the requirement of high quality agricultural video or image data transmission. Therefore, new camera node design technology with further transmission distance and higher pixel of image/video transmission performance is necessary.

Therefore, this study proposed a vision sensor remote transmission control scheme (VSRTC) for the HRAVS (VSRTC-HRAVS) that can be applied to WVSN and the Internet of Things. It hopes that the new camera node with VSRTC could transmit higher pixel of image/video data over a greater distance.

1 Principles of VSRTC

1.1 Application architecture of VSRTC

Fig.1 shows the application architecture of VSRTC. The whole system consists of three parts: camera nodes, transmission control protocol, and application software. The WVSN includes all the camera nodes, and responsible for collection and transmission of video/image data. Transmission control protocol connects camera nodes, gateway and server, and is responsible for receiving instructions and transmitting the data back to the server. Application software serves the server and client, which runs on the server in a B/S mode.

In Fig.1, the camera node is a new HRAVS with VSRTC (also known as HRAVS camera node). The HRAVS camera node can communicate with the others through cable, 3G, 4G and Wi-Fi communications technologies, and it consists of central processor, HRAVS, communication module, power supply module and the other interfaces.

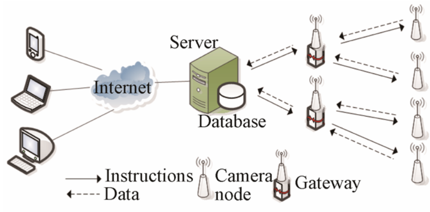


Fig.1 Overall design of vision sensor remote transmission control schema

Gateway receives instructions from the server, and also collects image data from camera nodes. It requires at least 2 wireless transmission interfaces. The 3G or 4G interface connects to the remote server, and the Wi-Fi interface communicates with camera nodes. S3C6410 ARM platform is used as a gateway platform for its abundant peripheral resources.

There are two types of data flow between camera nodes and the gateway (Fig.1): the instruction flow from the gateway to the camera node, and the image or video data flow from camera node to the gateway. Three kinds of 3G technologies could be chosen in China, including wideband code division multiple access (WCDMA), code division multiple access 2000 (CDMA2000) and time division-synchronous code division multiple access (TD-SCDMA). Among them, WCDMA can provide the highest bandwidth (up to 384 k/s) and it is most commonly used in China. The WCDMA technology was thus used to transmit data in the VSRTC.

1.2 Transmission control protocol

1.2.1 Instruction and data transfer encoding

According to the characteristic features of the data transmission, the ASCII code is used as a transfer encoding with the format standard in Table 1. All the instructions begin with a "@"; image data begin with a "%"; video data begin with a "#". All information is ended with a string of "000" and the instruction is consisted of uppercase characters and numbers. A camera node has three capture modes: command response, cycle response and video types. And its pixel is adjustable. Some detailed instructions that sent from server to camera node are shown in Table 1.

Table 1 Transfer instruction code

Instruction code	Name	Parameters
C001	Capture	Resolution, white-balance, bright, contrast, saturation
C010	Cycle capture	Cycle timer, auto pixel effect
V001	Video start	Auto pixels effect
V010	Video stop	Null
E000	Task end	Null

1.2.2 Transport interface

The TCP protocol provides reliable transmission for instruction data, and the flexible UDP transmission protocol is used for a large amount of data, such as the image or video with a small transmission time delay. Communication protocols between the camera nodes and the gateway are realized through the network socket programming in the application layer. A streaming socket (SOCK_STREAM) is created to apply the TCP connection to the gateway in a reliable way, and a data-gram socket (SOCK_DGRAM) is created to apply the rapid UDP connection to the gateway to transport image and video data. The communication protocol used by camera nodes is illustrated in Fig.2.

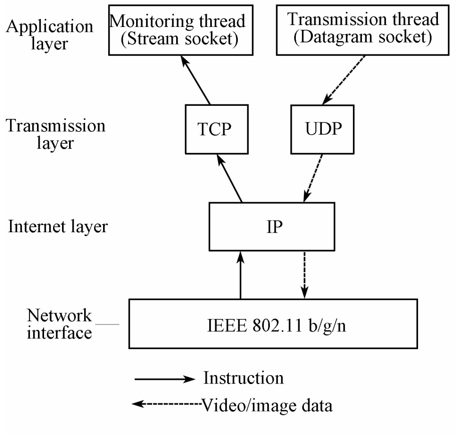


Fig.2　Transport interface protocol

1.2.3　Protocol control

In order to control the capture modes and the pixel effect, the driver and the application layer need to work in harmony. A detailed schema of the pixel effective control is presented in reference [15]. In order to put the camera nodes in use in the agricultural Internet of Things, this paper proposed a camera node transmission control protocol using 3G/4G and Wi-Fi communication technology. Camera node runs in multi-threading for the requirements of control for capture mode and pixel effect. As shown in Fig.3, main threads of the program are network monitoring, image acquisition control and data sending thread. The network monitoring thread is responsible for accepting instructions from the gateway. The image capture control thread is responsible for capturing the video/image data and controlling pixel effect, which is also the working thread of the camera node. Sending thread is responsible for transmitting the video/image data back to the gateway. The re-transmission network protocol scheme was adopted by the VSRTC to guarantee the reliable transmission.

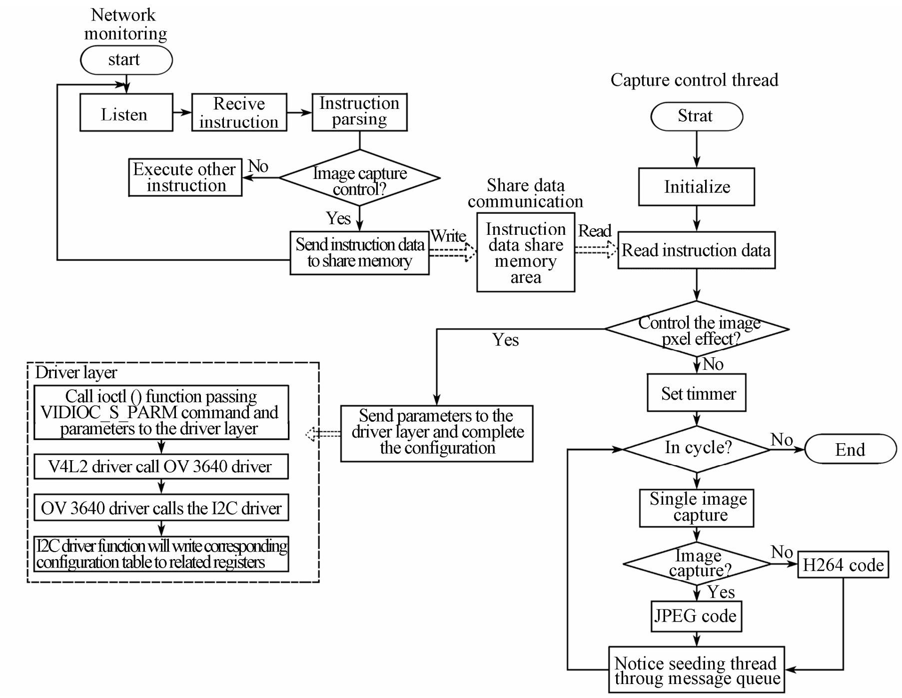


Fig.3　Control flow diagram

1.3　Application software

The application software service is needed for camera nodes, the gateway and the server. The camera node software design is the most important part of the whole application software. It is not only responsible for capturing and sending the video/image data, but also responsible for controlling transmission.

The main software process is shown in Fig.4. The software deployed on the server is agricultural image capture management platform (AICMP). The Windows operating system is used for its wide scale and convenience. The AICMP includes data query, system maintenance, camera node control and logging sub-modules. Main modules of AICMP is shown in Fig.5. The camera node control module and the system maintenance module are the core of the implementation. Their principal functions are sending, receiving, and displaying information. The Interface of the AICMP provides a nice user interface utilizing the Baidu map as the main web layout. The new camera nodes provide 3 types of capture modes for user: command response, cycle response and video mode.

2　Experiments with VSRTC in WVSN

2.1　Experiment design

A 25-day WVSN experiment was conducted in the vegetable plantation of South China Agricultural University in CenCun (23°16′19″N, 113°37′34″E). It tested the actual image quality and transmission control performance. Ten camera nodes divided into two groups individually layout in different plots of vegetable plantation were used. Every two nodes were installed with a distance about 30 m and the gateway was placed on the ridge of the field. An example of one of the camera nodes is shown in Fig.6. Node control stability of the Internet application, the image capture and encoding performance of the new camera node in local state, the overall average image processing time and the other networking transmission performances were evaluated in the experiment.

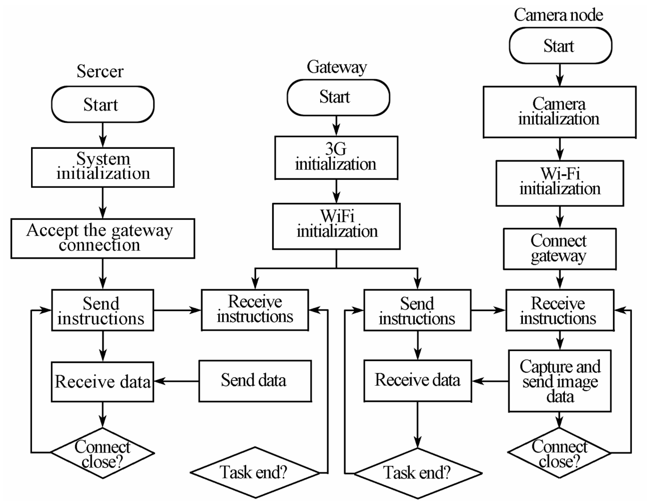


Fig.4 Main process of system

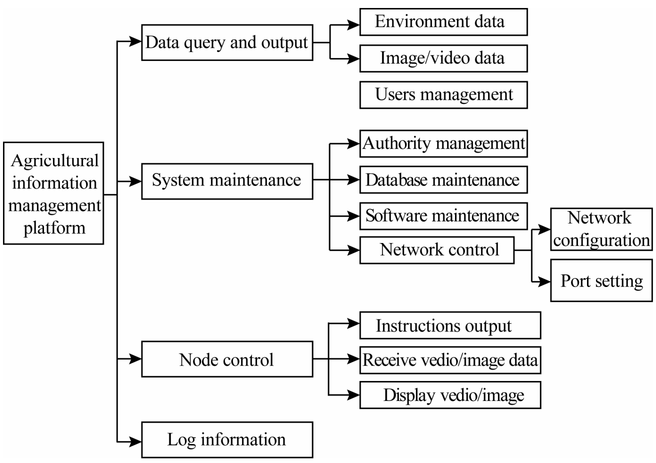


Fig.5 Functional diagram of agricultural image capture management platform

Fig.6 One of camera node in field

2.2 Determination of indexes

2.2.1 Control stability

The instructions loss rate from server to camera node (λ_{loss}) was used to evaluate the node stability in the Internet application before and after an instructions re-transmission scheme was applied:

$$\lambda_{loss} = \frac{N_{loss}}{N_{loss} + N_{rec}} \times 100 \quad (1)$$

Where, N_{loss} and N_{rec} were the number of failed instructions from the server to the camera node, and the number of successfully received instructions by camera node. The instruction loss rate is calculated based on a total of 1000 times instruction transmissions from the server to the camera for every node.

2.2.2 Capture and encoding performance

The camera nodes were tested in different pixel capture images of 0.3 (640×480), 1.3 (1280×1024), 2.0 (1600×1200) and 3.2 Mpixel (2048 × 1536), respectively. Additionally, the camera nodes capturing images and video were tested without the network, and the average time consuming in capturing and compressing images with different resolution were evaluated for about 1000 times captures.

2.2.3 Networking transmission performance

To evaluate the transmission ability of the camera node system, the overall time of image capture was tested for about 1000 images to each pixel for every node, and the video frame rate was tested for about 1 hour to each pixel for every node. The average transmission consuming time of the images and the received frame rate of video were evaluated by Wi-Fi (from the node to the gateway), 3G (from the gateway to the server), and by Wi-Fi & 3G (from node to the server) in different pixels. Four types of pixel image were assessed in those tests; they are 0.3, 1.3, 2.0 and 3.2 Mpixel, respectively.

3 Results and analysis

3.1 Control stability

Table 2 shows the instructions loss rate. The maximum loss rate before re-transmission scheme application was 8.67%, and the instruction loss rate after re-transmission scheme application was below 1% for all the nodes. Experiment indicated that instructions re-transmission scheme can ensure the reliability of transmission.

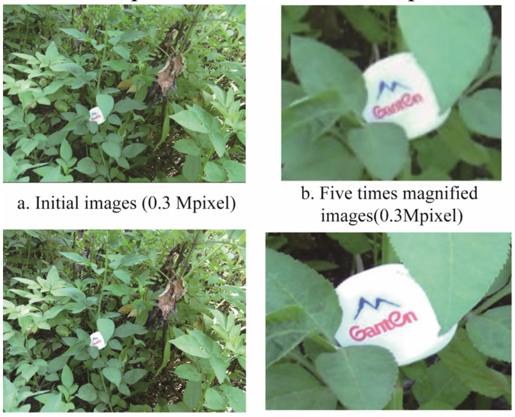
Table 2 Instructions loss rate before and after application of re-transmission scheme

Node ID	Before re-transmission scheme/%	After re-transmission scheme/%
1	1.33	0.01
2	6.00	0.63
3	0.67	0.57
4	6.67	0.78
5	7.33	0.88
6	4.00	0.38
7	8.67	0.92
8	0.67	0.01
9	6.67	0.64
10	8.00	0.94

3.2 Capture and encoding performance

Different from schemes in previous studies, the camera nodes in this study could capture images of various resolutions such as 0.3, 1.3, 2.0 and 3.2 Mpixel. Comparably, the pictures captured by the camera node with the minimum

(0.3 Mpixel) and maximum (3.2 Mpixel) resolution seemed similar (Fig.7a and Fig. 7c), but the white sign "M" in the magnified images (Fig.7b, Fig.7d) were much clearer in the picture with 3.2 Mpixel than that with 0.3 Mpixel.



a. Initial images (0.3 Mpixel)　b. Five times magnified images(0.3Mpixel)　c. Initial images (3.2 Mpixel)　d. Five times magnified images (3.2 Mpixel)

Fig.7　Initial and magnified images captured by 0.3-Mpixel and 3.2-Mpixel camera node

3.3　Networking transmission performance

Table 3 also shows the consuming time of capture and received frame rate of video by 3G, Wi-Fi, and 3G & Wi-Fi per second with different capture pixels. Among nodes with the image pixel of 1.3, 2.0 and 3.2 Mpixel, the shortest image transmission consuming time were 1.6, 9.2 and 13.3 s, respectively in Wi-Fi communication, 9.8, 9.2 and 13.3 s, respectively in 3G communication, 17.6, 26.9 and 49.6 s respectively in a whole networking communication (by 3G & Wi-Fi), and the highest video frame rates were 20.2, 16.1 and 9.3 frames per second respectively in a whole networking environment (by 3G & Wi-Fi). The results from the consuming time of capture and H264 encode frames per second with different resolutions showed that among nodes with resolutions of 1.3, 2.0 and 3.2 Mpixel, the shortest average capture and compress mage consuming time were 6.2, 8.2 and 11.1 s respectively, and the largest video frame rates were 58.7, 34.6 and 16.4 frames per second, respectively (Table 3).

Table 3　New HRAVS node performance tests in different pixels

Images Pixel/Mpixel	Images size/kB	Average capture and compress consuming time without network/s	Capture frame numbers without network	Image transmission consuming time by Wi-Fi/s	Image transmission consuming time by 3G/s	Average image overall consuming time by 3G & Wi-Fi/s	Received frame rate of video by Wi-Fi/fps	Received frame rate of video by 3G/fps	Video receive frame rate by 3G & Wi-Fi/fps
0.3	120	3.1	86.4	0.5	6.7	10.3	39.4	27.5	26.3
	136	3.5	85.8	0.4	5.9	9.8	40.1	27.1	25.7
	140	3.9	86.1	0.4	6.8	11.1	41.2	26.7	24.2
1.3	220	6.2	57.3	1.6	9.8	17.6	37.1	23.4	21.2
	228	6.4	56.8	1.7	10.8	18.9	36.2	22.1	20.7
	231	6.7	58.7	1.8	10.2	18.7	36.8	23.8	20.8
2.0	328	8.2	34.6	9.8	9	27	30.1	18.6	16.1
	335	8.8	33.9	9.6	8.5	26.9	29.1	17.5	15.7
	340	9.9	34.4	9.2	7.9	28.1	30.7	16.2	15.9
3.2	448	11.1	15.6	13.3	25.7	50.1	25.2	14.1	9.2
	450	12.4	16.4	13.4	24.8	49.6	25.6	13.8	9.1
	453	11.3	15.5	14.4	28.5	54.2	24.8	13.6	9.3

4　Conclusions

This study presented a high resolution vision sensor transmission control scheme for WVSN and the agricultural IOT. During the scheme, a wireless visual sensor network was constructed using Wi-Fi and 3G technologies in order to make the camera node working in a wider area and getting a higher data rate, and a web-based agricultural information comprehensive management platform was also developed to manage the camera nodes. The transmission performance of the new camera node with the VSRTC scheme was evaluated in a series of tests. The results showed that the system could work reliably and steadily. However, there is still a large delay in the transmission of high resolution image and video. But in most cases, the requirement of real-time is not very strict in agricultural image acquisition. So the new HRAVS camera node can meet agricultural image acquisition requirements to some extent. It is worth to say, the camera node system can work well in video mode below the 1.3 Mpixels. But it cannot reach at 20 frames per second when the video mode was higher than 1.3 Mpixels. The main reason probably was the bit rate of Wi-Fi and WCDMA was much lower than their theoretical value in the surrounding environment. For example, the theoretical bit rate of Wi-Fi technology was up to 54 Mbps, but in the real tests, it was about 32 Mbps in our experimental fields. The theoretical bit rate of WCDMA was up to 384 Kbps, but in the real tests, it was about 180 Kbps. So, the video transmission of higher pixels was difficult for the new HRAVS camera node in wireless communication. The future study can try to use cable communication or 4G for high resolution video transmission in facility agriculture.

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基于 3G 和 Wi-Fi 的高分辨率视觉传感器传输控制方案

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摘　要：智能视觉传感器技术因其低成本和图像高效采集优势成为当今无线视觉传感器网络（wireless vision sensor network，WVSN）的研究热点。该文在之前基于 ARM 平台 S3C6410 设计的低成本高分辨率农业视觉传感器（agricultural high resolution vision sensor，HRAVS）设计基础上，进行了网络和远程控制扩展，设计了一种基于 WCDMA 和 Wi-Fi 的高分辨率视觉传感器远程传输控制方案（vision sensor remote transmission control schema for the HRAVS，VSRTC）。使新型 HRAVS 节点可以利用有线、Wi-Fi、3G 和 4G 等支持 WVSN 和农业物联网的应用。该文详细设计了 VSRTC 的应用体系结构、传输控制协议、应用软件。利用扩展的网络化视觉感知传感器，在华南农业农业大学试验农场部署了 10 个图像采集节点构成的 WVSN，并开展了 25d 的运行测试，测试了新型节点的稳定性、图像采集与编码的性能，采集图像的平均耗时，以及在不同分辨率下的视频帧速率等。结果表明，该节点能够有效地支持命令响应式、周期响应式、视频流 3 种采集模式；在重传方案支持下所有节点指令丢失率在 1%以内；在非联网状态下节点本地工作模式下，节点在 1.3、2.0 和 3.2 Mpixel 下采集图像的最短节点平均耗时分别约为 6.2、8.2 和 11.1 s，最大视频帧速率分别为 58.7、34.6、16.4 帧/s；在全网络环境中，节点在 1.3、2.0 和 3.2 Mpixel 下采集图像的最短节点平均耗时分别约为 17.6、26.9 和 49.6 s，最大视频帧速率分别为 20.2、16.1、9.3 帧/s。该方案对实时性要求不太高的农业领域来说，基本能满足其高分辨率图像和视频传输的需要。

关键词：无线传感器网络；视觉；传输控制协议；高分辨率农业视觉传感器；视觉传感器远程传输控制