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A System Architecture of Wireless Communication for Fire-Fighting Robots

Jung-Hyun Park *, **Byung-Wook Kim** *, **Dong-Jo Park** * **and Moon-June Kim** **

* *Korea Advanced Institute of Science and Technology (KAIST), 335 Gwahangno, Yuseong-gu, Daejeon 305-701, Republic of Korea (Tel: +82-42-869-8038; E-mail: junghyunpark@kaist.ac.kr, byungwook.kim@kaist.ac.kr and djpark@ee.kaist.ac.kr)*
** *WIA corporation, 8F, Hansol building, #736-1, Yeoksam-1-dong, Kangnam-gu, Seoul, 135-924, Republic of Korea (Tel: +82-2-2033-8113; E-mail: mjkim@wia.co.kr)*

Abstract:
Robust communication systems between fire-fighting robots and remote operators are investigated. The communication system consists of two components; a digital packet data communication system and an analog image communication system. For a reliable data packet communication system, we adopted the commercial CDMA (Code Division Multiple Access) network architecture. Using the CDMA modules, it is possible to transfer serial data after a connecting procedure that is specified by the network service provider. Digital packet data communication systems transfer data packets back and forth in order to control fire-fighting robots and to monitor their status. Remote operators can view a video display of robot surroundings via an analog image communication system.

1. INTRODUCTION

Advances in economic growth in modern industrialized society have resulted in factories, complex office buildings, and dense apartment blocks located in metropolitan areas. Associated gas stations, oil reservoirs, and LNG storage facilities, which are all vulnerable to fire due to inflammable materials, are also found in these areas. When a fire occurs in such places, fire fighting is difficult due to mazes of crowded buildings, high temperatures, smoke, and the danger of explosion.

Fire causes enormous damage to life and property. In April, 1925 the first fire department was established in Korea and such facilities quickly spread so that nowadays, fire stations are located all over the country. Current fire fighting systems are based on humans using water guns and chemical fire repression systems. However, humans cannot work effectively in all fire environments. In this case, it is desirable to extinguish a fire quickly using fire-fighting robots. Recently, in order to cope with catastrophic fire related accidents, research on fire-fighting robots has advanced in many countries: Amano [2002], Chien [2007], Kuo [2006], Feng [2002], Pack [2004], Dearie [2001], Ahlgren [2001].

Fire-fighting robots are operated in places where fire fighters are not able to work. Hence, it is desirable to control fire-fighting robots using a remote control system located away from the fire. In order to control fire-fighting robots in remote places, robust radio communication systems are necessary.

This paper considers robust wireless communication systems between fire-fighting robots and remote operators. These communication systems consist of two parts; a digital packet communication system and an analog image communication system. Digital packet communication systems transfer data packets in order to control fire-fighting robots and to monitor their status. Remote operators can view video of the area around the robots via an analog image communication system.

This paper is organized as follows: In Section 2, a system configuration is presented. A wireless data communication system is presented in Section 3, and a wireless image communication system is illustrated in Section 4. Section 5 concludes this paper.

2. SYSTEM CONFIGURATION

The fire-fighting robot system is composed of a remote operator and a fire-fighting robot body. The fire-fighting robot body is operated in a dangerous area and is controlled by a remote operator (Figure 1) using a digital packet communication system for control and an analog image communication system for video observation.

The fire-fighting robot body is depicted in Figure 2 and a remote operator is shown in Figure 3. The fire-fighting robot is designed to be robust at high temperatures. The remote controller is designed to be light for portability.

The size of the robot body is $3400 \times 1750 \times 1800mm^3$ to allow access in a narrow path between buildings. The weight of the body allows stability when using the water

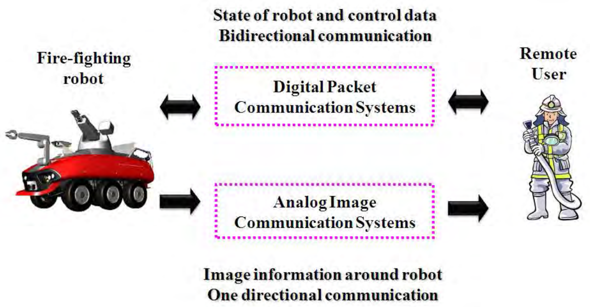

Fig. 1. Communication system structure between fire-fighting robots and remote operators

Fig. 2. Fire-fighting robot body

Table 1. Specifications of the fire-fighting robot body

Items	Specifications
Dimension	3400 x 1750 x 1800 mm^3
Weight	1500kgf
Maximum speed	20km/h
Driving method	6x6 in-wheel motor
Operation period	1 hour
Fire extinguishing apparatus	Water cannon self water spray
Durable temperature	Typically 100 ^oC and temporally 1000 ^oC

cannon. Six wheels are powered by in-wheel motors that can achieve a speed of up to $20km/h$. To withstand high temperatures, the robot is equipped with a self water spray system for cooling. The robot body can endure sustained temperatures up to 100^oC and, temporally, 1000^oC. Detailed specifications are summarized in Table 1.

The total structure of the fire-fighting robot is depicted in Figure 4. The main control is operated through a Real-Time Application Interface (RTAI) based on Linux. The other parts include a power train, a steering mechanism, remote-sensing equipment, a fire-extinguishing system, and communications. Detailed descriptions are as follows:

Power: Fire-fighting robots need propulsion for effective operation. Liquid gasoline or diesel fuel can be explosive due to fire or high temperature. Hence, electric motors and batteries are used. A high power battery is used for the 6x6 in-wheel motors. A separate battery is used and for the controlling computers. One battery would cause operation of the control computer to be unstable as the in-wheel motors require a lot of current.

Fig. 3. Remote controller

Driving: The fire-fighting robot has the overall physical appearance of a small car. For this type of design, control and steering are important. The components of control include a non-local driver, in-wheel motors, and wheels with nonflammable tires. The 6 wheels can be operated independently, so that the skid method can be used to turn around.

Remote Sensing: The remote operator must have access to information from around the fire-fighting robot in order to maintain stability and avoid conditions that would disable the robot. The temperature around the robot, remaining battery power, GPS (global positioning systems) information, speed, and the video image in front of robot are sensed and reported to the main control computer.

Fire-Extinguishing System: The purpose of this robot is to extinguish fires. A secondary purpose is rescue of injured people. A directional water cannon is used that can be aimed independently of the position of the robot.

Communications: Robust wireless communication systems are required. Both a digital data packet communication system and an analog image communication system are used

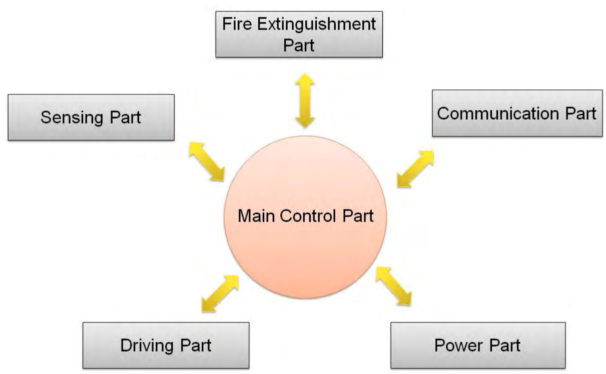

Fig. 4. Total system structure of the fire-fighting robot body

In the next two sections, the wireless data packet communication system and the wireless image communication system are discussed.

3. WIRELESS DATA PACKET COMMUNICATION SYSTEMS

A reliable digital packet communication is necessary to control the fire-fighting robot body. Environmental information around the robot is transmitted from the robot body to the remote operator. By checking this information, the operator can know the status of the robot and transmit appropriate control data corresponding to the status.

3.1 System requirements for digital packet communication

Requirements for a reliable data packet communication system as follows:

- Real-time processing
- Checking correctly received packets
- Preventing malfunctions
- A flexible protocol
- An adjustable packet transmission rate
- Checking the successively received packet rate
- Multiple access

3.2 System configuration for digital packet communication

Figure 5 shows the packet data structure. A series of packets are transmitted. A packet is composed of a **Header** and a **Payload**. The **Header** consists of **Sync**, **TxIndex**, **RxIndex**, **PacketIndex** and **Reserved** parts. **Sync** is used to detect the starting point of an individual packet in a series of packets. **TxIndex** and **RxIndex** indicate the index of the transmitter and the receiver. This information is used for multiple accesses. Multi-remote operators having distinct indexes can simultaneously operate multiple fire-fighting robots that have distinct indexes. Sometimes data packets are received in an incorrect order, or with multiple copies or with losses due to the multipath effect and the fading channel. **PacketIndex** can help to identify the order of packets and to detect multiple copies. Reserved is allocated for future usage. The **Payload** has two parts: Data **Bit Stream** and **Parity**. Using **Parity**, the correctness of **Data Bit Stream** is determined. For these systems, a CRC (Cyclic Redundancy Check) of 32 bits, a CRC of 16 bits, and a checksum of 8 bits are selectable for channel conditions.

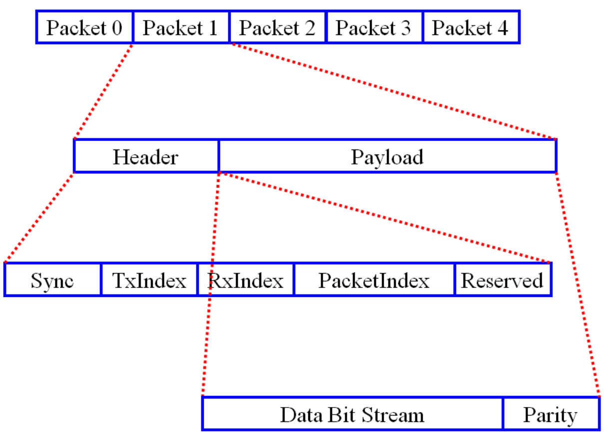

Fig. 5. Packet structure for digital packet communication

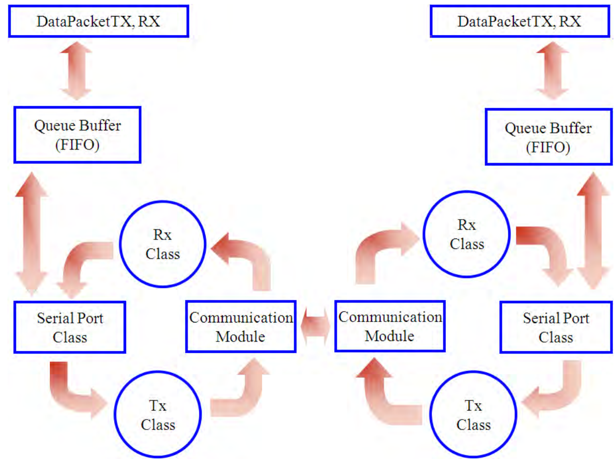

Fig. 6. Class chart for digital packet communication

The class chart is shown in Figure 6. Once data packets are generated, they are stacked in a **Queue Buffer** that is a FIFO (first-in first-out) type memory. Periodically, the data packets in the **Queue Buffer** move to a **Serial Port Class**, which is properly designed for the operating system (OS). Finally, **Tx Class** is used to transmit data through the communications module. The receiving process is operated in the opposite manner.

For reliable data packet communication, we adopted the commercial CDMA (Code Division Multiple Access) network. Using CDMA modules, it is possible to transfer serial data after a connecting procedure that is specified by the network provider. The procedure is illustrated in Figure 7. First, the communication program starts and initializes the communication module. For the link setup process, the remote user calls to the fire-fighting robot that is waiting for a call. If the fire-fighting robot can catch the call, a connection carrier is transmitted to the remote user. Otherwise, the remote user should call again to the fire-fighting robot. Once two CDMA modules are connected to the network, they are connected in bypass mode, meaning that the two systems are connected seemingly without any communication module. This connection emulates a direct wired channel.

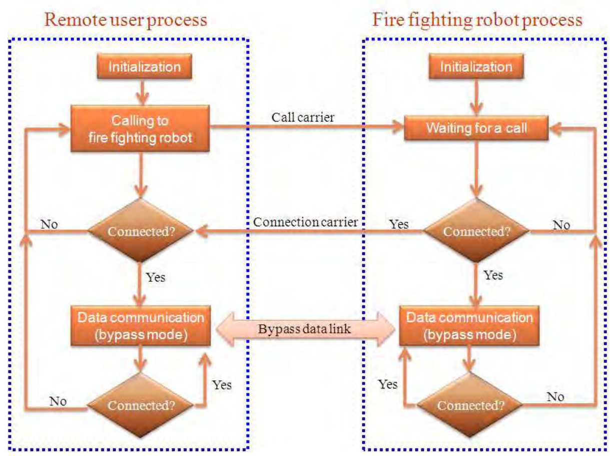

Fig. 7. State flow chart for CDMA-based communication systems

4. A WIRELESS IMAGE COMMUNICATION SYSTEM

In order to transmit images, both digital transmission techniques and analog transmission techniques are available. The digital transmission technique requires signal compression, such as sampling and MPEG (Motion Picture Experts Group), thus increasing the computational complexity and resulting in an additional hardware cost. In some cases, digital image reception is impossible when noise becomes significantly large or when the transmission distance becomes out of bounds due to the threshold effect. On the other hand, the analog transmission technique is capable of showing image contours in harsh environments with significant noise and large distances. Therefore, the analog transmission technique is used in this work.

4.1 System requirements for analog image transmission

As remote operators communicate with fire fighting robots using analog image transmission systems, there are two major considerations, as follows:

Low Complexity: When an image processing program requires a high degree of computational complexity, the performance of the data packet process program operation is degraded. To prevent this problem, a low computational complexity is required for the analog image transmission technique.

Real Time Process: Images captured from the fire fighting robot should be transmitted to remote operators without any time delay. The fire-fighting robot can be damaged and additional property damage can occur if the robot response to the situation is late due to a time delay.

To satisfy the above two requirements, we have designed a simple image transmission, an image reception, and an image processing system.

As shown in Figure 8, the fire fighting robot sends image data to the remote operator. Image data are composed of both color image and infrared ray (IR) image data. Images from multiple cameras are combined using a multiplexer. Thus, the united image of the fire fighting robot surroundings is transmitted and received by the image transceiver module. After extinguishing a fire, reviewing the situation at the fire scene will help to find the cause of the fire or to evaluate the situation. For this purpose, the image communication system is equipped with a real time image recording system. The unified image from multiple camera images is saved to a hard disk (HDD) after digital conversion.

4.2 Analog image noise and reduction techniques

In our work, we used the NTSC (National Television System Committee)-based analog image transmission scheme. This method is affected by various kinds of noise Lopez [1998]. Four kinds of noise are especially dominant for NTSC image transmissions (Figure 9). To deal with this problem, we used a noise cancelation algorithm in the remote control software to improve the quality of transmitted images.

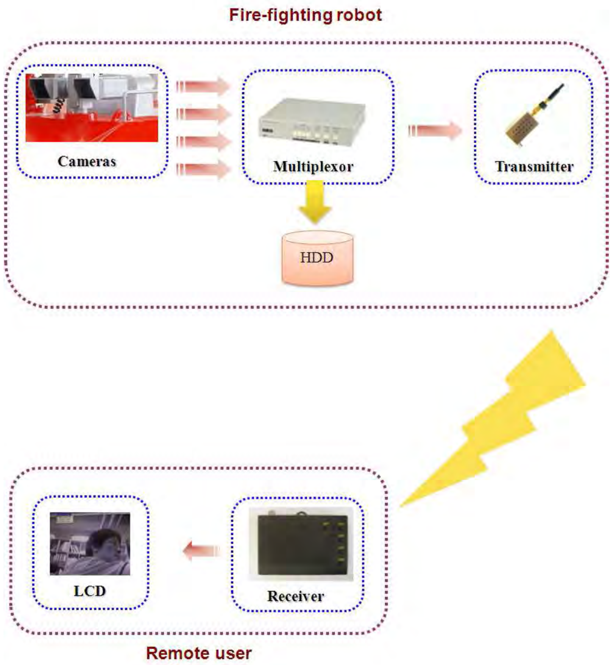

Fig. 8. An analog image communication system between fire-fighting robots and remote operators

As shown in Figure 9-(b), impulse noise is present as incorrect data in the values of some distributed pixels in the image. For example, each pixel with an error presents either 0 or 255 values for the 8-bits per pixel image. This kind of noise is also called salt and pepper noise.

Gaussian noise, as depicted in Figure 9-(c), is one of the most common noise types. The distribution of this kind of noise follows a Gaussian distribution. This is usually caused by Brownian motion of air molecules and electron Brownian motion in electric circuits. Figure 9-(d) shows film grain noise that can be present in NTSC images or in recorded images on film. Among the pixels of an image, some pixels with large intensities are distorted by this noise. Especially high intensity pixels, like clouds, contain this film grain noise. Finally line noise, depicted in Figure 9-(e), removes some horizontal lines in the NTSC image. This is caused by the NTSC transmission technique that sends images line by line. To compensate for these NTSC noise effects, image processing schemes are used to improve the quality of the image, as follows:

Impulse and film grain noise cancelation technique: Due to the characteristics of impulse and film grain noise, there is a high probability of noiseless pixels around a distorted pixel. Therefore, we can use a median filter to remove pixels with a peak value of 0 or 255. We have designed a 3×3 median filter to cancel the noise. However, the filter slows the computational speed when the middle value among 9 pixel values is determined. To increase the speed, we modified the algorithm to calculate the average value of 9 pixels and determine the closest pixel value to the average value.

Gaussian noise cancelation technique: A low pass filter is used to effectively remove this kind of noise. This is due to the fact that the Gaussian noise in each pixel has an independent and zero mean. In our system, a 3×3 low

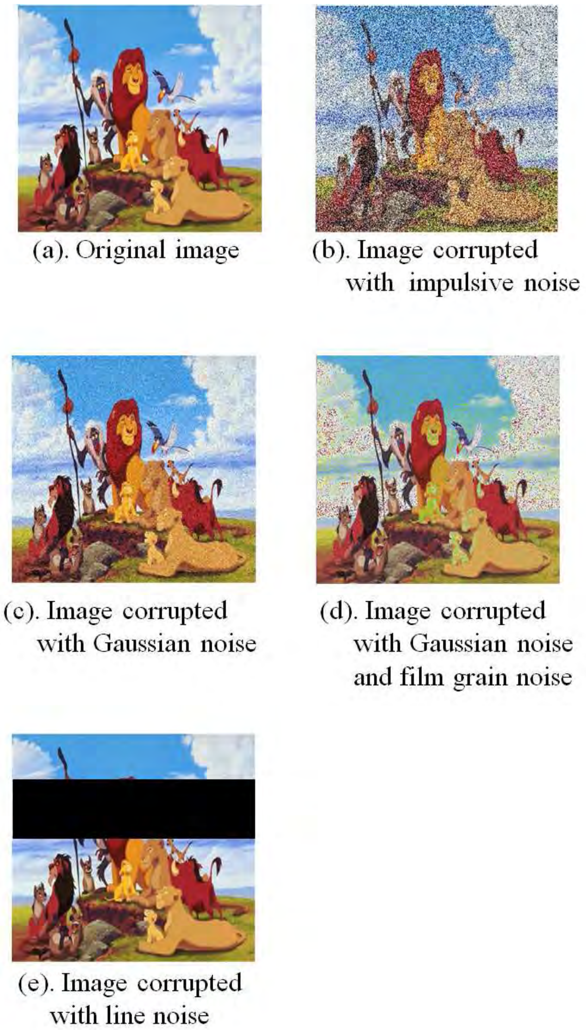

Fig. 9. Various kinds of noise and distorted images for the NTSC image transmission scheme

pass filter is used to calculate the average pixel value. This scheme can perform in nearly real time.

Line noise cancelation technique: There are two kinds of schemes to solve the line noise distortion problem. When a large number of lines of an image disappear, the previous image, which is recorded, can be substituted for the distorted image. On the other hand, when a few lines disappear, lost lines are simply supplied from the previous image. A real time process is observed with using these two line noise cancelation techniques.

We compensated for NTSC noise by using the above noise cancellation techniques, which operate in real time. This image noise cancelation system does not affect other systems, including the data packet transmission system.

5. CONCLUSION

Fire causes tremendous damage and loss of human life and property. Recently, in order to cope with such catastrophic accidents, research on fire-fighting robots has been carried out in many countries. It is sometimes impossible for fire-fighting personnel to access the site of a fire because of explosive materials, smoke, and high temperatures. In such environments, fire-fighting robots can be useful for extinguishing a fire. These robots should be controlled by remote operators who are located far away from the fire site using remote communication systems. In order to control fire-fighting robots in dangerous places, robust radio communication systems are one of the important components of the robots.

We have considered the communication system between fire-fighting robots and remote operators. The communication system consists of two parts; a digital packet communication system and an analog image communication system. The digital packet data communication system uses commercial CDMA networks for reliable communications. The digital packet data communication system transfers data packets in order to control the fire-fighting robots and to check the status of the robots. For the wireless image communication system, an analog communication system based on the NTSC standard is used. Remote operators can view video around the fire-fighting robots by using the analog image communication system. Using these communication systems, robust wireless communications between fire-fighting robots and remote operators are possible.

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