Shanghai Jiao Tong University
University of Michigan- Shanghai Jiao Tong University Joint Institute

Mesh Network Oriented Handoff and Multi-Mode based Apparatus Identification in Smart Grid

by

Yuhang Zhang

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Committee in charge:
Associate Professor Xudong Wang, Chair
Associate Professor Mian Li
Assistant Professor Weikang Qian

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Abstract

Smart grid is deemed to be the next generation power grid, for its capability of delivering power in more efficient ways and responding to more complicated conditions and events, by utilizing modern information technologies. There are several key techniques for smart grid system, which are distributed energy resources, power line communications, smart substation, and smart metering. For smart substation play a significant role in power delivery, substation monitoring via infrared thermal instrument is of great significant, and how to transmit thermal images taken by instrument to server for substation monitoring is a big problem. In this thesis, a link quality based handoff protocol oriented by mesh network and an algorithm for apparatus identification based on multi-mode is proposed, by setting up a real system for the transmission of thermal images and recognition of apparatus in images.

In the first research topic, a protocol called mesh network oriented is designed based on the best link quality. Aiming at verifying the correctness of the protocol, a mesh network is devised and realized by schematizing functions of routers in the network, and implementing software and hardware of the nodes. Besides, a real system is established in Sijing Substation in Shanghai to solve the problem of substation monitoring with the protocol designed in this thesis.

In the second research topic, an algorithm to locate and identify apparatuses in smart grid is come up with by using image recognition technology, wireless positioning technology and other information provided by sensors on the smart devices, such as compass, gyroscope, and accelerator. This research topic is motivated by monitoring substation via sensors on smart device and identifying apparatus in thermal image automatically. The algorithm is designed on account of the multi sensors on smart phone and mutual image recognition technology, and verified by setting up a demo system including functions tag recognition, human behavior pattern recognition and apparatus identification.

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Chapter 1

Introduction

1.1 Smart Grid

Smart grid is a term referring to the next generation power grid, with the capability of delivering power in more efficient ways and responding to more complicated conditions and events, by utilizing modern communication and information technologies. (Fang et al., 2012) In traditional power grid, power is generally carried from a few central generators to a large number of customers, while smart grid can create an automated and distributed energy delivery network with a two-way flow including electricity and information. Due to this energy delivery network and communication technologies, smart grid can automatically and intelligently respond to events occurring anywhere in the grid, such as power generation, transmission, distribution and consumption, and can adopt the corresponding strategies (shown in Figure 1.1). (Yan et al., 2013) Besides, several techniques, including power line communications, smart substations, distributed energy resources, and smart metering can be applied to provide monitoring and protection for smart grid system. (Fang et al., 2012)

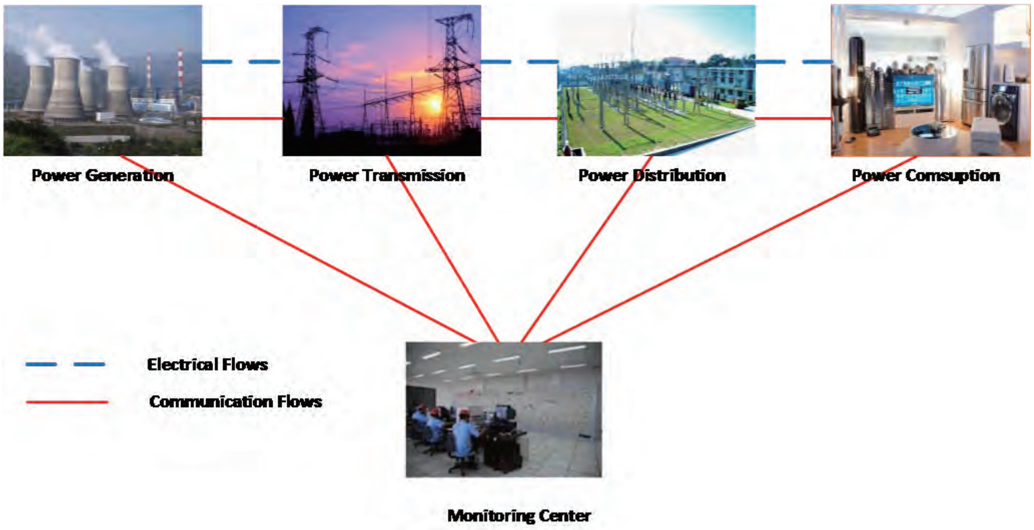

Figure 1.1: Conceptual model for smart grid

Figure 1.2: Smart substation

1.2 Smart Substation

Between the power generating station and consumer, substation play a significant role in transmission and distribution, because electric power flow through several substations during the delivery. Electrical substations are the critical delivery nodes within the power grid, providing the voltage conversion, power conditioning, and protection functions required between the various levels of transmission and distribution networks.(Bombourg, 2014)

Substation monitoring indicates the supervisory of the operation status of apparatus in

Figure 1.3: Infrared video camera

substation by detecting temperature, humidity, vibrations, voltage, current, and other physical parameters. There are mainly two procedures for substation monitoring, which are information collection and information process. Information collection refers to the acquisition of information, such as data, images, videos, and other types of information reflecting the status of apparatus by means of sensors, camera and other instruments, and transmitting information to a server via network. Besides, information process refers to the data manipulation at server, so that the operation status of substation can be achieved by analyzing the information.(Palensky and Dietrich, 2010)

For example, by the end of the year of 2013, there have been 941 high voltage transformer substations, including switch substation in Shanghai, China, and many of them are unattended, relying on supervisory control and data acquisition for remote supervision and control. (Online, 2013)But, substation monitoring has become a big problem in substation automation. As for now, many devices, like infrared video camera, X-ray thermal instrument, vibration measurement instrument, are applied in the substation monitoring to detect the temperature, vibration, and other parameters of apparatuses and equipment. However, the problem is that these devices depend on human beings behavior overmuch. Take infrared video camera as an example, thermal images for every transformer and switch in substation should be taken to monitor the operating status in case of too much heat accumulated in the equipment, every

Figure 1.4: Thermal image

day, especially in summer. (Robert, 1968)At first, inspectors should take thermal images for apparatuses and equipment by infrared video camera (shown in Figure 1.3), walking around in the substation, and then, store images into the storage disk in the infrared video camera. Besides, they have to use a notebook to record the information of the apparatus for the image, like the location of the apparatus, the type of the apparatus (switch, transformer, power box or other kinds of equipment), and the time of taking images. After taking images for the whole substation, inspectors should copy images form the camera to the server, and identify each image for which apparatus and which part of the apparatus according to the records on the notes. At last, they will check every image to detect if there is any abnormal for apparatuses. The flow of this traditional method is shown in Figure 1.5. There are several drawbacks for this traditional method.

- Non-real-time system

  Because, inspectors using storage disk to store thermal images. All of the images can be checked, until inspectors copy all the thermal image to the server. The average delay is about half an hour. Staff could only check the image taken half an hour ago.

- Inefficiency

  By recording the information of apparatus on the notebook, inspectors have to match the thermal image and apparatus manually, which will cost lots of time.

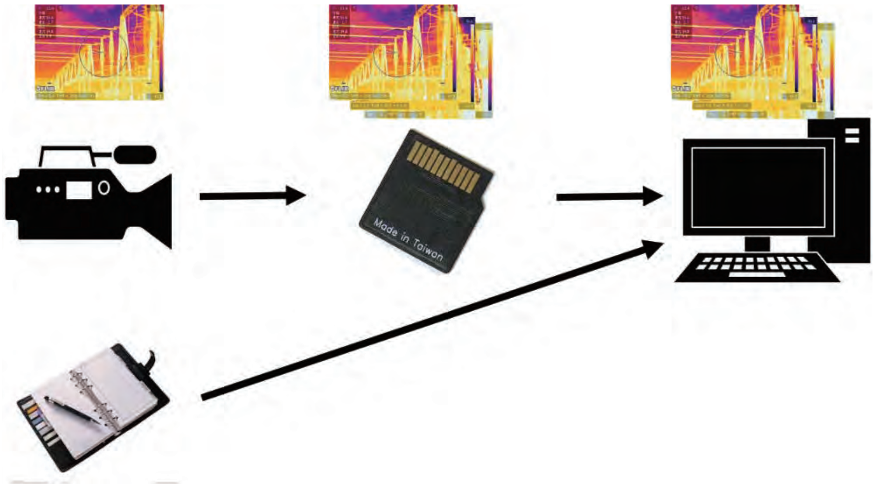

Figure 1.5: Traditional method for substation monitoring by infrared video camera

- Inconvenience

  Staff have to copy images to the server and record data on the notebook, and it cannot be completed automatically.

- Error-prone system

  For the system depends on human being's behavior, if inspectors make a mistake in matching image to apparatus, a big trouble will happen.

Therefore, an automatic and intelligent system should be designed for substation monitoring. For information collection, network can be used instead of storage disk, and for information process, data from sensors via network can be used instead of recording in the notebook.

In this thesis, I proposed a scheme for substation monitoring by setting a network for information collection and using smart phone and sensor for information process to realize substation monitoring (shown in Figure 1.6). Instead of employing storage disk, a network is set up to transmit thermal images from infrared video camera to server, and instead of recording information onto the notebook, smart phone and sensors are used for identifying apparatus. The flow of the method is shown in Figure 1.6. Staff utilize infrared camera to take thermal images firstly, and at the same time, sensors on the smart phone detect useful information for the image, like location of camera from GPS (Global Position System), angle of

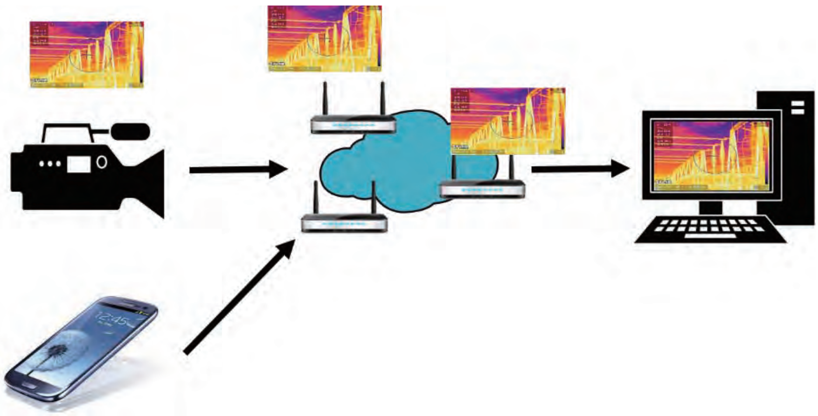

Figure 1.6: Method proposed in the thesis for substation monitoring

elevation from gyroscope, direction of camera from compass sensor and other data. The data accompanied with thermal image is transmitted to the server via network. At the server, by using identification algorithm, thermal images can be matched to the corresponding parts of apparatus. In this way, information collection and information process can be accomplished automatically. In this way, a high efficient and convenient real-time system with low error rate will be set up.

To accomplish the method for substation monitoring by using network, a protocol called mesh network oriented handoff protocol is designed for information collection to support the network transmit thermal image from camera to server at a high speed. Besides, an identification algorithm based on multi-mode is designed to recognize apparatus from the thermal images by using sensors on the smart phone.

1.3 Organization of the Thesis

The rest of the thesis is structured as follows. In Chapter 2, the protocol of link quality based handoff is discussed in detail, including protocol design, network design, software design and hardware design. Besides, the implementation and the corresponding experiment results are also contained. In Chapter 3, the identification algorithm based on multi-mode is presented, including algorithm design, software design, hardware design and implementations, but parts of

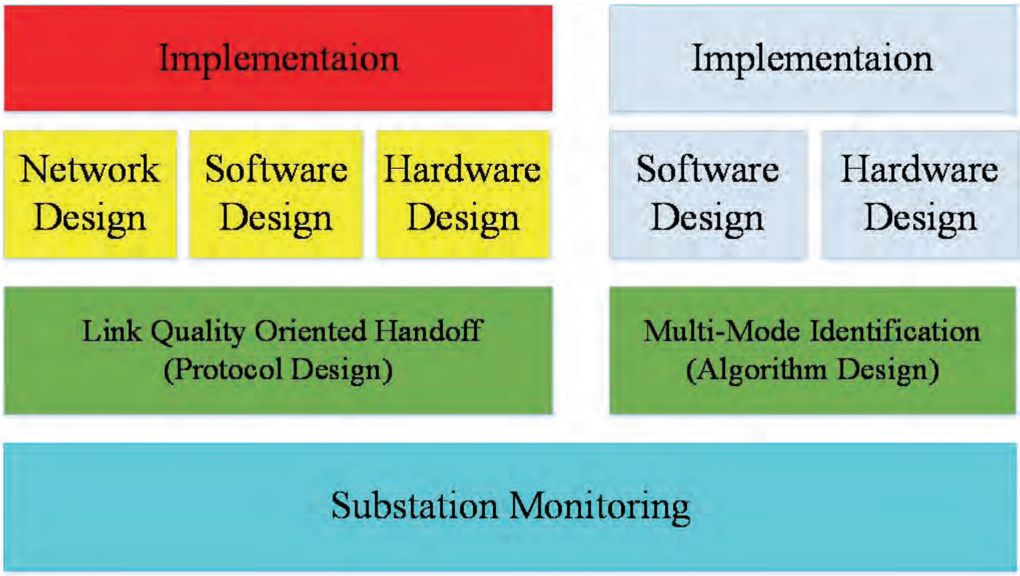

Figure 1.7: Research framework

software design, hardware design and implementations will be completed in future. In Chapter 4, the future research plan is scheduled. In Chapter 5, a brief summary was concluded for the whole thesis.

Chapter 2

Mesh network oriented Handoff for Information Collection

In this chapter, the protocol of mesh network oriented handoff for information collection is described in detail. Extensive experiment results are also presented to illustrate that the protocol effectively support fast handoff among the network.

At first, I will give an introduction to how to set up a network for information collection including motivation, customer requirements, restrictions for hardware and software, and design principles, and then raise the problem for transmission in the network. What's more, I will propose the mesh network oriented handoff protocol to solve the problem. Besides, implementation part including network design, software design and hardware design will also be contained. At last, I will present the experiment results and conclude a brief summary for the protocol.

2.1 Overview

2.1.1 Motivation

Using infrared video camera to detect the temperature of devices is an important method for examining and maintenance for operation of apparatuses and equipment in substation to ensure safety and reliability of power grid. However, how to transmit thermal images taken by the infrared camera to the server in a timely and efficient method is a difficult problem. In traditional methods, it needs staff to store images in storage disk or USB first, and then copy them to the server. These methods are inefficient and inconvenient, and most importantly system using methods is a non-real-time system, which may bring error messages for operators. In recent years, wireless communication interface is add to infrared thermal instruments, including Bluetooth, Zigbee and Wi-Fi Interface. Bluetooth can only be used for short distance transmission, and cannot is not appropriate for substations. Besides, Zigbee can only support low speed transmission, and cannot be applied for image transmission. Hence, Setting up a wireless network with Wi-Fi is the best choice to transmit thermal images in substation.

2.1.2 Customer Requirements

According to the actual situation of infrared temperature measurement in substation, there are mainly three requirements for the wireless network.

Working Environment

For the working environment of the network is in substations, some factors from power system should be taken into account. First, in consideration of the size of substations, the network should work in an $100(m) \times 100(m)$ square at least. Besides, the shielding effect of power facilities should also be considered. Generally, transmission frequency should be more than 1GHz influenced by corona phenomenon of high voltage. What's more, for power system is sensitive to external interference, the power of transmission devices should be low enough (lower the power of common walkie-talkie system, no more than 5W).

Transmission Throughput and Transmission Delay

Generally speaking, there are about 100 images taken in each inspection and the size of each image is about 1MB. The interval time between two images is more than 20 seconds. Hence, the throughput of the network should be more than 10Mbps, and the average delay should less than 60 seconds.

Customer Requirements

Because infrared video camera is expensive, and usually several substations share a common one infrared camera, the network should be compatible with most types of infrared cameras. Besides, there are several restrictions for infrared thermal instrument.

Hardware Restriction

- For the complexity of infrared thermal instrument, its hardware cannot be changed.
- The interface provided by infrared thermal instrument restricted, and there is only one USB interface.

Software Restriction

- The driver of the infrared thermal instrument can be revised, and only default operating system can be used.
- For it is only allowed default program running on the system, no scripts and other programs can be run on it.
- The network function of the system is simple. Only some simple functions, like IP address and network name can be reconfigured. Besides, fast switch between different networks is allowed on the instrument

2.1.3 Design Principles

Taking customer requirements into account, design principles of the system are presented as follows.

Correctness

Every image should be transmitted to the server with no loss and no damage. No image loss indicates all images taken by the camera should be transmitted to the server totally, and no image damage means any image cannot be destroyed in the network.

Stability

The system ought to be running stably in a long time, and no system crash is permitted.

Short Delay

Images need to be sent to the server in a short delay. In order to realize real time monitoring, transmission delay should be no more than 60 seconds.

Recoverability

Suppose some routers of system are shutdown or crashed, it cannot bring a big influence on the whole network. Besides, when these routers rebooted, the system will work normally again.

2.1.4 Wireless Mesh Network

According to the customer requirements and design principles, wireless mesh network (WMN) is applied in the network design. Working in the substation, the network system should provide a high bandwidth to transmit images and a minimal interference with the wireless devices in the substation. For Wireless mesh network's advantages of flexible structure, good robustness,

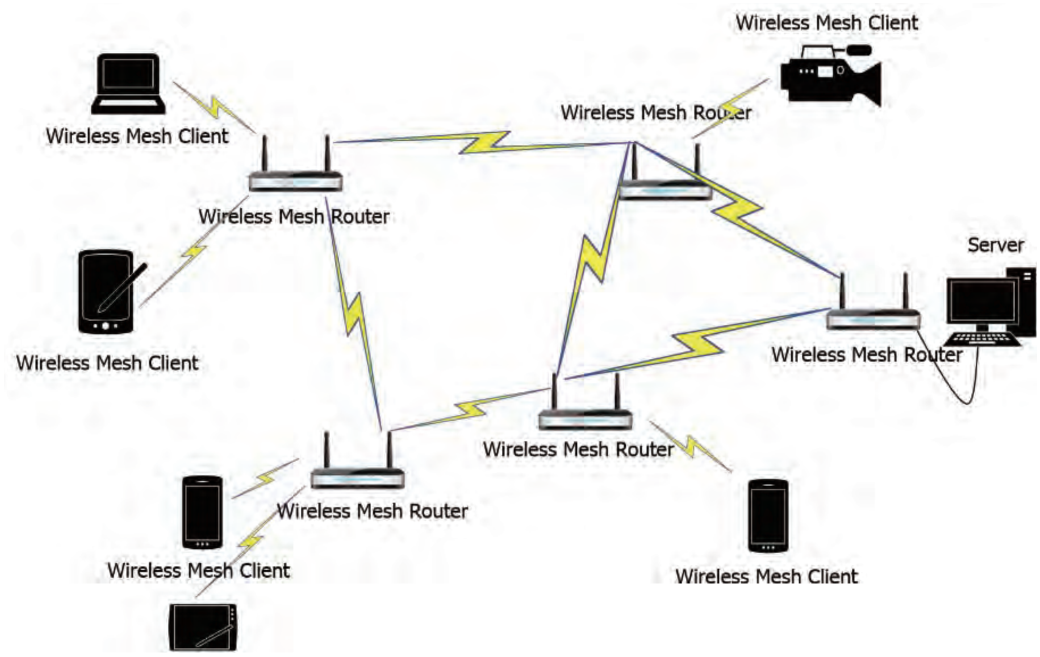

Figure 2.1: Wireless mesh network

high bandwidth and large coverage with lower power, wireless mesh network is preferred to the conventional networks for the system.

Introduction to Wireless Mesh Network

Wireless mesh network (shown in Figure 2.1) is a communication network made up of radio nodes organized in a mesh topology, comprised of two types of nodes: mesh routers and mesh clients. Mesh clients are often laptops, cell phones and other wireless devices while mesh routers have minimal mobility and form the mesh backbone for mesh clients. Mesh routers forward traffic to and from the gateways which may, but need not, connect to the Internet.

Other than the routing capability for gateway/bridge functions as in a conventional wireless router, a mesh router contains additional routing functions to support mesh networking. Compared with conventional wireless network, there are no central routers in wireless mesh network, and every router in the network operates identically.

Advantages of Wireless Mesh Network

- Scalability

  Wireless mesh network is a scalable system, with great flexibility. Because wireless mesh networks are dynamically self-organized and self-configured, with the nodes in the network automatically establishing an ad-hoc network and maintaining the mesh connectivity. When all of the mesh routers are configured in the same subnet, the mesh routers can maintain the mesh connectivity themselves. As a result, even applied in other substations with different areas and different shapes, the system can also work well without changing any hardware and software by adding or reducing the number of mesh routers. Although a conventional wireless network, like AP-based (Access Point) network, can also work in different substation by adding routers, it is limited by the area of the coverage. If the area is large enough such that the central router cannot cover, such a system cannot work anymore. As a consequence, wireless mesh network can be applied in different substations for its scalability.

- Robustness

  A mesh network offer redundancy, making system reliable. Because mesh routers distributed as a mesh topology, there can be more than one path between any two routers. For example, when one router node fails to operate, the rest of the nodes can still communicate with each other, directly or through one or more intermediate nodes, even though there is a route disconnected.

- High Bandwidth

  Wireless mesh network has a high bandwidth to transmit images. Because of multi-hop transmission used in wireless mesh network, and the short distance between two hops, it will obtain higher bandwidth, compared with long distance transmission. Therefore, more images can be transmitted simultaneously in the wireless mesh network.

- Wide Coverage with Low Power

  Through multi-hop communications, the same coverage can be achieved by a mesh router with much lower transmission power. In conventional wireless network, the central router should be connected with other routers directly, such that, in a large substation, the central router should provide a high power to communicate every router in the substation. In a wireless mesh network, mesh routers need communicate with its neighbor routers, so the power for mesh routers can be very low. With low power, mesh routers can be designed small enough and they can be easily installed and maintained in the substation. Besides, low power also has little interference with other wireless devices and apparatus in the substation.

Consequently, due to the advantages of the wireless mesh network, it is suitable for being applied in the substation, for it can provide high bandwidth to transmit images, and can be easily installed without interfering other devices.

2.1.5 Problem Description

After setting up the network modeling, there is a big problem, that is, when moving in the network, the client (infrared thermal instrument) cannot switch perfectly among routers. For instance, as shown in Figure 2.2, at first, the wireless client (infrared thermal instrument) is in the coverage of Router A and communicates with A. When the client moves from the coverage of Router A to the coverage of Router B, the client should have switched the network and communicate with Router B, for the client is closer to B and has a better channel with B than A. However, because the client still can receive the signal from Router A, and the client will not disconnect with A, which lead that the client still download from routers with a bad channel until the client cannot totally receive the signal from router A.

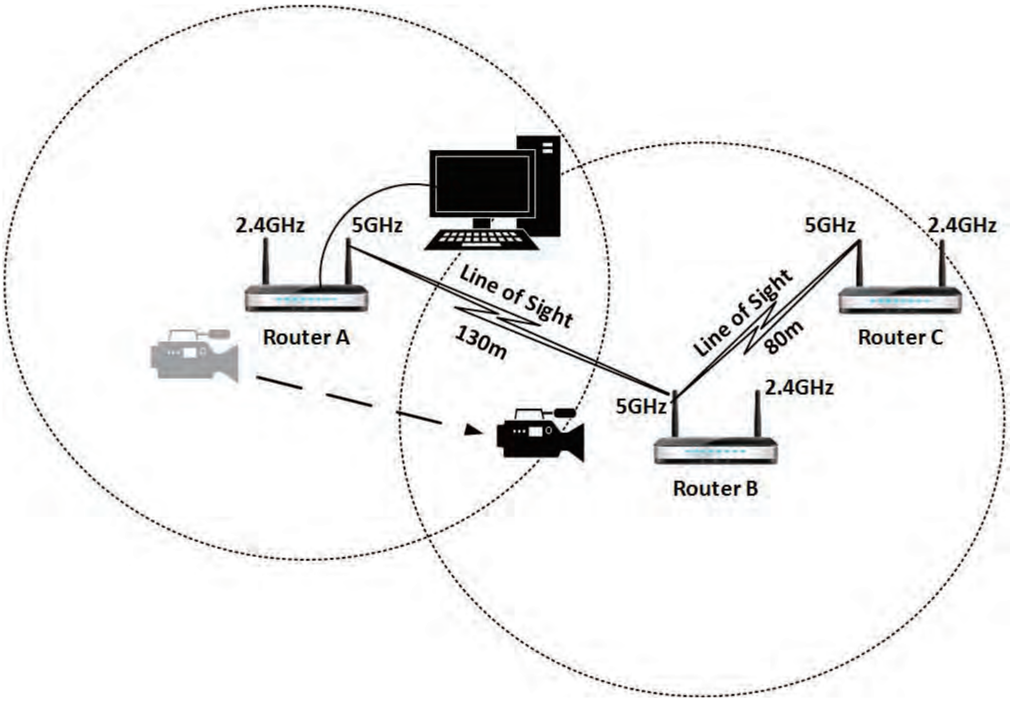

Figure 2.2: Problem of network switching

2.1.6 Traditional Method

Most traditional methods depends on clients to switch network, that is, clients at first search all networks all the time, and choose a best network to connect by comparing signals from routers. For example, when client moving from Router A to Router B, at first, the client search all the networks and choose to communicate with Router A, for the signal received from A is stronger than that from B. When the client moves to B, for the client search all the internet, and find that signal from B is stronger, and then the client connect with Router B instead of Router A.

There are several drawbacks with traditional methods.

- The client must have functions of switching network.

  If the client has no functions of switching network, then it will not disconnect with Router A and connect with Router A.

- New drivers need to be loaded onto the client.

  If the client does not support loading new drivers, then this method cannot work.

- The client needs to spend extra resources for switching network.

  The client have to search all networks all the time, which will produce extra burdens for the hardware of client.

- It will cost extra time to switch between two networks.

  Switching between two networks needs more time for network card on the client.

Because of these drawbacks, traditional methods cannot be applied for the infrared thermal instrument, for the restrictions stated above indicate that no new drivers can be loaded onto the camera. Besides, the camera has no functions of switching network. Hence, new protocol for the infrared thermal instruments should be designed.

2.2 Protocol Design

The new protocol is called mesh network oriented handoff based on link quality. The basic idea for protocol is that network oriented is applied instead of client oriented, that is to say, connecting to which router depends on network instead of client. As can be seen from Figure 2.3, in the protocol, there are three types of nodes: one client used for sending data (e.g. thermal images), server used for receiving data and making decision for which router to download from the client, and several routers set up for the network and used for transmit data between client and server.

The protocol is described as follows.

- All of the routers in the network detect link quality with the client at set intervals.

- All of the routers send the information of the link quality to the server.

- The server choose the router with the best link with the client by comparing all link qualities received from routes;

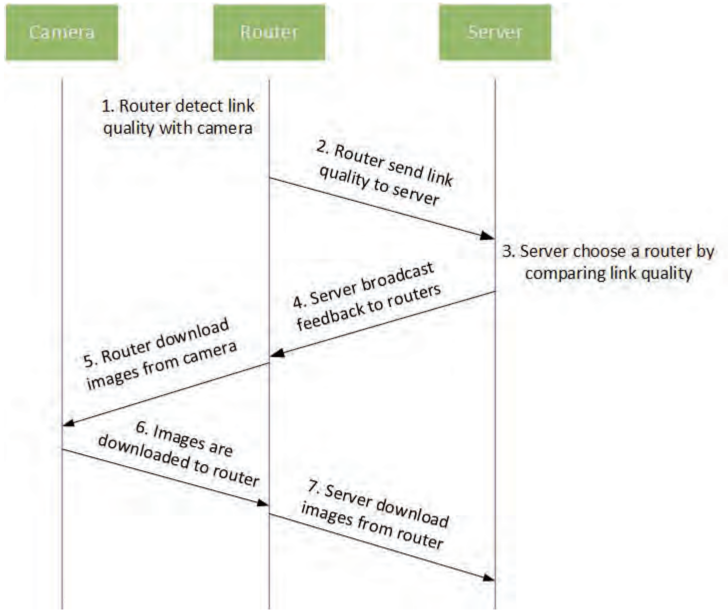

Figure 2.3: Protocol of mesh network oriented handoff

- The server broadcast feedback commands to all the routers.
  - For the router with the best link, the command sent from the server is 'download data from the client'.
  - For the router without the best link, the command sent from the server is 'not download data from the client'.
- The router received the command of 'download data from the client' send a request to the client for downloading;

  The routers received the command of 'not download data from the client' do not send any request.
- The client received the request send data (thermal images) to the router.
- The router send data to the server.

For example, as shown in Figure 2.4, the client moves Router A to Router B. In our protocol, at first all routers (Router A, Router B, Router C, Router D, and Router E) detect the signal

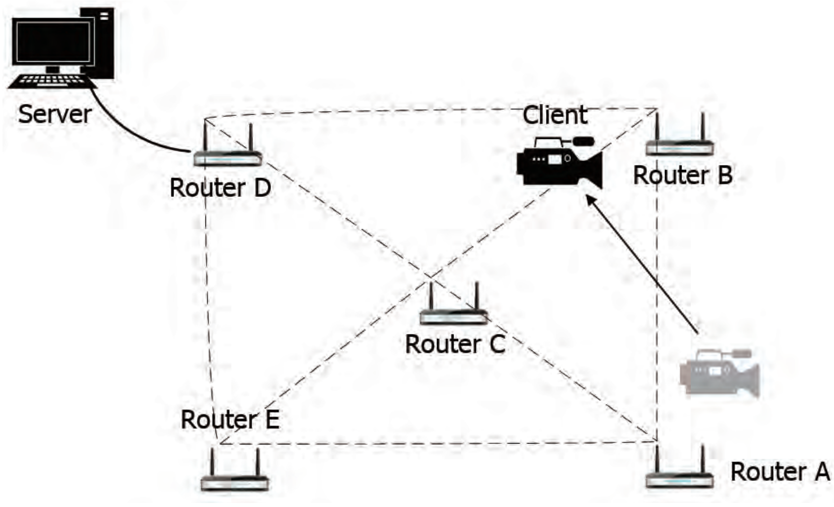

Figure 2.4: Example of new protocol

with the client and send the detecting results to the server. The server find that Router A has the best link quality with the client and send command of downloading to Router A, and not downloading command to other routers. Then router A download data from the client and send it to the server. When the client is closer to B, the server find Router B is the router with best link quality, and then send B downloading command instead of. Then B download the data from the client. In this way, the client transmit data to the server with best link quality all the time. Besides, because all routers are set up in the same network, there is no need for the client to do the network switching

2.3 Implementation

In order to verify the advantages of the protocol, implementation is completed. There are three parts of implementation, which are network design, software design and hardware design.

2.3.1 Network Design

Node Functions Design

According to the protocol, three are three types of nodes: client, router and server.

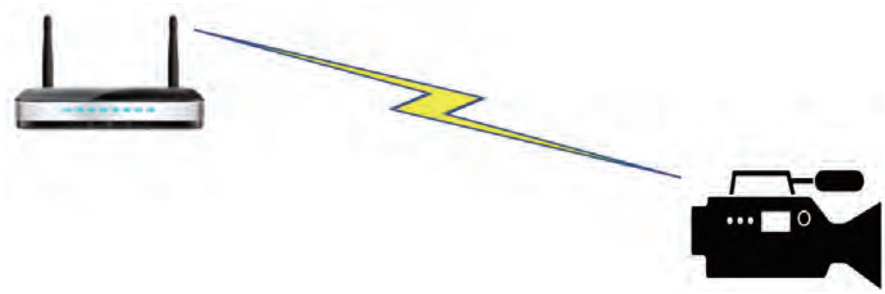

Figure 2.5: Network between client and router

- Functions of Client

  As stated before, for the restriction of the infrared thermal instrument, the functions on the client is very simple, supplying a file transmission server for downloading, which has been provided by default operating system.

- Functions of Router

  As state in the protocol, the functions of routers are detecting the link quality with client, sending and receiving information with server, downloading files from the client and providing a file transmission server.

- Functions of Server

  The main functions of server are providing a user interface (UI) and controlling the operation of the whole network, which are receiving information from routers, choosing a router with best link quality by comparison, broadcasting commands to routers and downloading files from routers.

Types of Network

From there are three steps for information transmission, which client to router, transmission among routers, and router to server.

- Network Between Client and Router

  Because the client needs moving around in substations, the network between client and

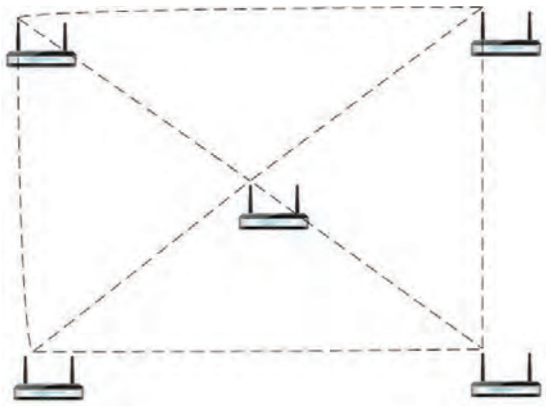

Figure 2.6: Network of routers

routers should be wireless. Besides, client will not switch networks among routers, so all routers and client should be in the same network. Network among routers.

- Functions of Router

  For routers should be set up in substations, and no wires is allowed in power grid, the network among the routers should be wireless.

- Functions of Server

  Because the server should be set in the supervising room, the network between routers and server should be wired instead of wireless, for walls of rooms will be obstacles for wireless communication.

2.3.2 Software Implementation

Platform

- Platform for Client

  Platform for client is a default operating system with a file transmission server.

- Platform for Router

  Platform for router is a development board with openwrt operating system with Linux kernel.

- Platform for Server

  Platform for server is a common computer with windows operating system.

Network Configuration

- Configuration on Client

  Configure wireless network name (SSID of network) with wlabforclient by user interface.

  Configure IP with 192.168.2.1 by user interface.

- Configuration on Routes

  - Configure wireless network type, network name (SSID of network), and network channel in the file of /etc/config/wireless.

    wlan0 Interface: //Interface for the network to connect with client

    option mode adhoc

    option ssid wlabforclient

    option channel 40

    wlan1 Interface: //Interface for the network to connect with other routers

    option mode adhoc

    option ssid wlabforrouters

    option channel 11

  - Configure ip for network in the file of /etc/rc.local

    ifconfig eth0 192.168.105.2

    ifconfig wlan0 192.168.2.5

    ifconfig wlan1 192.168.3.5

- Configure routers for network in the file of /etc/config/olsrd.conf

  Hna4

  192.168.105.0 255.255.255.0

  192.168.3.0 255.255.255.0

  192.168.2.0 255.255.255.0

- Configure firewall for network in the file of /etc/rc.local

  iptables -A forwarding_rule -i eth0 -o wlan1 -j ACCEPT

  iptables -A forwarding_rule -i eth0 -o wlan0 -j ACCEPT

  iptables -A forwarding_rule -i wlan1 -o wlan0 -j ACCEPT

  iptables -A forwarding_rule -i wlan1 -o wlan1 -j ACCEPT

  iptables -A forwarding_rule -i wlan0 -o wlan0 -j ACCEPT

  iptables -A forwarding_rule -i wlan0 -o wlan1 -j ACCEPT

  iptables -A forwarding_rule -i wlan0 -o eth0 -j ACCEPT

- Configure path, username and password for file transmission server in the file of /etc/vsftpd.conf

• Configuration on Server

  Configure IP with 192.168.105.1 by user interface.

Software and Scripts

From node functions we know, for functions on the client are provided by default operating system, what we design are just software on the server and scripts on the routes.

• Scripts on Routers

  The flow of the scripts on routers is shown in Figure 2.7.

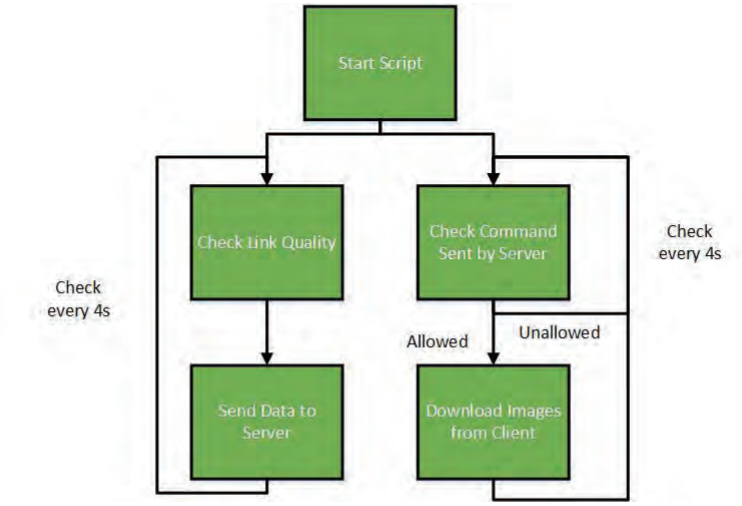

Figure 2.7: Flow of functions on routers

Detect link quality using *iw wlan0 station dump* command to detect signal intensity with client.

Communicate with server using *netcast* command, like

$$echo \ \$COM | \ nc \ \$IP \ \$PORT$$

Download images from client using $lftp$ command, like

$$lftp \ \$FTP \ \ll \ FTIP$$

Record log files by using command

$$timestamp = \text{`}date\text{`}; \quad echo \ Start \ \$i : \$timestamp \ \gg \ log$$

and

$$timestamp = \text{`}date\text{`}; \ echo \ End \ \$i : \$timestamp \ \gg \ log$$

- Software on Server

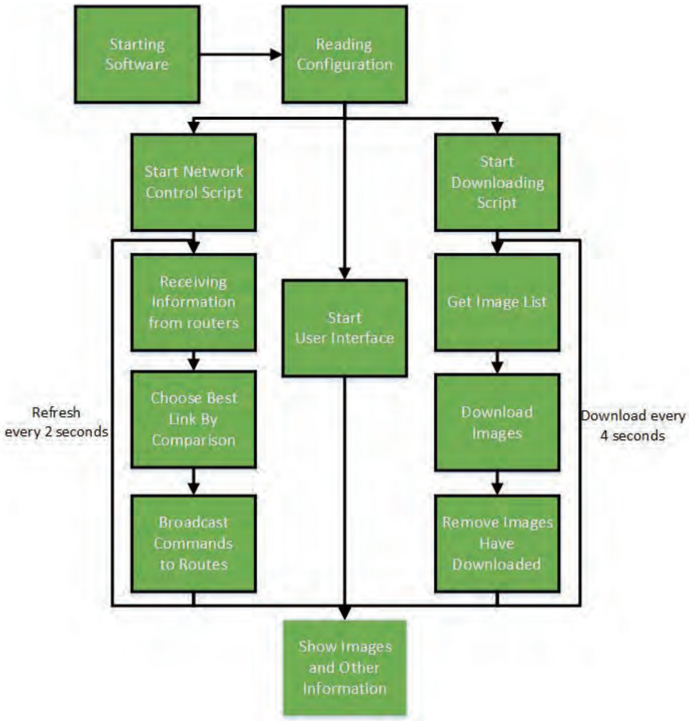

Figure 2.8: Flow of functions on server

The flow of the functions on the server is shown in Figure 2.8, which are including three modules, network module, image download module, and image download module.

- Network Module

  Use *netcast* command to write the information of link quality received from routers to a file

$$nc.StandaerdInput.WriteLine("nc\ -L\ -p\ 6666 > \ FILE")$$

  Use *tail* command to read the newest information from the file.

  Compare the signal intensity and send feedback commands to routers with *netcast*.

  Use FTP (File Transport Protocol) command to download files from the router

- Image Download Module

Figure 2.9: Software on server

Login to the ftp server on the router.

List names and dates of all the images on the server.

Download images from the router with the names listed.

Delete images downloaded on the router.

- Image Display Module

  In this part, a software with a user interface is developed programed with WPF (Windows Presentation Framework) in *C#* language. Using *listview* module to list the 200 newest images, and display an image on the right. Besides, other information about the network is also shown on the software, as shown in Figure 2.9.

2.3.3 Hardware Implementation

- Hardware on Infrared Thermal Instrument

  The network interface card (NIC) for the infrared thermal instrument is a USB wireless card working in the frequency of 2.4GHz with a USB interface used to compatible with the instrument.

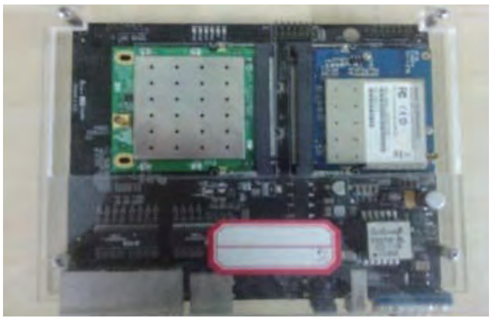

Figure 2.10: Development board

Figure 2.11: Antennas on routers

- Hardware on Routers

  The hardware of routers is development board produced by Ubiquiti (shown in Figure 2.10). There are two NICs on the board, which is one card with 2.4GHz to communicate with client and the other one with 5GHz to communicate with other routers (shown in Figure 2.11).

- Hardware on Server

  Server is a common computer with windows operating system.

2.4 Performance Evaluation

2.4.1 Testing Scheme

We set up our system in the substation of Sijing in Shanghai (shown in Figure 2.12). The testing topology is shown in Figure 2.14. As can be seen from figure, two routers (Router B

Figure 2.12: Substation of Sijing in Shanghai

Figure 2.13: Router in the field

and Router C) as shown in Figure 2.13 are set up in the field of the substation and one router is set up on the monitoring building which is connected to the server. And inspection personnel with infrared thermal instrument moves in the field and takes picture. The length of the field is about 160 meters and the width is about 120 meters. The distance between Router B and Router C is about 60 meters and the distance between Router A and Router B is about 70 meter.

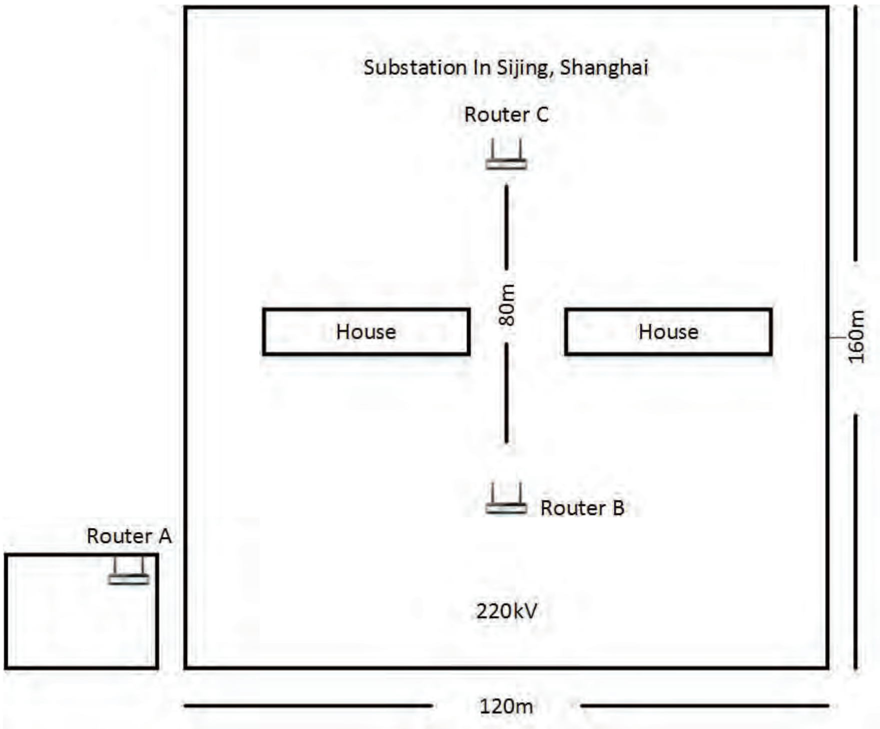

Figure 2.14: Testing topology

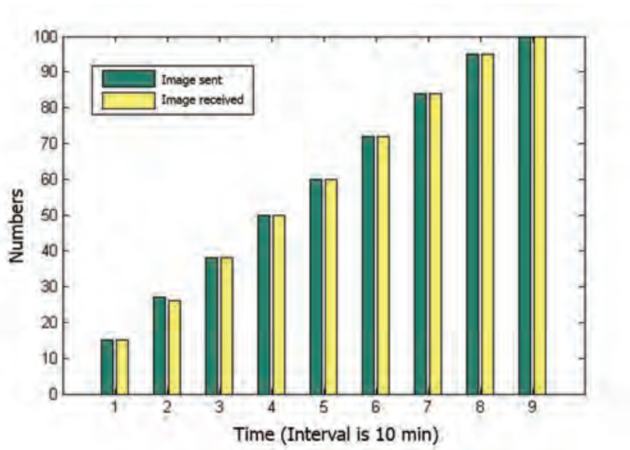

Figure 2.15: Correctness of system

2.4.2 Testing Results

According to the design principle stated before, we design four scenarios to test the correctness, stability, timeliness and recoverability.

Table 2.1: Number of images taken and received for correctness

Time (minute)	10	20	30	40	50	60	70	80	90
Number of images taken	15	27	38	50	60	72	84	95	100
Number of images received	15	26	38	50	60	72	84	95	100

Figure 2.16: Testing result for correctness

Correctness

As can be seen from the Figure 2.15 and Table 2.1, every image is transmitted to the server with no loss and no damage. After testing of 90 minutes, all of the 100 images taken have been received by server, indicating with no loss. Besides, from the table, images taken every 10 minute are nearly received. Although in the 20th minute, number of images taken is 27 and number of images received is 26, the reason is transmission delay, and the 27th image is received at the 30th minute. Besides, from Figure 2.16, every image taken by the camera transmitted to the server is totally correct without any damage. Therefore, from the number and the quality of images received exactly, the correctness of the system is verified.

Stability

After 12 times test in the campus, the system can work normally at least 4 hours, and no crash and abnormal phenomenon happens. Besides, the system has been running stably in a month

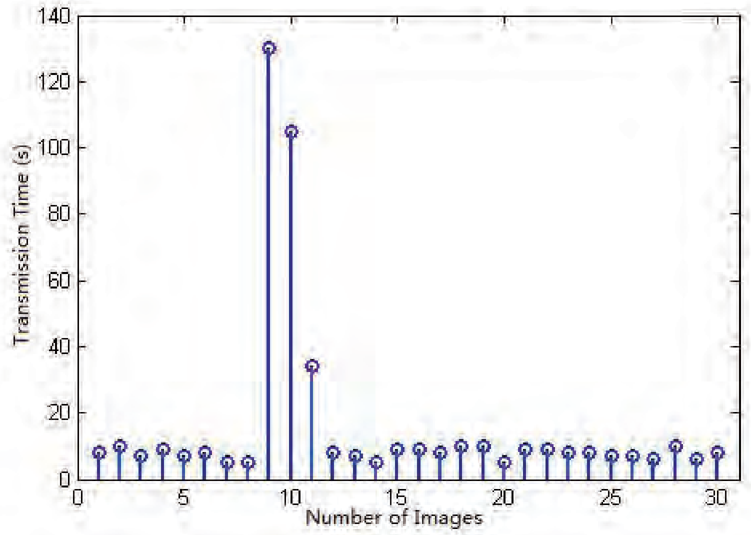

Figure 2.17: Testing result for delay(1)

in Sijing substation, and no crash happens, indicating the stability.

Delay

As can be seen from Figure 2.17, most of the infrared images are transmitted to the server in 4 to 8 seconds, while the time for transmission image Number 9, Number 10, and Number 11 is long, which are 137 seconds, 102 seconds, and 36 seconds separately. The reason of that is these images are taken in the blind zone between Router A and Router B. After images taken, the infrared camera cannot communicate with any router because of the blind zone, and it can not sent images to the server instantly. After camera moves out of the blind zone, images can be transmitted instantly from Figure 2.18. Therefore, the normal transmission delay for the system is 4 to 8 seconds, which according with the request for substation monitoring.

Recoverability

As can be seen from Figure 2.19 and Table 2.2, Router C is shutdown at the 45th minute, and no images are transmitted after that because the camera is in the area covered by Router C, while at the 60th minute 6 images are transmitted to the server via Router B, for the camera

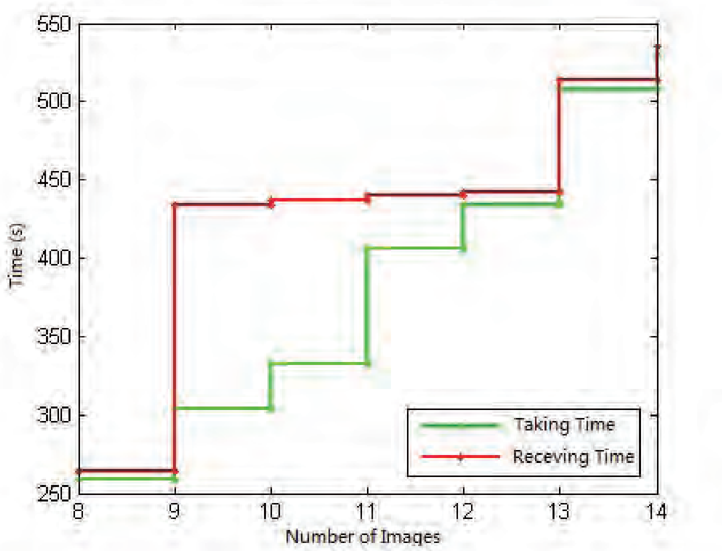

Figure 2.18: Testing result for delay(2)

is in the area covered by Router B, and comes into the Router C' area, so no images received between the 60th minute to the 70th minute. Router C is rebooted at the 73th minute, all of the images stored in the Router C are transmitted to server and the whole system comes to normal. The Figure 2.20 and Table 2.3 indicates the same situation for shutdown and rebooting Router B, and the result is the same. All images are received eventually and the system can work normally after rebooting. Therefore, we can see that even if some routers of system are shutdown, and it will not bring a big influence on the whole network. Besides, when these routers rebooted, the system will come to normal again.

Table 2.2: Number of images taken and received for recoverability(1)

Time (minute)	10	20	30	40	50	60	70	80	90
Number of images taken	12	23	30	46	68	77	83	94	100
Number of images received	12	23	30	44	64	70	70	93	100

Table 2.3: Number of images taken and received for recoverability(2)

Time (minute)	10	20	30	40	50	60	70	80	90
Number of images taken	14	22	35	47	57	63	77	92	100
Number of images received	14	21	34	34	57	59	59	90	100

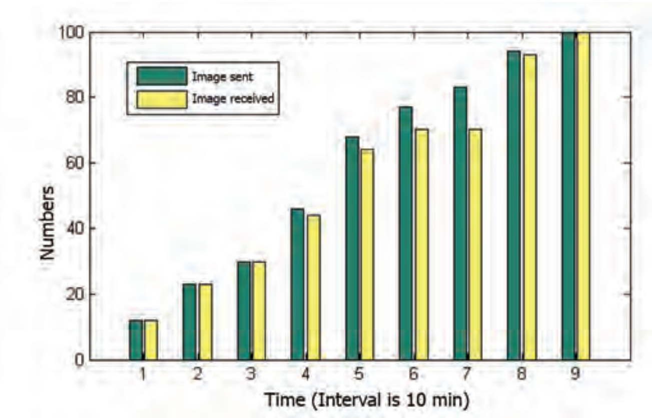

Figure 2.19: Recoverability of system(1)

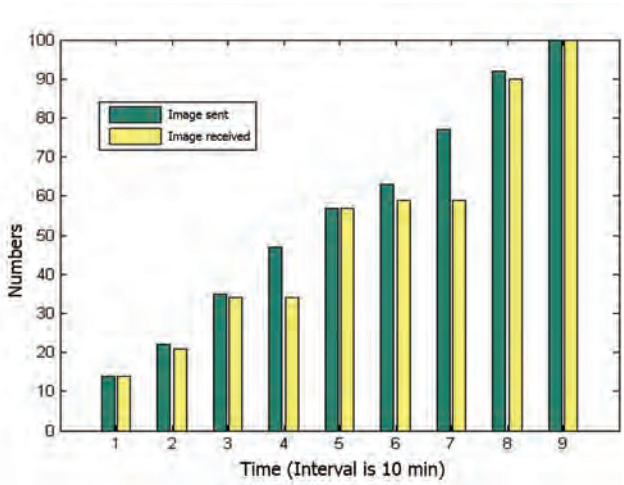

Figure 2.20: Recoverability of system(2)

System Testing

For system testing, smoke testing method is used, and only the correctness of that the whole system can work normally in the real working environment. The Figure 2.21implies testing scheme, and Table 2.4 implies the result. From the testing scheme, inspectors 69 images from

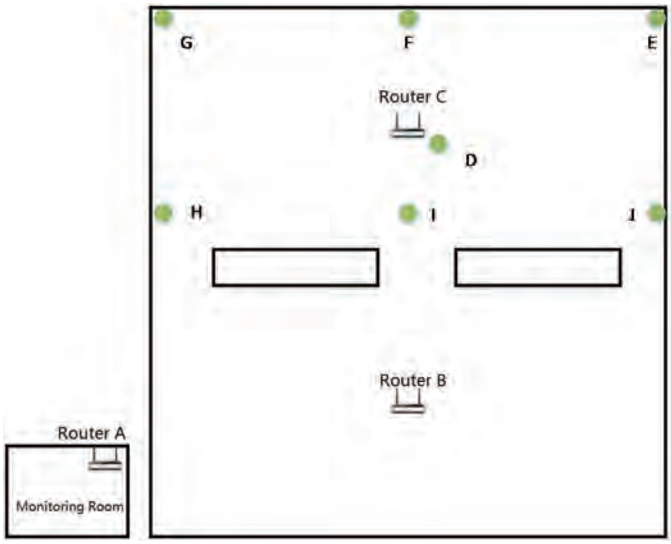

Figure 2.21: System testing scheme

the points of E-H, and from the testing result, we can see that all of images are received eventually and 67 of them are received in one minute. Therefore, system can work well at the smoke testing with this result.

Table 2.4: System testing result

Transmission Time (second)	Number of Images Received
15-30	20
30-45	32
45-60	15
>60	2

2.5 Summary

For information collection, we investigate a method to find a path with the best link quality to transmit when making handoff between routers. In order to complete the method, we design a protocol called mesh network oriented handoff, and set up a network to verify the protocol by designing and implementing functions of nodes in the network, software and hardware of the nodes. Besides, a real system is set up in Sijing Substation in Shanghai to realize the protocol.

Chapter 3

Apparatus Identification based on Multi-Mode for Information Process

3.1 Overview

Using infrared video camera to detect the temperature of devices is an important method for examining and maintenance for operation of apparatuses and equipment in substation to ensure safety and reliability of power grid, and how to transmit thermal images taken by the infrared camera to the server in a timely and efficient method can be solved by utilizing wireless mesh network with Wi-Fi. However, how to identify the specific devices and apparatuses in the grid taken by the infrared video camera also becomes a big problem, because inspectors are desirous to know which device and which apparatus shown by the image with high temperature taken by the camera, for example in Figure 3.1. This figure shows the inspecting procedure in smart substation. As mentioned in Part 2, an inspector with infrared video camera perambulating around the substation, takes pictures for each apparatus, and each gray circle in the figure indicts a convertor pillar or a switch pillar in the substation. When the inspector comes to a convertor pillar (shown as the red circle), and takes an infrared image for the convertor, the infrared image will be transmitted to the server in the monitoring room by the wireless mesh network as Part 2 indicates. After the inspector returns back to the monitoring room and finds the image with high temperature, he has forgotten which convertor for this image, for he has been walking around the substation for a long time after taking this image.

In traditional method, inspectors will note down the shooting time, the device number, the apparatus name and the image serial number, after taking an image. When he returns to the monitoring room, he will compare the image from the camera and the data from the notebook, and finds out which apparatus with high temperature. This method is too inefficient, and depends on human beings behavior. If inspectors make a mistake, then the image will be matched with the wrong apparatus. Therefore, an effective and an efficient apparatus identification method is needed to match the image taken by the infrared video camera with the apparatus in the substation.

In this paper, a method to identify the specific devices and apparatuses in the substation is considered, based on multi-mode recognition, including image process technology, machine learning technology, wireless positioning technology and other information provided by sensors on the smart devices, like compass, gyroscope, and acceleration sensor to improve the efficiency and the accuracy.

3.2 Related Research

As the method provided above, some notable technologies and algorithms will be applied in thesis to realize a demo system. In the location detection part, OCR (Optical Character Recognition) Algorithm and Tesseract Engine is utilized to complete the scanning tag and obtain characters. In human behavior pattern recognition part, machine learning algorithm is used. Concretely speaking, decision tree algorithm is applied to determine human's behavior. In image recognition on server part, SIFT and SURF algorithm is applied. The following is an introduction to these technologies and algorithms in details. (Shih et al., 2012)

3.2.1 Optical Character Recognition Algorithm

Optical character recognition (OCR) is the technology to convert images with typewritten or printed text into machine-encoded text.(Holley, 2011) It will be common used for digitizing printed texts, in order that texts can be edited, searched, displayed, and stored electronically.(Suen et al., 2008) It is a new subfield of pattern recognition, computer vision and artificial intelligence. (Zhou et al., 1997) In the 2000s, WebOCR as an online service in the cloud computing environment is made available, as is made in mobile applications on smart phones.(Shih et al., 2012)

Tesseract: an Optical Character Recognition Engine

Tesseract is an optical character recognition engine (Smith, 2007) (Smith et al., 2009), sponsored by google since 2006, for various operation system including Windows, Linux, IOS, and Android system operating on the smart phone, released under Apache License.(Google, 7 12) It is available for free and is considered one of the most accurate open source OCR engines.(Sarma, 2009) It was first invented by HP (Hewlett-Packard Development Company, L.P.) in 1985 and was improved by Google by eliminating bugs and optimizing algorithms.(Kay, 2011). In this thesis, the Tesseract engine is installed on the smart phone to conduct the operation of recognizing characters by scanning tag.

3.2.2 Machine Learning Algorithm

Machine learning, a subfield of computer science and statistics, nowadays, is a key technology in the analysis of data, including topics such as data classification, data clustering and linear regression of data(Watkins and P., 1992). It is a scientific discipline, which exploring the construction and study of algorithms that can learn from data, strongly tying to artificial intelligence and optimization.(Bishop, 2006) By building a model based on inputs, usually called features, machine learning can be used to make predictions and decisions, without following programmed instructions from the computer. Machine learning algorithms, including supervised learning algorithms, unsupervised learning algorithms, reinforcement learning algorithms and deep learning algorithms,(Bishop, 2006) can solve many problems, such as data filtering, search engines, and computer vision. It sometimes focuses more on exploratory data analysis than data mining.(Watkins and P., 1992)

Decision Tree Learning Algorithm

Decision tree learning is a simplest supervised algorithms of machine learning algorithm. (Breiman, 1996) It usually uses a decision tree as a predictive model mapping observations about an item and features, like the direction and accelerator in this thesis, to conclusions about the item's target value for filtering and classification. (Freund and Mason., 1999) The decision tree is modeled with leaves representing class labels and breaches representing conjunctions of features or conditions. (Quinlan, 1996) Compared with other data mining methods, decision trees have various advantages.It is simple to understand and interpret, and just requires little data preparation. Besides, it is possible to validate a model using statistical tests by setting a *whitebox* model. (Mitchell, 1997)

3.2.3 Image Recognition Algorithm

Image recognition is the classical problem in computer vision, image processing(Barghout and Lee, 2003), which is to determine whether or not the image data contains some specific object, feature, or activity, and in this thesis, image recognition technology is used to detect apparatus in the image and do the matching with the apparatus in the sample database. (David, 1982) (Rosenfeld and Kak, 1982) Image identification is an individual instance of an object is recognized. Nowadays, SIFT-SURF algorithm is a common method for image recognition for its high efficiency and high effectiveness, which is also used in this paper. (Berthold and Paul, 1986) (Olivier, 1993)

SIFT (ScaleInvariant Feature Transform) Algorithm

SIFT Algorithm is an image process algorithm, is short for Scale-Invariant Feature Transform Algorithm, come up with by David G. Lowe in 2004. In his paper, $Distinctive\ Image\ Features\ from\ Scale-Invariant\ Keypoints$ (Lowe, 2004b), he presents a method for extracting distinctive invariant features from images so that one object in different images can be used to perform reliable matching. The main idea for his algorithm is use the invariance for the features of an object in different images in spite of image scale and rotation, addition of noise, change in illumination, and change in 3D viewpoint(Lowe, 2001), because these features are highly distinctive, so that a single feature can be correctly matched with high probability against a large database of features from many images. The main steps for the method are scale-space extreme detection to perform pre-treatment, keypoint localization to find image features, orientation assignment, keypoint descriptor to give a detail description for these image features, keypoint matching to match features between different images. (Lowe, 2004a)

SURF (Speeded Up Robust Feature) Algorithm

SURF (Speeded Up Robust Features) algorithm is first presented by Herbert Bay et al. in his paper $SURF\ \ Speeded\ Up\ Robust\ Features$ (Herbert et al., 2006) in 2006, which can be used for object recognition in computer vision task by. Inspired from the SIFT algorithm, SURF is several times faster based on an efficient use of integral images in keypoint detection part and sums of 2D Haar wavelet responses in keypoint description paring.(Panchal et al., 2013)

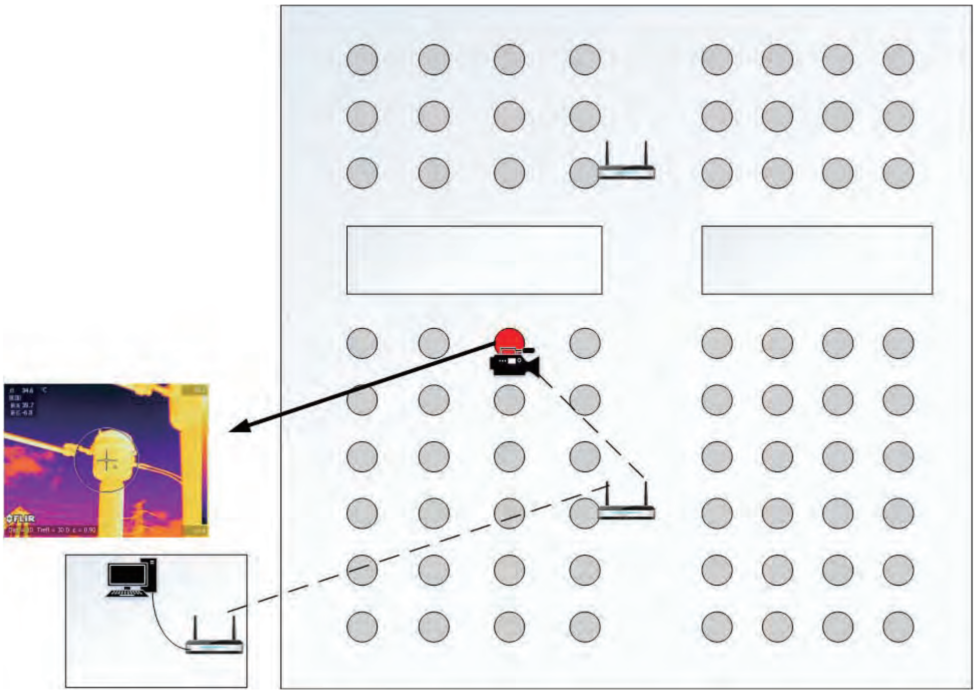

Figure 3.1: Inspecting procedure in smart substation

3.3 Framework Design

Basic ideas for our method for apparatus identification is shown in Figure 3.2. A smart phone combined with the infrared video camera is utilized, which is used to detect the location of the camera and send a common instead of infrared picture of apparatus to the server through the wireless mesh network. Besides, a server receiving photos from the smart phone and recognizing the images of the apparatuses, compared with sample images is also set up. With the location and the recognizing results, we can easily identify images with apparatuses in substation.

The framework design is shown in Figure 3.3. As can be seen from the figure, the whole framework can be divided into three parts modules on the smart phone, modules on the server and modules for transporting images between them. For the modules on the smart phone, two tasks will be handled, which are location detection and shooting behavior recognition. By achieving location information, which device (which switch pillar or which convertor pillar) is the apparatus on can be known, while by using shooting behavior recognition technology, the

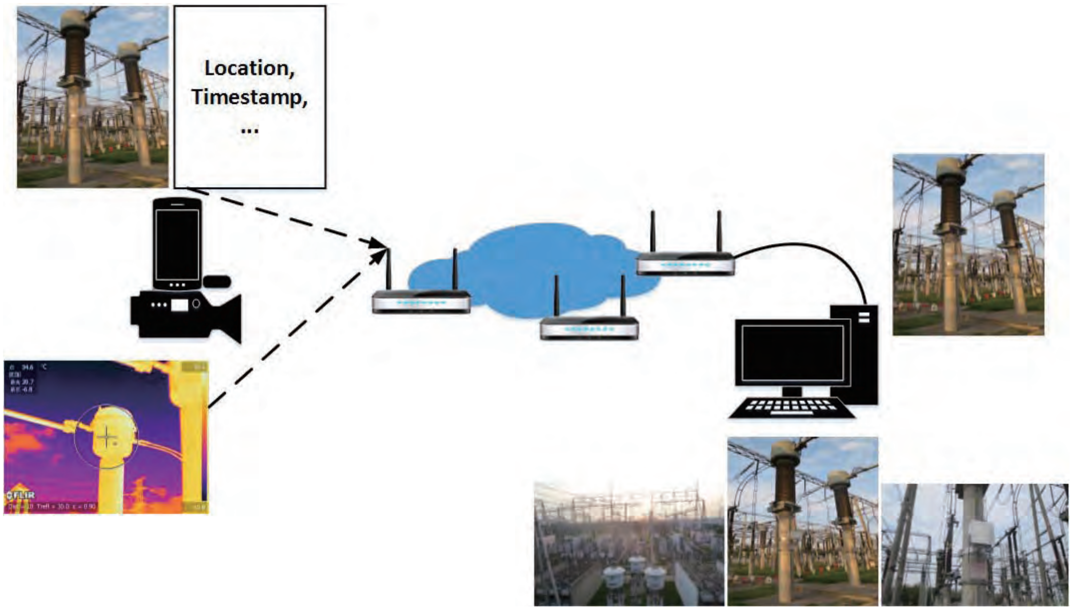

Figure 3.2: Apparatus identification method

timestamp of the infrared image taken by the camera can be realized by the smart phone. To solve location detection problem, some OCR (Optical Character Recognition) algorithms, aided with GPS (Global Position System) is used in the method provided in this paper, and to solve the shooting behavior recognition problem, sensors on the smart phone, such as accelerator, gyroscope and compass sensors, and some machine learning algorithms for sorting is employed. For the modules on the server, the task of image recognition should done. With the help of the image process technology, like SIFT-SURF algorithm, the problem can be easily solved. For transporting images, FTP (File Transportation Protocol) application is used between smart phone and server, which a FTP server is set up on the server end and a FTP client is started on the smart phone to transport images from smart phone to the server. The network for the FTP application is the wireless mesh network set up in Part 2. So as to match images taken by the smart phone with image shot by the infrared video camera, time synchronization should be completed both on the smart phone end and on the server end.

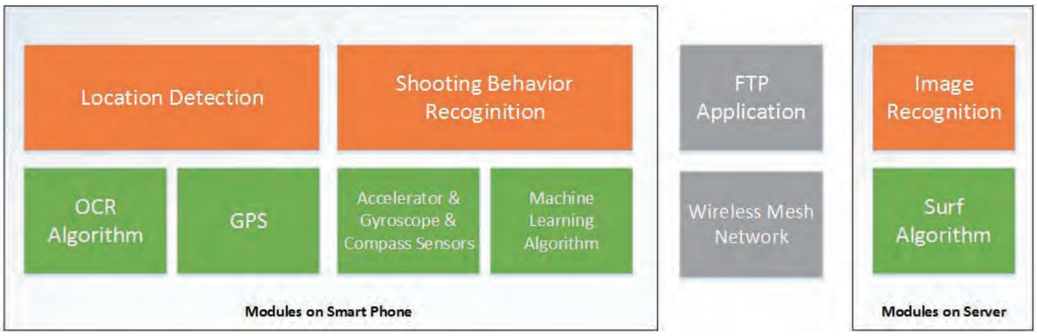

Figure 3.3: Framework design

3.4 Function Design

As stated before, from the framework design described in the Part II, functions design of the whole system can be divided into two parts, functions on the smart phone combined with the infrared video camera and functions on the server in the monitoring room. For smart phone design, functions of location detection of the photographer, recognition of photographer¡¯s shooting behavior, taking images by the smart phone automatically, transmission of images and information, like location and timestamp should be contained, and for the function design on server, reception of images and data, image recognition from image sample library, time synchronization between images from the smart phone and images from the infrared video camera should be considered.

3.4.1 Function Design on Smart Phone

Location Detection

When inspectors in the monitoring room observe images taken by the infrared video camera and find that the temperature of the apparatus from one image is extremely high, he wants to figure out where is this apparatus, so relevant information about apparatus should be acquired. In this paper, the location information on the apparatus is utilized, that is to say, which switch pillar or convertor pillar is this apparatus on should be known, for all the apparatus and devices in substation is set up on the pillars. Therefore, the apparatus can be found through the map of the substation with the location information with aware of which pillar the apparatus belongs to.

Behavior Recognition

For inspectors wandering in the substation, with an infrared video camera to take infrared images for substation monitoring and a smart phone to take common photos for apparatus images. If he is willing to observe one apparatus, two photos should be taken at the same time. One is from infrared camera, and the other one is from smart phone. Aims at clicking one button and two images taken, the action of taking infrared images by inspector should be detected by the smart phone, and a common photo for the apparatus can be taken automatically. In this paper, the method of behavior recognition is used, that is to say, the behavior of inspectors, such as walking around, taking images, scanning tag, and resting, should be detected with the help of the sensors on the smart phone and machine learning algorithm. By recognizing shooting behavior, smart phone will take photos.

Image Taken Automatically

As stated above, images from the smart phone should be taken automatically. In addition to recognizing shooting behavior, the quality of the photos should also be considered. A clear image should be taken so that further image recognition at the server can be performed. Besides, it should also be considered that the apparatus taken by the infrared video camera should be contained in the image from the smart phone.

Time Synchronization

Aims at matching the image from the smart phone with the image from the infrared video camera for the same apparatus, time synchronization for the smart phone and the infrared video camera should be done. In this paper, the time difference between smart phone and infrared camera can be detected and sent to the server. Besides, the timestamp of taking images from smart phone and camera will also be sent to server. With these information, the server will perform the matching.

Image and Data Transmission

In order to share the information, like location and timestamp, and images with the server, image and data transmission should be done. In this paper, FTP (File Transportation Protocol) is utilized. With the help the wireless mesh network and FTP servers set up on the routers in Part 2, smart phone can upload data and images to the FTP servers, and server can also download the images and information from these FTP servers.

3.4.2 Function Design on Server

Image and Data Reception

In order to fulfill the other functions on the server, data and images from the smart phone should be received from the FTP servers. Therefore, an FTP client should be set up on the server.

Image Recognition

After obtained images of the apparatus from the smart phone, the server can figure out which type the apparatus belongs to using image recognition algorithm by comparing sample images stored in the server. In this paper, SIFT-SURF algorithm is used when matching images from the smart phone with images from the sample library.

Time Synchronization

As stated before, the image from the smart phone should be matched with the infrared images from the video camera, time synchronization between smart phone and infrared video camera should be performed. At the server part, the information including, the time difference and information for images taken by video camera and smart phone can help a lot to do the matches.

3.5 Implementation

In order to realize the functions listed in the last section, each function has been modularized and implemented with software design and hardware design in this section.

3.5.1 Software Implementation

Location Detection

In this thesis, two types of method are used to detect the location of the apparatus. One is dependent on GPS information, and the other is to scan tag on the pillar indicating pillar's location with OCR technology. For GPS information, because the accuracy of GPS on smart phones is low, about 10 meters, and the distance between pillars is about 3 meters, it is not enough to determine the specific pillar that inspector taking images by, only achieving GPS information. Hence, the method using GPS information can be treated as an auxiliary method, to rectify the location of the pillar. Besides, tag on each pillar is exclusive, indicating the flow direction of the transmission line through this pillar shown in Figure 3.4, which can be employed to determine the location of the pillar by scanning tag and recognizing characters on the tag.

The working flow of location detection is shown in Figure 3.5. At first, camera on the smart phone is used to scan the tag on the pillar, and then characters on the pillar is recognized by OCR technology. By post-processing, the words composed by the characters recognized will be corrected by compared with the words stored in the database including all tag, so that the tag can be recognized. After obtaining the tag, it will be verified by the GPS information through the map of the substation. After obtaining and confirming tag, inspectors can be informed by

Figure 3.4: Tags of pillar in substation

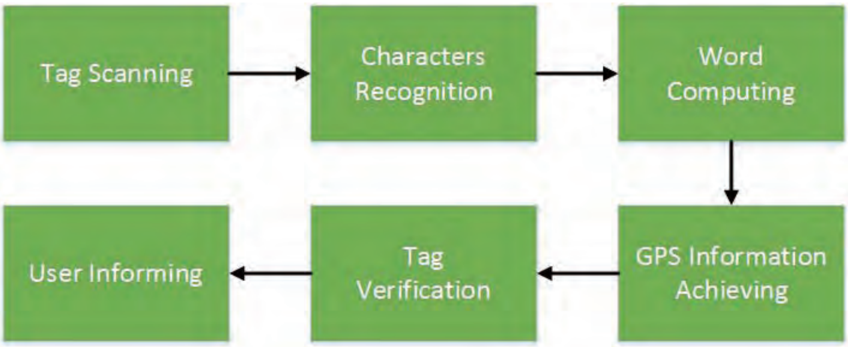

Figure 3.5: Flow of location detection

smart phone to take next steps.

- Tag Scanning

  In tag scanning part, the smart phone needs to take a photo of the tag on the pillar. Dependent on camera API and graph API, camera and graphics library should be imported.

  $$import\ android.graphics.Bitmap;$$

  $$import\ android.hardware.Camera;$$

  The function of taking photos is a callback function, and the program listen to the taking event and save photos into the SD card by using file output stream.

$$FileOutputStream\ outputStream\ =\ new\ FileOutputStream(jpgFile);$$

$$outputStream.write(data);$$

$$outputStream.close();$$

- Character Recognition

  In this part, tessart library provided by Google is used to do recognition. Firstly, import the TessactBaseAPI library into the program.

  $$import\ com.googlecode.tesseract.android.TessBaseAPI;$$

  And use tessart API to get the image taken by the camera and recognize the characters.

  $$TessBaseAPI\ baseApi\ =\ new\ TessBaseAPI();$$

  $$baseApi.init(Environment.getExternalStorageDirectory(),\ "eng");$$

  $$baseApi.setImage(bitmap);$$

  $$String\ chartacters\ =\ baseApi.getUTF8Text();$$

- Words Computing

  For words computing, characters recognized is corrected with the sample database.

  $$var\ words\ =\ rectify(chartacters, db)$$

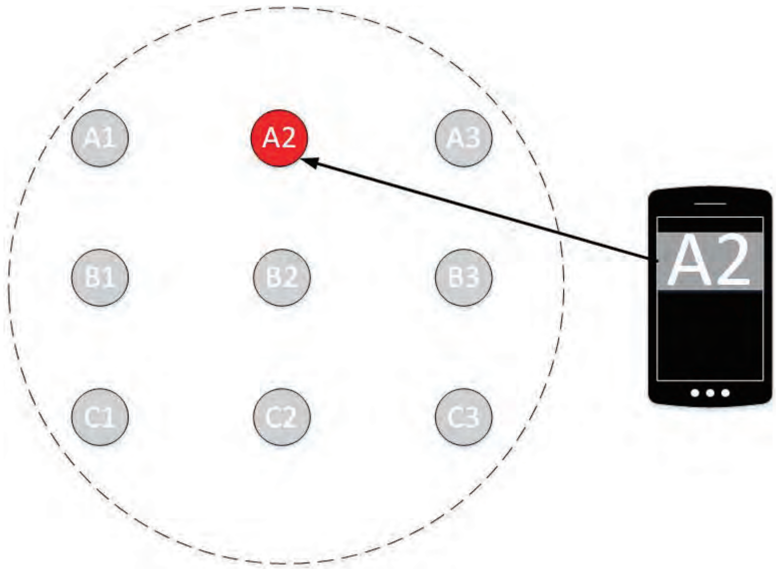

Figure 3.6: Tags verification

- GPS Information Achieving

  GPS Information is achieved by using locationManager interface in android API by using $Location\ location = locationManager.getLastKnownLocation(provider);$, and listen to events of location changed to call callback functions, so that information of longitude and latitude can be obtained by applying $location.getLongitude()$ and $location.getLatitude()$ functions.

- Tag Verification

  In tag verification part, the tag recognized will be compared with possible optional tags determined by the method applying GPS information, like Figure 3.6. If the recognized tag does not belong to the options, then inspectors should re-scan the tag.

- User informing

  After tag is recognized and verified, smart phone will use a warning tone to inform inspector to take photos of apparatus.

$$var\ music = MediaPlayer.create(this,\ MusicId);\ music.start();$$

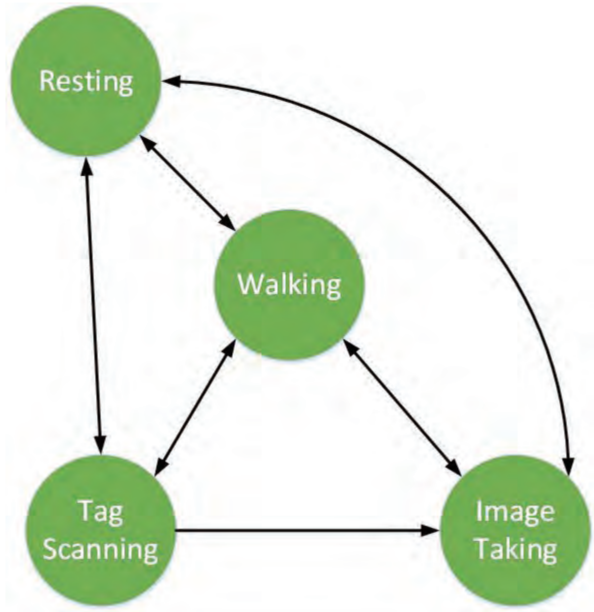

Figure 3.7: States of behavior

Behavior Pattern Recognition

In the behavior pattern recognition part, human's behavior is classified into four state, state of tag scanning, state of image taking, state of walking, and state of resting,. The state of tag scanning indicates inspector is scan a tag on the pillar to detect the location stated above. The state of image taking indicates inspector's shooting infrared images, and the state of walking indicates inspector wandering in the substation with the smart phone. The state of resting indicates inspector is neither walking, nor using smart phone. There some relationship between four states, shown in Figure 3.7. For example, the state of taking photos is behind the state of scanning tags and the state of resting, and the state of scanning tags cannot be behind the state of taking photos. Hence, a behavior chain is modeled. To determine which state is the inspector belongs to, information from sensors such as accelerator, compass, gyroscope and decision tree algorithm assists. In Figure 3.8, different states can classified in different conditions.

- State of Resting

  The decision of state of resting is determined by the upward accelerator. If the accelerator is 0, it implies the state is at the resting state.

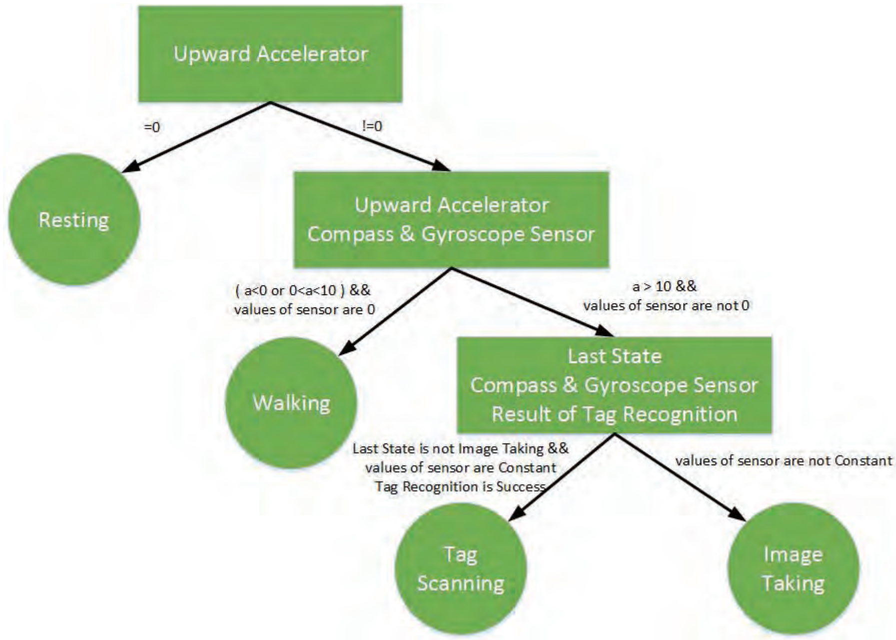

Figure 3.8: Decision Tree of States

- State of Walking

  The decision of state of walking is determined by the upward accelerator and the values on the sensors of compass and gyroscope. If the accelerator is not 0 and is not bigger than 10, and in addition the value of compass and gyroscope is not equal to 0, it can be said the state is walking right now.

- State of Tag Scanning

  The decision of state of walking is determined by last state, the values on the sensors of compass and gyroscope, and the result of tag recognition. If last state is not image taking, and the value of compass and gyroscope is not equal to a constant value set by us and the result of tag recognition is success, it can be said the state is walking right now.

- Sates of Image Taking

  In other conditions, the state is thought to be image taking.

For the method used in android system for sensor is an event driven method, all the value of the sensors used in the demo has 1 second delay, that is to say, all values sensed are the ones

1 second before. Another problem should be considered is that for error of the sensors, all of values of sensors used in the demo is a scope instead of a constant.

For Implementation, values of accelerator, compass, and gyroscope sensor are obtained by android sensors API, like,

$$public\ void\ onSensorChanged(SensorEvent\ event)\ \{$$

$$int\ sensortype\ =\ event.sensor.getType();$$

$$switch(sensortype)\ \{$$

$$case:\ Sensor.TYPE_ORIENTATION:$$

...

$$case:\ Sensor.TYPE_GYROSCOPE:$$

...

$$case:\ Sensor.TYPE_ACCELEROMETER:$$

...

Image Taken Automatically

Image taken automatically simply to take a photo by smart phone itself, if it figure out that the state is image taking or tag scanning. In addition, before the action of shooting, 'autofocus' function should be used to confirm that the image taken is clear. After image taken, it will be rename with the recognized tag and timestamp taken, so the location information and timestamp information will be transmitted to the server combined with the corresponding image.

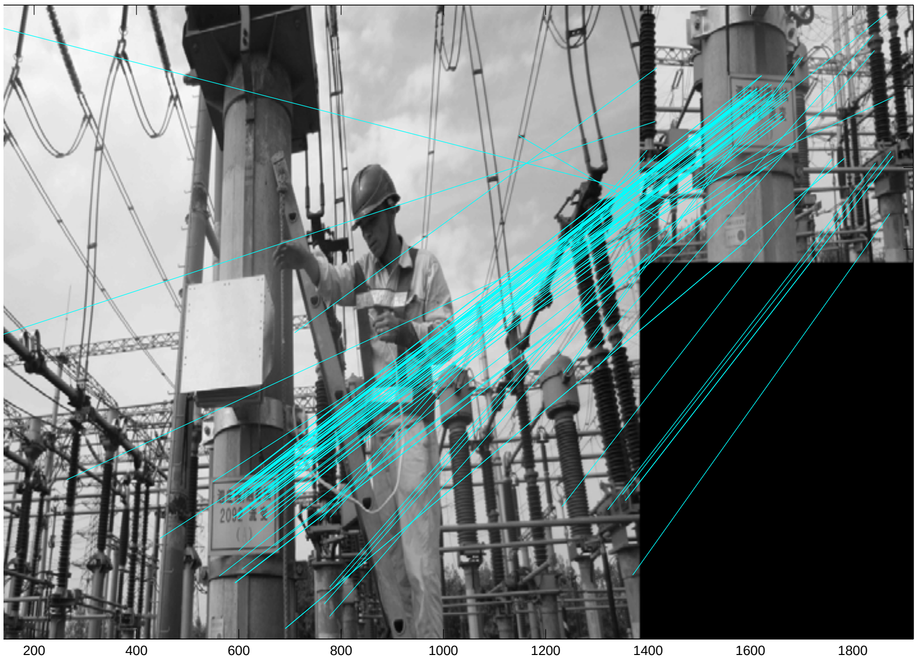

Figure 3.9: Image recognition

Image Recognition

Image recognition is designed in the server end, so that apparatus identification can be realized by applying SIFT-SURF algorithm. In this thesis, the algorithm is realized with matlab code, because of the available and friendly image process functions. As can be seen from the Figure 3.9, the two images, one is received from smart phone and the other one is from sample database, are firstly pre-processed by gradation, disappearing chirp, and normalization. Then, using $sift$ command to find all features or keypoints in the two images and describe two images. What's more, compare all the keypoints by applying matching algorithm to find common features. At last, use $showKeyporint$ function to show the same features in the two images and statistics. If the ratio between number of common features and image features is high enough, then the image from smart phone os believed to the same image in the sample database. In this way, apparatus can be identified.

Image and Data Transmission and Reception

Figure 3.10 indicates the procedure of data transmission and reception between smart phone and server. A FTP server is set up on the routers, and two FTP clients are used on smart phone and server separately, which is compatible with design in wireless mesh network in Part 2. At smart phone, $ftp4j$ library provided by Sauron Software is used, like

$$FTPClient\ client\ =\ new\ FTPClient();$$
$$client.connect("portal.sjtu.edu.cn",\ 21);$$
$$client.login("zhangyuhang",\ "xxxxxx");$$
$$client.changeDirectory(name);$$
$$client.upload(this.file);$$
$$client.logout();$$

At the server, a polling scheme is performed for the FTP client request for images from FTP server every 10 seconds using a windows BAT command.

$$for\ /l\ \%\%i\ in\ (0,1,10000)\ do\ ($$
$$ping\ /n\ 5\ 127.0.0.1\ >\ nul$$
$$ftp\ n\ s:"ftpLogin.bat"\ >>\ autoftp.log$$
$$)$$

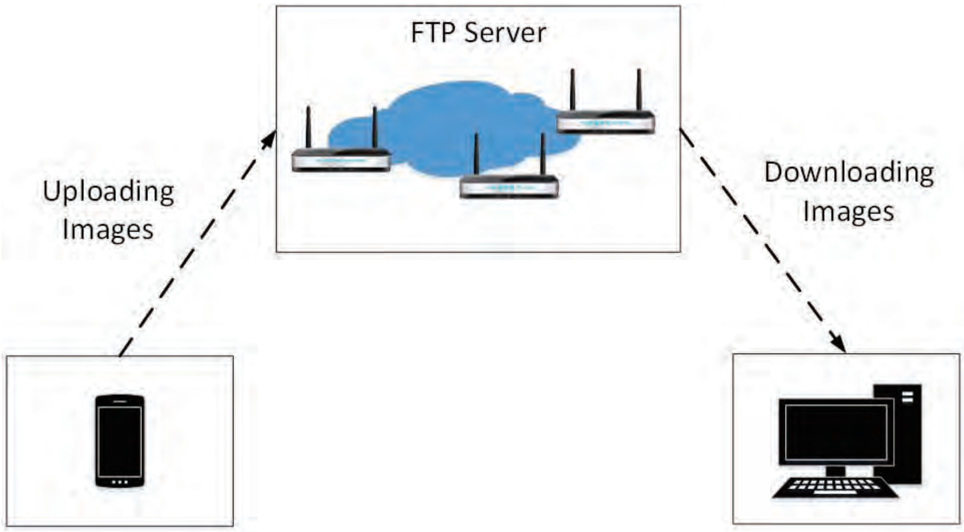

Figure 3.10: Flow of data transmission and reception

Time Synchronization

For time synchronization, user should take an image with the infrared camera for time calibration before inspecting the substation each time. Then, the server will get two images from smart phone and infrared camera and the timestamp difference will be recorded for time synchronization. Afterwards, server will minus the difference with the timestamp of the images taken by smart phone, and compare the result with the timestamp of the image taken by the infrared video camera, so as to match two images.

3.5.2 Hardware Implementation

For hardware implementation, smart phone and server will be designed for the demo system.

- Server

  Server used in the demo system, a common 64bit computer with windows operating system. The software packages installed are ftp command and corresponding matlab library for image recognition.

- Smart Phone

Smart phone used in the system is Galaxy S5 from Samsung, and ftp4j library and tessart library is downloaded and installed. In order to connect with the infrared video camera, a smart phone holder is mounted, so that the two parts can be treated as a whole.

3.6 Performance Evaluation

To test the performance of the system, three parts need to be evaluated, which tag recognition part, behavior pattern recognition and apparatus identification.

3.6.1 Tag Recognition

Tag recognition part indicates the accuracy of location detection. From Figure 3.11, we can see that the tags written on the paper with characters 'abcdefg' and 'ABCDEFG' can be recognized correctly. The words in the red box are "ABCDEFG_20141230035634.jpg", and "abcdefg_20141230035256.jpg", and first part of the string is the tag recognized and middle part of string is the timestamp the image taken. From the figures, the tags can be recognized and the timestamp can also be stored.

3.6.2 Behavior Pattern Recognition

Behavior pattern recognition part indicates the action of the inspectors can be sensed and smart phone will take photos automatically. As can be seen from Figure 3.12, the action of the inspector can be detected can perform according with inspector's behavior. The left part of the figure is the timestamp that the smart phone detect the action of inspector raising up the phone, and the right part of the figure is timestamp that the smart phone detect inspector is in the state of taking images, and inform camera on the phone to take a photo.

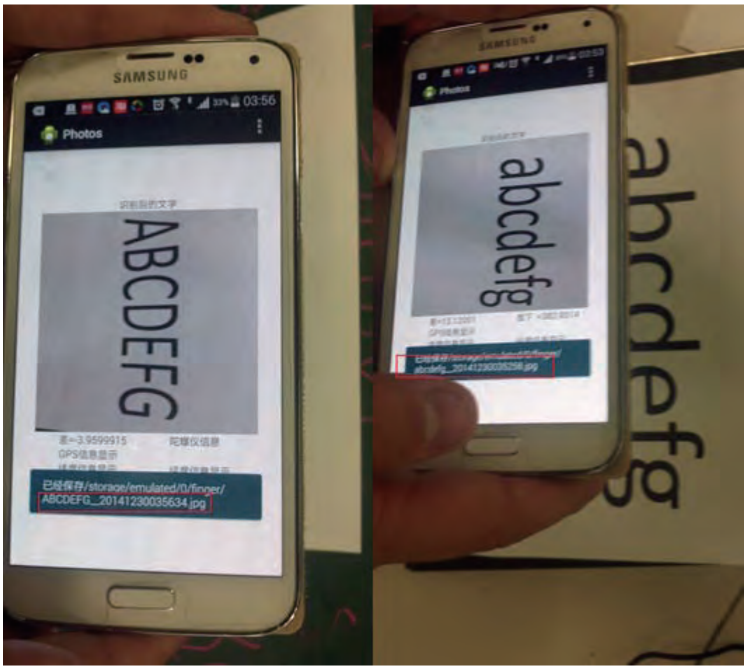

Figure 3.11: Result of tag recognition

Figure 3.12: Result of behavior pattern recognition

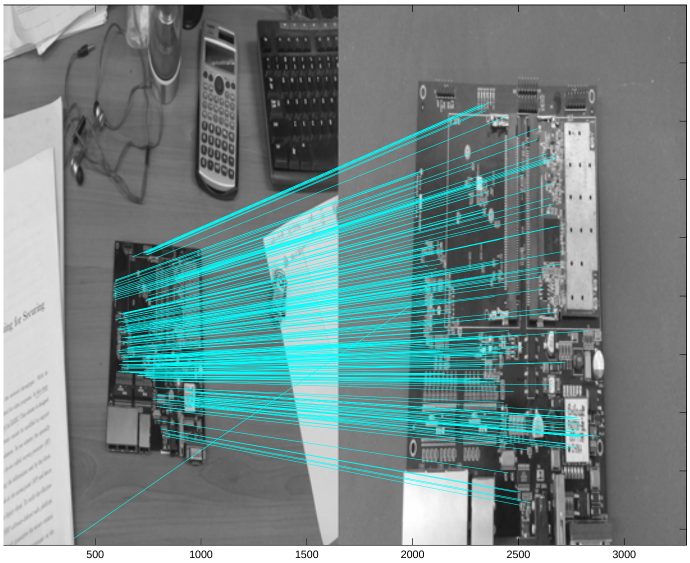

Figure 3.13: Apparatus identification(1)

3.6.3 Apparatus Identification

Apparatus identification is used for server to identify the apparatus in the image by compared with images in the sample database. The right part of Figure 3.13 is the image of WIFI board in sample database, and the left part is the image taken by smart phone and transmitted to the server. From this figure, we can see the number of common keypoints of the two images are 249 and the number of keyporints of images in the sample database is 2435. The ratio is about 8%, which implies there is a WIFI board in the image taken by the smart phone, which is corresponding to the two images. However, the result is not always good. From Figure 3.14, the number of common keypoints is 17 and half of the keyporints are pointed to the wrong part, because there are about 8 interfering points. There are only about 8 commnon keypoints, and the featured in the sample image is about 500 images. Therefore, the program make a wrong decision with no common images between these two images. The reason is that the featured keypoints in the sample image is little. Therefore, to decrease the recognition mistakes, the sample image should be has more featured keypoints and less interfering keypoints. For

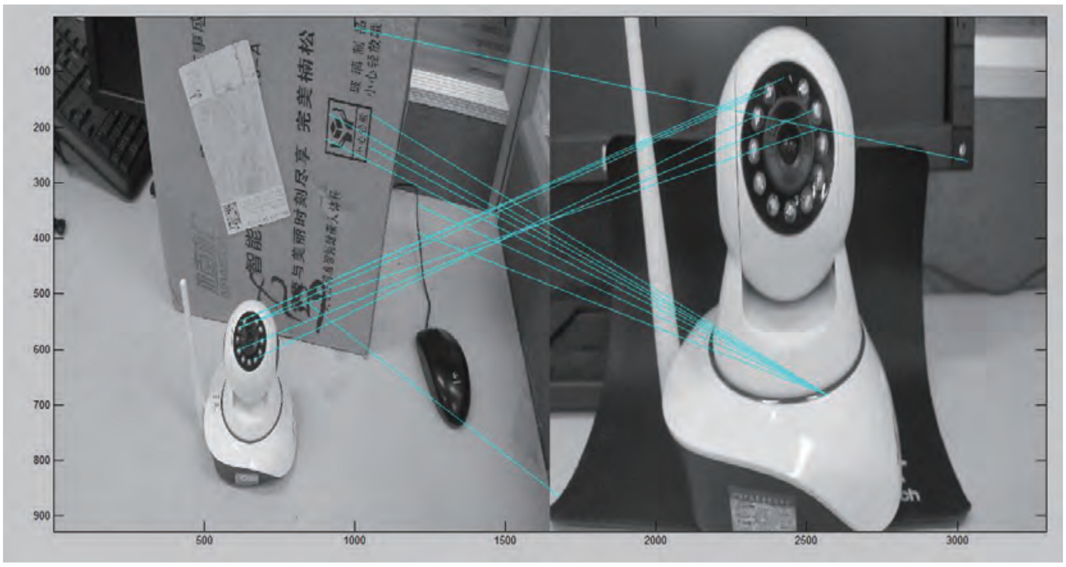

Figure 3.14: Apparatus identification(2)

example, the sample image should be taken in a pure color background, like white background, and the quality of the sample image should be high and clear without noise.

3.7 Summary

In this topic, apparatus taken by the infrared video camera in the substation can be identified with algorithm proposed in this thesis. To accomplish the identification, the whole framework of the system is designed. Hence, the functions of each part in the framework is schematized, including detecting the location of the apparatus, recognizing patterns of human's behavior, taking images of the apparatus automatically according to human's behavior, transmitting images to the server with the information of location and timestamp on the smart phone. Besides, on the server part, the functions of receiving images, identifying apparatus by comparing images in the sample database and the image taken by the smart phone, and matching photos taken by the smart phone with the ones taken by the infrared video camera. After the design, the investigation about relevant technology, including optical character recognition algorithm , tessact engine, decision tree classification learning algorithm, and image recognition algorithm including SIFT and Surf algorithm is performed. Afterwards, these modularization of functions are conducted and implementation for the software and hardware is design. For software design, sensors of accelerator, compass, gyroscope and GPS is used, and decision tree algorithm is designed to recognize patterns of behavior, and open source library like $ftp4j$, $tessBaseAPI$, and $SIFTWin$ is used to aid to realize the system. At last, a demo system is set up, with some modules, including tag recognition, behavior pattern recognition and apparatus identification tested. To sum up with, in this topic, an algorithm for apparatus identification based on multi-mode is designed and realized by setting up a demo system.

Chapter 4

Conclusion

Smart grid is believed to be the next generation power grid, and substation monitoring plays a significant role in smart grid. In this thesis, two topics for substation monitoring are proposed for information collection and information process. In the first topic, a mesh network oriented handoff protocol is proposed and verified by setting up a real system. The new protocol is suitable for substation monitoring, because even if no new drivers and softwares are installed on clients in the network, clients can also choose the router with the best link quality to communicate. And in the second topic, we proposed a new algorithm to locate the infrared images and figure out the type of the apparatus of the image, by setting up a demo system, using OCR technology, pattern recognition, decision tree algorithm, sensors on the smart phone such as GPS, compass, gyroscope and image process technology.

We have finished some patents and papers by conducting the two research topics. Besides, some awards were achieved for the systems we set up in this thesis certificated by Shanghai Company of National Power Gird. More information about our publications and awards can be found in Appendix A.

4.1 Contributions

Based on the completed research, the contributions from this thesis are summarized as follows.

- A Mesh Network Oriented Handoff Protocol

  In the first topic, a new handoff protocol oriented by mesh network is designed. The protocol for fast handoff based on link quality is verified by setting up a network and and implemented by a real system including software and hardware design, still running in Sijing Substation in Shanghai. This new protocol is suitable for substation monitoring, for the procedure the fast handoff among routers independent on the client, that is to say, no new drivers and software need to be installed on the clients.

- An Apparatus Identification Algorithm based on Multi-Mode

  In the second topic, an apparatus identification algorithm based on multi-mode is designed, by setting up a demo system that can identify the location and the type of apparatus from images taken by infrared video camera.

4.2 Future Work

In spite of the contributions listed above, which we have made so far, there are still many interesting areas and problems need to be solved.

In the first topic, mesh network oriented handoff for information collection in smart grid, the problem uploading images from infrared video camera to server have been solved, while downloading protocol is still need to be well designed. For example, when the inspectors would like to surf the website on the server or download images from the server, using a cellphone under the wireless mesh network set up in Chapter 2, then problem comes. Because the protocol provided by this thesis is dependent on the capability of the server's information collection from routers, that is to say, the starting point of the protocol is the server. While in the example, inspectors using cellphone to download data from server, so the starting point becomes the cellphone, which cannot be solved by the protocol in this thesis. However, there are two basic ideas which can be followed for the future work to solve this problem.

- Design a New Protocol By Exchanging Client and Server

  That is so say, a protocol can be designed by exchanging the position of the client (cellphone) and the server in the protocol in this thesis, so that the cellphone can be treated as the server to start the protocol and also can download data from the old server. However, the drawback of this method is that, cellphone should has the capabilities that the old server has, like communicate with routers for signal information, making a connection decision and downloading data from router. Therefore, in order to achieve these capabilities, new scripts and software should be installed into the cellphone, which is not compatible with our former design.

- Use a Polling Scheme for Server

  In this method, the starting point is still the server, and it run the polling scheme to request the cellphone whether it would like to download data or not. If the response from the cellphone is 'yes', then the server will upload data to the router and will inform router to upload data onto the cellphone. However, for this method, there are two drawbacks. One is that the delay for the cellphone depending on the polling time of the server, and the other is that there are lots of waste for the polling request, because the cellphone is always downloading data from the server.

In the second topic, apparatus identification based on multi-mode for information process, a demo system has been set up in this thesis, which can identify the location and the type of apparatus from images taken by infrared video camera, there are still many new interesting areas can be discovered. As stated in this thesis, for each part of the functions designed in the framework of the system is modulized, each module of the system can be improved in the aspects of the complexity of algorithm, accessibility of the method of each module and the user experience of the system. Here are some examples can be treated as future tasks for improvement.

- Location Detection

  For location detection, in this thesis, the method used is OCR (Optical Character Recognition) technology and GPS (Global Position System) information. OCR is utilized, because the information from GPS is not accurate enough to locate the real position of the infrared video camera, only a rough scope known from GPS, and for there are instructing tags for convertor pillars and switch pillars in the substation, OCR can work well cooperating with the camera on the smart phone. However, in other cases, sometimes, there probably are no tags on the pillar, so OCR technology cannot be used. In this case, new method should be come up with, such as use sensors on smart phone, like compass sensor, gyroscope sensor, distance sensor. Besides, image process algorithms can also help.

- Behavior Pattern Recognition

  In this thesis, only five types of human behavior patterns are designed in the states of the behavior. In future, more types can be added, if more features are added as the inputs. In that case, more human behaviors can be detected by the smart phone, like sleeping, driving, studying, shopping and so on, so that smart phone can serve better for humans in different situation.

- Apparatus Identification

  In this thesis, the complexity of image recognition is too high, which can be well used in the real system, although SURF algorithm is used in our method. Therefore, more efficient algorithms can be designed, for example features of sample images from databases can be computed at first and stored in the storage. Besides, pre process can conducted before image recognition, like compressing images and eliminating useless information of images.

All in all, as smart grid becomes more common, substation monitoring will become more significant. Therefore, the two interesting systems set up in this thesis can be well applied for substation monitoring in future, and combined with other technology like robotic technology and image process technology, the dream of smart substation monitoring automatically will be realized.

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Appendix A

Publications and Awards

A.1 Award

- The Third National Prize for Progress in Science and Technology awarded by National Grid Shanghai Electric Power Company.

A.2 Publication

- Up to now, one paper called "A Cyber-Physical System Framework for Smart Grid Wireless Communications" for ICTC 2013 has been accepted as an invited paper.

A.3 Patents

Up to now, two patents for the mesh network oriented handoff are submitted and both patent application numbers are received. One patent is for protocol design, and the other is for hardware design.

- X. Wang and Y. Zhang, "An analog self-interference cancellation deign for single input and single output full duplex wireless communications," Chinese Patent Application No.

201310749579.7

- X. Wang and Y. Zhang, "An analog self-interference cancellation deign for single input and single output full duplex wireless communications," Chinese Patent Application No. 201310749579.7

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