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Research paper

Control System for Security Enhancement of CCTV Camera Maintenance Devices

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Abstract

Background/Objectives: Automatic lift systems are used for the convenient and safe maintenance of CCTV cameras installed in high places. However, the control unit is often installed in an area easily accessible by outsiders, and this may lead to camera manipulation by an unauthorized person.

Methods/Statistical analysis: To maintain the existing control unit and enhance its security, first, the control button for the ALS located inside the control unit needs to allow input signals only upon approval by the control center. Second, the program for ALS control should be added to the installed NVR for image storage purposes. Finally, an algorithm for encrypted key generation needs between the Network Video Recorder and ALS to enhance the security and reliability.

Findings: To address these issues, this study designed a control system that offers enhanced security for an automatic lift system by enabling system control in a control tower. The server of the control system only approved requests by authorized persons for any operations. In addition, the system was designed to monitor the surrounding environments of all CCTV cameras within the operation area. Through these functions, the system was able to detect a fire, a gas leak, fine dust concentration levels, etc. within the surveillance area to ensure the safe maintenance of facilities.

Improvements/Applications: This control system is expected to enhance the security of CCTV systems used for the surveillance of key facilities

Keywords: CCTV camera, Lifting equipment, Maintenance, NVR, Encryption.

1. Introduction

Recently, the use of CCTV cameras for the surveillance of key facilities and traffic and crime data collection, as well as security systems using image processing technology, are rapidly expanding. Among these, CCTV cameras for surveillance and data collection purposes are usually installed in high places. This has rendered it inevitable to engage in maintenance work in high places using a ladder or cherry-picker to remove foreign substances on camera lenses, fix malfunctions or defections, or for regular maintenance. However, the maintenance of CCTV cameras in high places causes issues such as the risk of falling, inconvenience, and additional cost. To address these issues, an automatic lift system (ALS) for CCTV cameras has been developed and implemented [1]. The ALS lifts down CCTV cameras to the ground for maintenance and lifts them back to their original position to function as usual. The control device for an ALS is comprised of a controller, a main board, communication unit to receive input signals, and a power unit. These control devices are inserted in the control unit at the bottom of the pole to which the CCTV cameras are installed. At the front of the control unit is a locking device with a key that allows only authorized individuals to access the system. However, as the control unit is located at a low place, it is easily accessible to outsiders, and the locking device is often damaged by an external force as it is not sufficiently durable. CCTV cameras are mainly installed in places of critical importance or where access by outsiders needs to be restricted. If these CCTV cameras are manipulated or damaged by unauthorized individuals and changes in the scope of the surveillance area occur, it may result in surveillance gaps and grave security issues. In this context, there is a need for a function that allows the ALS operation to only be controlled by the control center in charge of facility maintenance [2].

CCTV cameras installed in the past usually stored analogue image data to a digital video recorder (DVR) using a coaxial cable, requiring a separate network from the ones used for broadcasting, control signal transmission, and sensors. However, CCTV cameras installed more recently are internet protocol (IP)-based cameras that store digital image data to a network video recorder (NVR) using an unshielded twisted pair (UTP) cable. Using the network of IP-based CCTV cameras, an audio output device can be installed near the cameras to transmit announcements. A sensor network can also be installed that can monitor the surrounding environments of cameras. These will allow the real-time detection of fires, gas leaks, humidity, and fine dust concentration levels in the surveillance area. In addition, sensors can detect the access to the control unit to alert the control center, allowing a fast and economic integrated maintenance system.

In this study, an NVR maintenance program and a sensor network for facility environment surveillance were developed for the security enhancement of the ALS, and ultimately an efficient and highly secure integrated maintenance system was designed for the control tower.

2. CCTV System

As shown in Fig 1, the CCTV system comprised of a recording unit for obtaining image data, a transmission unit for transmitting recorded images to a receiver, and an image processing unit for storing received images.

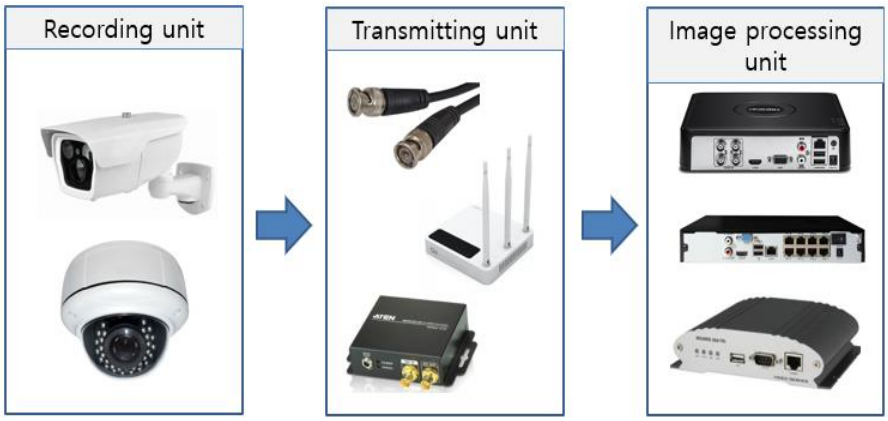

Figure 1. CCTV system composition

A recording unit generally comprises of cameras, a lens, and lighting. It is classified as either an analogue type or a digital type depending on the image size and transmission method. Sensors for obtaining images include the charge coupled device (CCD) type and the complementary metal–oxide–semiconductor (CMOS) type [3]. The lenses that ensure that the subject data is accurately transmitted to the image sensors include a fixed-focus lens, variable-focus lens, and a zoom lens [4].

A transmitting unit is mainly classified as either wired unit or a wireless unit. A wired transmitting unit comprises of a coaxial cable, signal amplifier, image distributor, and noise filters for the transmission of analogue image data, while a TCP/IP network is used for the transmission of digital image data. A wireless transmitting unit has two transmission methods: transmitting modulated analogue image data in micro-wave frequencies and millimeter-wave frequencies and transmitting digital image data through WIFI or mobile communication networks [5]. CCTV systems with the primary purpose of key facility surveillance mainly use the wired transmission method due to issues such as loss of image or hacking.

An image processing unit is classified as either an analogue type or a digital type depending on the form of input image. A digital video recorder (DVR) is used as the primary device for storing and playing images and it converts the analogue image data into the digital format for storage. More recently, however, the use of high-definition (HD) large image data and the spread of Internet of Things (IoT) technologies have led to a wider use of network video recorders (NVRs) that are network-based digital image storage systems. Table 1 shows the CCTV system components by specific components for each system and by function.

Table 1. CCTV system components

Component	Specific component				Function
Recording unit	Analogue		PAL/NTSC cameras	Lens, housing, lighting, brackets, etc.	Acquisition of image data
	Digital		HD/IP cameras		
Transmitting unit	Wired	Analogue	Coaxial cable, amplifier, distributor, filters, etc.		Transmission of image data
		Digital	UTP cables, hub, router, etc.		
	Wireless	Analogue	VHF, micro-wave frequency, millimeter-wave frequency		
		Digital	WIFI, LTE, 5G mobile communication network		
Image processing unit	Analogue		VCR	DVR, video server, screen divider, etc.	Storage and display of image data
	Digital		NVR		

3. Proposed System Architecture

3.1. Control system design

Within the control unit attached at the bottom of the pole to which the CCTV cameras are installed, there are control devices for the ALS, a power unit for the CCTV cameras, and a network device for image transmission as the basic components as shown in figure 2. There may be other supplementary devices for broadcasting and lighting. As such, a control unit that houses several security devices is installed in a low place easily accessible by outsiders.

Figure 2. Control units installed to poles with CCTV cameras

In addition, the locking device for a control unit often has a durability issue as it is frequently damaged by external impacts.

To maintain the existing control unit and enhance its security, the control button for the ALS located inside the control unit needs to allow input signals only upon approval by the control center. As shown in Fig 3, an on-site operator who wishes to control the ALS would need to contact the control center to obtain approval. An operator at the control center would then access the ALS concerned through the NVR to transmit a permission signal. The ALS that received the permission signal would then allow an input signal from the on-site operator and lift down the CCTV cameras from a high place to the ground for maintenance. The ALS unauthorized for access by the control center would maintain a standby mode that rejected all input signals for control. Due to the characteristics of CCTV cameras installed outdoors, they are exposed to radio waves emitted from various wireless devices around the ALS. As the ALS is also controlled through a wireless system, it can cause malfunctions upon interference by external radio waves. Therefore, the standby mode of the system could prevent unexpected malfunctions caused by surrounding noises.

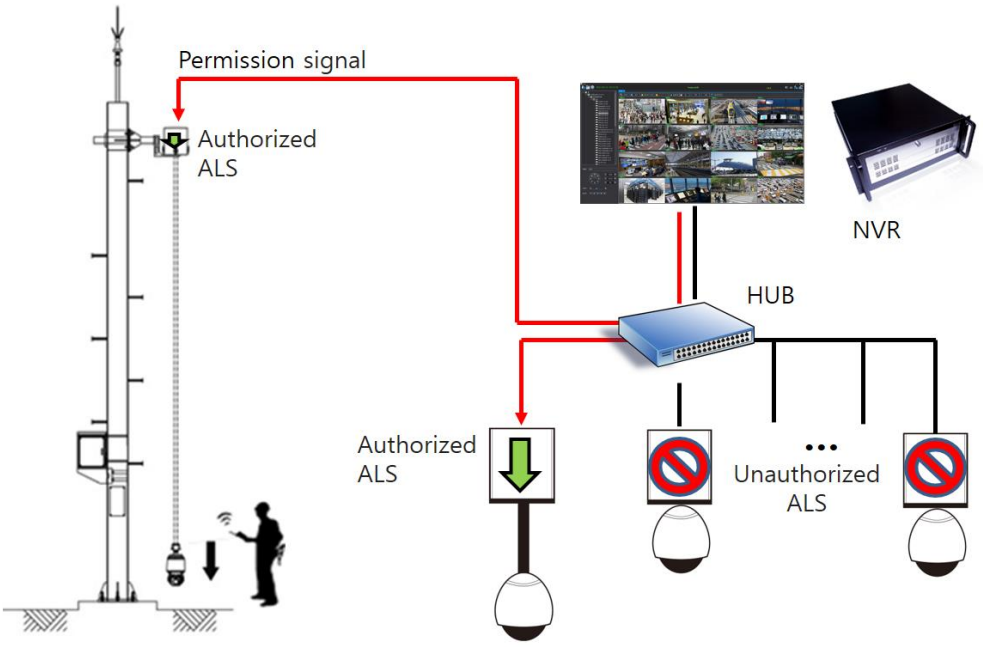

Figure 3.ALS and CCTV cameras controlled by NVR

3.2. NVR program for ALS control

A program for ALS control was designed to not require separate hardware or software by adding it to the existing NVR program used for image storage. The ALS control program integrated into the NVR provided the ALS selection function, status display function, and operation control function. First, the ALS selection function involved an action to register the IP address of the ALS connected to a network and to send a command for the permission signal by accessing the ALS, and an action to disconnect. Second, the ALS status display function involved displaying operations on the screen such as the power status of the ALS, connectivity with the CCTV cameras, and height control of the lift system. Lastly, the ALS operation control function involved lifting the CCTV cameras up and down with the ALS, setting the height of the lift system, and the monitoring of the current positions and designated positions of the CCTV cameras.

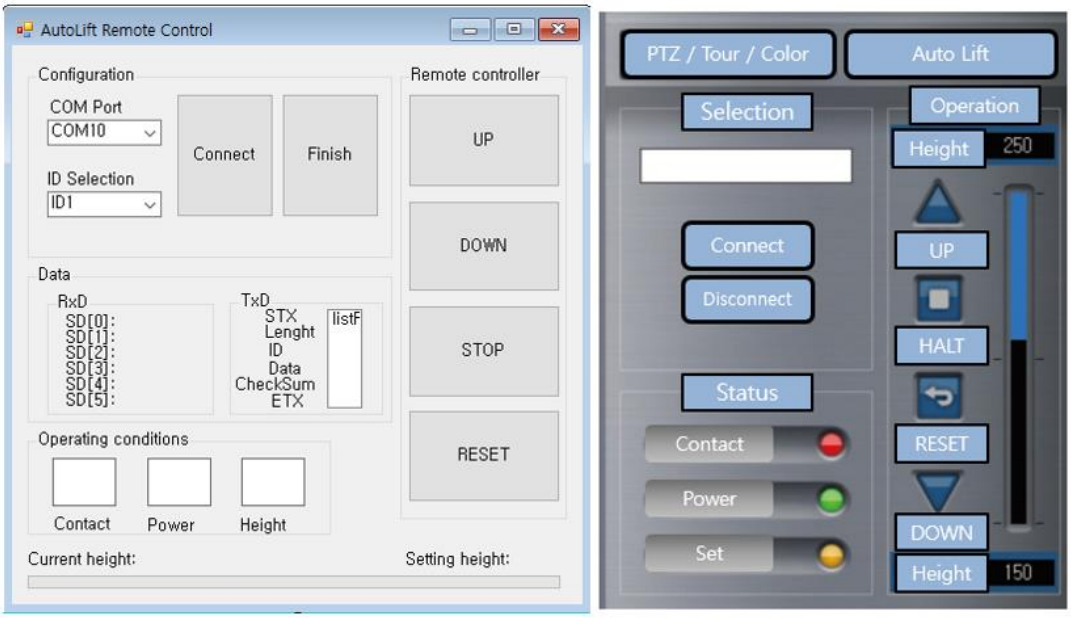

Figure 4. ALS control program a) Independent type b) NVR-integrated type

The ALS system featured a standby mode for security reasons and for preventing malfunctions caused by external noises. The system was designed to not permit any inputs from wired/wireless remote controllers while in this standby mode. The system was designed to exit the standby mode when a password is entered through the wired/wireless remote controller on the site where the ALS is installed or when the permission signal is received from the control center. Both of these operations could be monitored at the control center.

Figure 4 a) represents an independent program for image storage through a separate ALS program from that of the NVR program and was designed to prevent system freezes caused by an NVR overload and program errors. Figure 4 b) represents an integrated program in which the ALS control function is integrated into the NVR system, and it thus requires no supplementary installations.

Due to the characteristics of CCTV cameras installed outdoors, lightning and voltage surges are major causes of malfunction. A surge protector is installed to prevent this issue, but this is not a complete solution due to substandard performances and obsolescence. Therefore, when lightning is expected, an operator is dispatched to detach the power unit for the CCTV cameras [6, 7]. There is, however, difficulty in managing individual CCTV cameras that are installed across a vast area. To address this problem, this study designed a function that simultaneously lifts down all CCTV cameras connected to the ALS registered in the NVR to separate the power units, images, and control devices. The connection socket of the CCTV cameras, as shown in Fig 5, was designed to be inserted approx. 60mm deep into the upper socket inside the ALS. Using this structural characteristic, the CCTV cameras are lifted down to less than approx. 50mm, as shown in Fig 5, to prevent the direct exposure of electric connection terminals to the outside. Through this, all electrical connections of CCTV cameras would be shut down to be protected from external surge voltages, and the contamination of the connection terminals from rain or dust could be prevented.

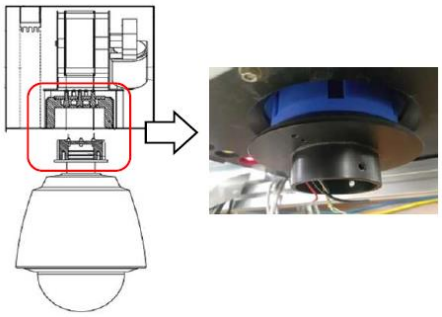

Figure 5. Lower socket detached inside the ALS

3.3. Sensor hardware

When the detection of environmental data such as fires, gas leaks, and increases in fine dust concentration were required at facilities under surveillance by CCTV cameras, a separate sensor network from the CCTV camera network used to be established [8] and this required additional network transmission equipment, server devices, sensor monitoring programs, etc. In addition, operators at the control center had to monitor the CCTV camera images and sensor monitoring images through separate screens. In this study, an integrated NVR program was designed with hardware for sending data from the sensors to the network through network transmission equipment mounted on the ALS and by combining data from the sensors with image data for the output. The ALS periodically transmitted a packet for sending status data on the CCTV cameras and ALS to the NVR. 4-bytes of data from this packet were used to send data from the sensors. The first byte indicated the type of sensors, and 7 bits were used to distinguish 127 sensor types, with the MSB as the sign bit. The other3 bytes were used to store data detected by the sensors.

There were various output methods for sensors applicable to the ALS, such as UART, SPI, I2C, 1wire, and analogue and digital ON/OFF outputs. The output data of the applied sensors were then sequentially processed by the main control unit (MCU) of the ALS to be stored in the memory. Once the data from all sensors were received, a packet was formed to transmit the data from the sensors. The packet of the sensor data contained the start of text (STX), ID of the ALS, data length, encrypted data, sensor IDs, sensor values, check sum, end of text (ETX), etc. A completed packet was then transmitted to the NVR through a serial to

Ethernet converter. After receiving the packet data from the ALS, the NVR confirmed the IP address and port number of the registered ALS. After that, the system checked the ID data of the ALS for security purposes, calculated the check sum, and decoded the encrypted data for receiving the final data. Fig 6 represents the composition of the sensor hardware with the MCU of the ALS and network devices, as well as the data from sensors displayed on NVR screens.

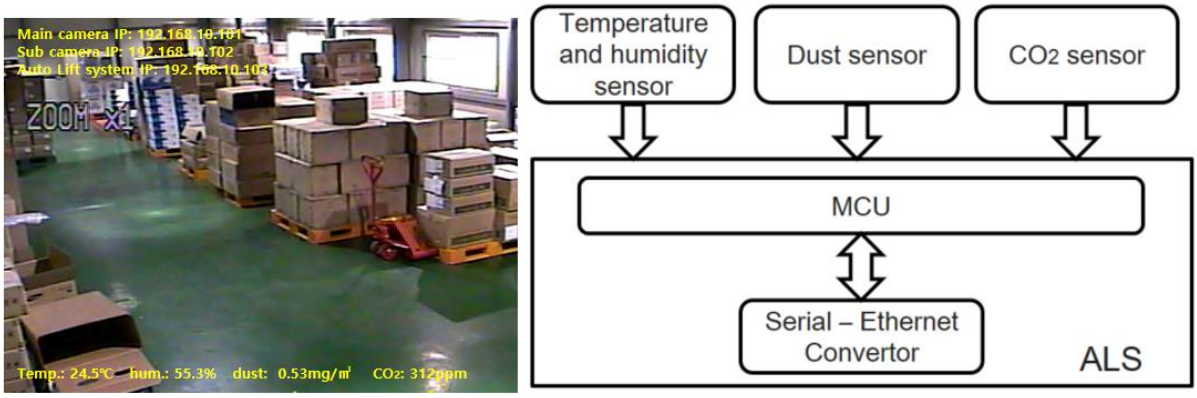

Figure 6. Display of data from sensors on screens and sensor hardware composition using ALS

The data received by the NVR from the sensors were displayed on the screen of the surveillance area by user settings, as shown in Fig 6. When the received sensor values were greater than the set values, the values concerned were indicated in red color and flashed on the screen to inform operators.

3.4. Security measures

Most of the CCTV camera networks for key facilities operate as a closed network. Recently, however, many control systems are connected either directly or indirectly to the Internet to transmit and receive data. In this process, they are exposed to threats such as data hacking, manipulation, remote control, and surveillance [9, 10]. In this study, an algorithm for encrypted key generation was applied between the NVR and ALS to enhance the security and reliability. Prior to transmitting control commands or status data between the ALS and NVR, the system was designed to generate an encrypted key based on the time data of the NVR, which functions as a network time protocol (NTP) server. The generated encrypted key is then transmitted to the ALS, and the key and transmitted data are then encrypted and transmitted again by the encryption algorithm. The NVR then decrypts the received data with the key and a decryption algorithm. The communication procedure involving the encrypted key is displayed in Fig 7.

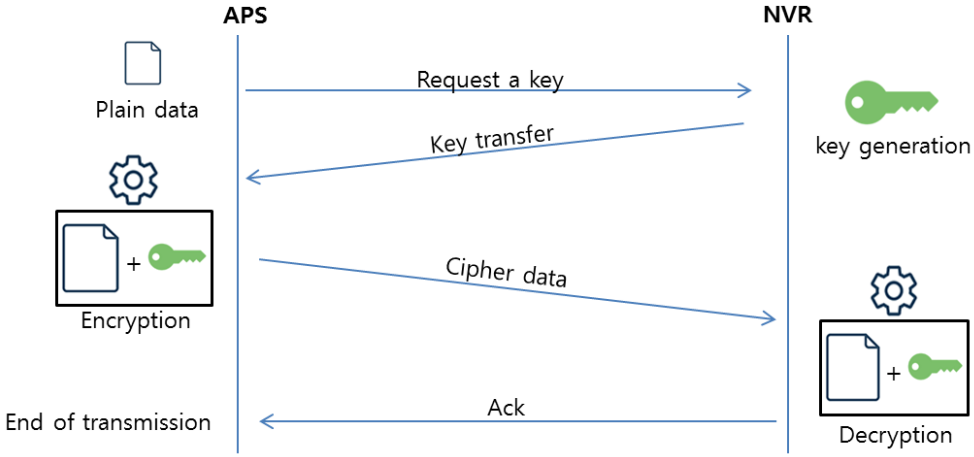

Figure 7. Communication procedure between ALS and NVR using encrypted key

4. Conclusion

In this study, a control system was designed to prevent the control of an automatic lift system and CCTV cameras by unauthorized individuals and to allow a control center to operate the automatic lift system for the CCTV cameras, thereby enhancing the CCTV system's security. The NVR of the control system designed in this study permitted requests for approval by authorized individuals to control the lift system for operation. In addition, the system was designed to monitor the surrounding environments of all CCTV cameras in the surveillance area. Through this, the detection of fires, gas leaks, and increases in fine dust concentration in the surveillance area became possible for safe facility maintenance.

Figure 8. Control systems applied on site

As shown in Fig 8, the system designed in the study was tested on site for approximately three months in a substation of the Korea Electric Power Corporation in the Chungcheongnam-do Province and on KORAIL railways in Daejeon and Busan. The control and communication errors of the NVR control program for the ALS that occurred in the test run were corrected, and the operation of the system is now stable. This control system is expected to enhance the security of CCTV systems used for the surveillance of key facilities.

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