Design and Implementation for Wearable Individual Inspection System

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Abstract. In order to improve the work efficiency of inspection for power transmission line and reduce the inspection personnel's labor intensity, this paper proposes a architecture of wearable individual inspection system suitable for inspection for transmission line, the architectural is designed with different wearable ways for different inspection equipment and it also makes a wearable design for the inspection equipment and processing terminal. It presents a reference design wearable information processing terminal by taking Intel J1900 as a platform, supports the access of inspection and interactive equipment in the modes of wired or wireless network, and various performance indicators of inspection information processing are obtained through experimentation. Practical applications of power transmission lines show that the wearable inspection system supports the access and management for all kinds of mainstream failure detection equipment, and it can perform automatic diagnosis for detection information and then generate an inspection report conforming to industry standards, which can satisfy the rapid, timely and efficient requirements for the power line inspection.

Introduction

The stable operation of the transmission lines, which is the premise condition to guarantee the complete operation of power system and the stability of the society, is a key in the link of power distribution. Due to the fact transmission line equipment mostly stay in long-term exposure to the complex outdoor environment, the wire, lightning protection conductor, insulator and hardware may encounter the phenomenon of oxidation, breakage, rust, overheating, and so on and so forth. In order to ensure the normal work of transmission lines, we need inspection personnel to do the transmission line failure inspection on a regular basis. With the view of avoiding leakage, inspection personnel need to carry a variety of detection equipment to conduct a comprehensive inspection [1]. However, this comprehensive inspection work will cost a lot of manpower. Even personnel carry a variety of detection equipment with them, instrument have no characteristic of linkage with each other, so each instrument need make contrast test phenomenon one by one, which is not only low in efficiency but also hard to find potential problems. With the increased diversity of inspection equipment, inspection workload is also constantly growing, therefore we badly need a convenient, comprehensive, efficient way of inspection.

With regard to the above problem, UAV or inspection robots are used in some regions, which, to a certain extent, improves the efficiency of the inspection, but still can't satisfy all the application scenarios. and it's quite expensive to use UAV and inspection robots, so popularity is low[2].Manual inspection is the most basic, the most flexible and the most extensive inspection means, so how to improve the efficiency on the manual inspection for the transmission line is the key. Currently, some domestic research institutions have begun to research individual inspection, but no unified framework and standards are formed. This paper proposes a solution of wearable individual inspection system for power transmission lines which is integrated running status of all the equipment. This system mainly studies the wearing, networking, data acquisition, integration,
processing, transmission, storage and display for various inspection equipment, which implements automatic failure analysis, task report output of various equipment.

**Design of Wearable Inspection System**

In order to reduce the manpower used in per inspection and improve the comfort of the inspection process, the inspection equipment should give priority to with light, the inspection analysis should come with automation ability, and inspection report should be generated in an intelligent manner. In the inspection of power transmission lines, the inspection equipment include spectral type, local-discharge ultrasonic type and the type of environmental monitoring. The first consideration in the design is the mode of wearable individual integration that is able to integrate all inspection equipment to a maximum extent; the second one is to implement the connectivity of various inspection equipment, build a data information processing system and consider the scalability of the whole system; the final one is to make all the inspection equipment wearable.

**Mode of Wearable Individual Integration**

Product forms of wearable equipment usually include: clothes, helmets, backpacks, necklaces, watches, etc., but the wearing modes suitable for inspection equipment mainly are clothes, helmets, backpacks and handhelds[3]. Trekker is one of many inspection acquisition equipment for drawing Google street views, and it carries camera, power supply equipment and transmission equipment in the way of back rack [4]. In combination with understanding of various equipment for power line inspection, this paper designs a wearable individual integration mode for power line inspection, and the main form of wearable modes include waistcoat, backpack, helmet and handheld equipment. Waistcoats can be used to carry power supply, information processing equipment, handheld equipment, and daily use tools. Backpacks can be used to carry spare power supply, environmental monitoring test equipment, information processing equipment and daily use tools. Helmets can be used to carry spectral inspection equipment and environmental monitoring equipment. Handheld types can be used to carry other kinds of detection equipment.

During the inspection, personnel can carry power supply equipment, transmission equipment, information processing equipment and environment acquisition equipment on their back, wear a spectral class detector to help them follow the vision. Inspection personnel conduct human-computer interaction of each equipment through the handheld PDA terminals. all the equipment in the system are connected in a wireless manner, and other inspection personnel can also access on-site inspection equipment through the remote terminal or the background.

**System Architecture Design**

The technical architecture designed for this system is shown in Figure 1.

The whole structure is divided into three parts: the first part is the wearable information acquisition equipment, the second part is the comprehensive information platform, and the third part is handheld PDA equipment. The information acquisition equipment, information processing platforms and terminal are connected through wired or wireless modes, among which, the wired interfaces adopt the form of general communication interfaces, such as network ports, RS232 / RS485, and USB, with a strong universality. Comprehensive information terminals are built with wireless network modules, and the function is for the networking of each equipment, which can be convenient to deal with services of the various equipment in information collection, processing, management, storage, forwarding and output.

**Data Information Processing System**

After completing wearable individual integration mode of inspection equipment, we need to conduct the connectivity between all the equipment, so that the system can play its value [5]. On the other hand, we need a Integrated information processing terminal to conduct the collection, processing, storage, management and output of all detection equipment information in a unified
manner, and in this way the system reduces the existing dependence on the function of the inspection equipment, and brings high portability in the wearable design later. In the transmission line inspection, there are detection equipment for various data types, and Integrated information processing terminals should include the processing for multi-channel video, voice, data and information, which should also come with the characteristics of low power consumption, small size, strong performance and easy extension.

![Diagram of System Architecture](image)

**Figure 1. System architecture of integrated information processing terminals.**

**Hardware Platform Selection.** Among all the information types, the requirements for information processing of multi-channel voice or data types are relatively low for the platforms, therefore solving the information processing of multi-channel video is the key to the system. In actual inspections, we should at least be able to conduct the collection, algorithm, coding and network output for three-channel video information, and we also need to have enough voice and general data transmission interface for the access of inspection equipment.

Information processing terminals usually choose X86 or embedded platforms, because single-chip embedded processors have been difficult to meet the performance requirements of this application, and the difficulty of the architecture and development is greatly increased when the comprehensive design in done through adopting ARM, DSP, FPGA, etc. With the continuous development of X86 hardware architecture, it has been gradually approaching embedded platform in power consumption and size, and X86 platform usually has a higher performance. In addition to power consumption, size and performance, we still need to consider the situation of development environment, openness and supply. A lot of actual applications show that the X86 platform is performing remarkably in wearable computing terminals [6].

In the selection of specific types, we select the Intel J1900 platform with the main frequency of 2.0 GHz, which supports the seventh generation of Intel display core[7]. In addition to high frequency, it can use GPU to conduct parallel algorithm development and video coding. The peak power consumption for the entire board of Intel J1900 is 10W, and it has more general data peripherals, thus fully satisfying the requirements of inspection systems for wearable power lines.
Software Architecture and Design. In the part of comprehensive information terminal, the diagram of the software structure is as follows:

![Software Architecture Diagram](image)

1. **Network Control Module**
2. **Channel Switching**
3. **Gain Control**
4. **Infrared Image Superposition and Translation**
5. **Power Query**
6. **Infrared Center Temperature Query**
7. **Preset Parameter Settings**
8. **Waveform Drawing Selection**
9. **Video Stream Sending Module** through the RTSP and RTP network protocols

Figure 2. Diagram of Software Architecture of Data Information Processing Systems.

The software architecture is divided into two modules: processing and control of information stream. Taking video streams as an example, the multi-channel information processing and control mode of audio and data types can completely refer to the software architecture of the video stream part. In video processing modules, we first conduct cache handling for the multi-channel video streams which go through the networking of network receiving modules, then extract per frame data in the cache for further processing; In the control protocol of video streams, through the way of built-in TCP server, we conduct the switching and parameter settings for each video stream through a standard protocol.

For each video stream, we have the image preprocessing interface, interface of image processing and algorithm analysis, image fusion interface and video compression interface which all can be customized. The image preprocessing interface mainly conducts the cropping, scaling and binarization processing; the interface of image processing and algorithm analysis is mainly used in the algorithm analysis of different video streams, such as, the algorithms for object recognition of visible light videos, temperature analysis of infrared videos, photon counting of UV video, etc.; The image fusion interface is mainly used for information interaction and integration between the different equipment; the video compression interface is mainly used in the H.264 compression of multi-channel videos so as to reduce the amount of information in the transmission. In the processing of the video streams, we can store the intermediate variables and the resulting file, so as to implement the localization storage of data, or the real-time call for other equipment through the RTSP and RTP network protocols. In addition, the provision the TCP servers can be available for other equipment to conduct the real-time switching and parameter settings of internal operation mechanisms.

In specific development, we adopt the multithreaded writing, with the integrated development environment of VS2013, and the software flow diagram is as follows:

After software initialization, the system will open a thread of data stream acquisition to the outside, which is used to video stream and other formats data stream accessing the system. When the system obtains the corresponding information, it will create a service thread to conduct a decoding process for the video stream obtain and an unpacking processing for the data stream, and then deliver the processed information stream to their corresponding buffer channels. At this
moment, the processing threads will be started to channel data already received, for the processing of UV and IR data.

Taking video stream processing threads as an example, it first extracts video stream from the corresponding buffer channels, and then conducts the processing of binarization, scaling, translation or cutting according to the software configuration. If there is a need for image analysis algorithm, it will call the corresponding processing and analyzing interface, such as inflation, corrosion and unicom area. After completing the analysis of multi-channel video streams, it can find corresponding frames in different channels, and then make selection and configuration on whether to conduct the image fusion’, superposition of OSD characters, etc. After the thread processing, it will be push the video information to the background service thread for the compression of video streams, and then get it stored in the queue buffer channels[8]. At the same time, it will start the service interface of RTSP streaming media for processing, so as to respond to external request of video access and implement the real-time broadcasting of video stream.

While processing threads of video streams are running, the threads of control command are running at the same time, for the purpose of real-time configuration and selection. The control threads are essentially TCP servers, which are used to monitor the control and query command sent by fixed ports, so as to conduct analysis, validation, processing and response.

**System Standardization and Scalability.** Given the diversity of electric power inspection equipment, in order to improve the scalability of the whole system, the integrated processing terminal has made scalability designs from three aspects: input, processing and output. In terms of input, it standardizes the interfaces of video, image, voice and data, so as to facilitate the access of various inspection equipment (such as partial discharge detection, environmental monitoring); in terms of output, it uses the wired/wireless network to access platform or terminal equipment[9]. In addition, because of the selection of the x86 platform, the integrated processing terminal has a very strong scalability in information processing. All types of equipment have a standard SDK for access and processing, as well as a friendly develop environment.
In practical applications, the system completes the access of the locator of partial discharge inspection through the USB interface. First, the driver of the partial discharge locator should be installed, and then through the standard SDK and data interfaces provided by the manufacturer of the partial discharge locator, in order to implement the access of the partial discharge locator. After completion of access, data information processing system starts the processing threads of data stream and obtains the data of the partial discharge locator from the buffer channel information. According to the configuration situation, we can perform the data preprocessing and waveform mapping under the ultrasonic/TEV model of the partial discharge locator, and conduct intelligent classification (no discharge, mild discharge, strong discharge, severe discharge) and early warning for the failure detected, according to the preset conditions. After the thread processing, we can push the data information of the locator to the background service thread, and then store it in the queue buffer channels. Meanwhile, we can start the TCP Server service to respond to the request of the handheld terminals to access the information stream of the partial discharge locator, so as to implement the real-time display of the partial discharge locator in handheld terminals.

After the system accesses the partial discharge locator, we can use hand-held terminals instead of the partial discharge locator screen for display, so as to make it a more portable instrument. The data of partial discharge locator, on the other hand, can go through real-time intelligent processing, which makes electric power inspection more comprehensive, in cooperation with other inspection means such as spectral inspection.

**Wearable for Equipment**

As inspection equipment are wearable in a varied ways, this paper proposes a miniaturization example for infrared detectors and UV detectors on the basis of the industry experience and even has made a successful implementation on that.

**Infrared Imaging Inspection Cap.** The infrared imaging inspection cap is mainly composed of HD visible light light camera, infrared temperature measuring camera, as well as infrared laser emission and circuit system. It can output visible light infrared ray fusion image and its detection data by wired or wireless modes, and inspection personnel can use hand-held terminals for equipment operation. It adopts head-mounted wearable design just to let images and human eyes be coaxial, and also uses infrared laser for failure positioning, which is more suitable for practical application. Fig. 4 shows the physical picture of the infrared imaging inspection caps:

![Physical picture of infrared imaging inspection caps](image)

Table 1 is the the technical parameters of the infrared imaging inspection cap, and its performance is superior to related parameters of handheld instruments in the market.

<table>
<thead>
<tr>
<th>Performance Indicators</th>
<th>Technical Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probe Type</td>
<td>Uncooled focal plane detector</td>
</tr>
<tr>
<td>Pixel</td>
<td>640×480</td>
</tr>
<tr>
<td>Viewing Angle</td>
<td>25°× 19°</td>
</tr>
</tbody>
</table>
Calibration method | fixed focus
---|---
Frame frequency | 25[Hz]
Temperature range | -10 to 150[°C]
Temperature measuring progress | Plus or minus 2[°C]
weight | 600[g]

**Portable UV Detector.** Portable UV detector is mainly composed of the HD visible light camera, UVC ultraviolet camera, common path structure and circuit system. Using the common light path structure can ensure the accuracy of UV videos and visible videos. Inspection personnel use handheld terminal equipment to conduct the its operation of visible light/UV ray fusion image and its detection data fusion. The portable UV detector can be held in hand or placed on the shoulder, so the mode is determined according to the practical application scenario. Fig.5 is the physical picture of the hand-held UV detector:

![Hand-held UV detector](image)

The Hand-held dual-light-path detection module of UV ray/visible light is mainly composed of full solar-blind channel and visible light path. In terms of light path, the incident beam transmits to spectrooscope and then get divided into two beams by the light path, with a beam of light into full solar-blind channel, and the other a beam of light into the visible light path. After the overlay of visible light path and solar-blind UV channel, it forms a visual reference, which can be used to locate the target position. Table 2 is the technology parameters of the portable UV detector, and its performance parameters have reached forefront of international levels.

<table>
<thead>
<tr>
<th>Performance Indicators</th>
<th>Technical Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>sensitivity</td>
<td>$2 \times 10^{-18}$[W/CM²]</td>
</tr>
<tr>
<td>Working band</td>
<td>240-280[nm]</td>
</tr>
<tr>
<td>Viewing Angle</td>
<td>10.4°×7.8°</td>
</tr>
<tr>
<td>focal length</td>
<td>78.1[mm]</td>
</tr>
<tr>
<td>F number</td>
<td>3</td>
</tr>
<tr>
<td>Focusing way</td>
<td>Manual focusing</td>
</tr>
<tr>
<td>light path coincidence</td>
<td>&lt;1[mrad]</td>
</tr>
<tr>
<td>Frame frequency</td>
<td>25[Hz]</td>
</tr>
</tbody>
</table>

**Integrated Information Processing Terminal.** Integrated information processing terminal is mainly composed of a X86 platform, power management, network modules and batteries. A battery can support 2 hours of power supply, and inspection personnel can bring their own battery for continued supply. The processing terminal is designed to be a 15 * 10 * 3 cm rectangle box, it can be placed in a backpack or waist during the inspection. The following is a physical picture of Integrated information processing terminals:
The main function of the processing terminal is divided into three parts: data stream link, control stream link and container. The data stream link is mainly about information collection, compression and transmission for the inspection equipment accessing the system; The control stream link is mainly for interactions such as parameter settings and functional switching of inspection equipment; the container is mainly for the information processing, integration and analysis of inspection equipment.

Among all the processing information, video image information raises the highest requirement for the platform, and Table 3 is related performance indicators of Intel J1900 platform in processing 1080P images after multiple tests on an average basis:

<table>
<thead>
<tr>
<th>Project</th>
<th>Content</th>
<th>Consumption Time (Fps)</th>
<th>Memory Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video Compression</td>
<td>H264</td>
<td>0.0297[s]</td>
<td>215.2[Mb]</td>
</tr>
<tr>
<td></td>
<td>MPEG4</td>
<td>0.0343[s]</td>
<td>307.6[Mb]</td>
</tr>
<tr>
<td>Image Processing</td>
<td>Tailoring</td>
<td>0.0173[s]</td>
<td>8.7[Mb]</td>
</tr>
<tr>
<td></td>
<td>Translation</td>
<td>0.0091[s]</td>
<td>9.2[Mb]</td>
</tr>
<tr>
<td></td>
<td>Fusion</td>
<td>0.0315[s]</td>
<td>17.3[Mb]</td>
</tr>
<tr>
<td>Image Analysis</td>
<td>Photon Counting</td>
<td>0.0464[s]</td>
<td>8.5[Mb]</td>
</tr>
<tr>
<td></td>
<td>Failure Zone</td>
<td>0.0382[s]</td>
<td>9.1[Mb]</td>
</tr>
</tbody>
</table>

**Actual Application**

The actual application is the implementation of individual inspection during the inspection in a substation, through infrared inspection cap, handheld UV detector, portable partial discharge detector and handheld interactive terminal, and Fig.7 shows the application status of on-site inspection.
When we start the inspection equipment, handheld terminals will display on-line notice and describe the relevant information of the equipment. When the automatic failure analysis model of the UV detector is set up on the handheld terminals, handheld terminals will pop up alarm message when a failure or a suspicious failure is detected. In an experiment, by using this set of inspection system, inspection personnel found 34 defects, including 16 infrared heating, 13 UV corona discharges and 5 partial discharge anomalies. After the potential safety hazards are screened out, we can select the one-click generation of failure information statements, including location, temperature and humidity, detection equipment, failure point and notes, so as to facilitate the task reporting and follow-up maintenance.

The whole system can work normally for two hours, but the adoption of multiple pieces of spare batteries can help meet the demand of the full-day inspection. After using this system, we found out that inspection equipment is in easy operation, the manpower quantity needed for per inspection is obviously decreased, the inspection information of all the equipment are in interactive response, and automatic failure positioning and analysis is available, so that failure detection rate is greatly increased.

**Conclusion and Outlook**

(1)This paper designs and implements a set of wearable power line inspection system, and presents a new-type efficient inspection mode for electric power line. The whole set of wearable inspection system is designed with a set of open standard interfaces for software and hardware, which can support the access to inspection equipment which use different technical means, The system can conduct a unified management, storage, analysis and report generation, and it can support the access of handheld terminals and remote network at the same time.

(2)In this paper, we have given examples for wearable modes of infrared inspection cap and hand-held UV inspection instrument. Under the premise of reaching the performance requirements of similar products in the market, they are more portable. Especially, the miniaturization of hand-held UV detectors are advanced in the international levels.

(3)This papers presents an integral solution of information processing platform in the inspection system, which completes the platform selection, software design, development and debugging. It also has implemented the whole set of functions on the Intel J1900 processing platform, and has tested specific performance indicators.
In practice, the wearable power inspection system implemented in this paper has greatly increasing the efficiency and quality of substation inspection, which meets the practical need of the basic operation personnel. Wearable products are the trend of the future, and in this paper, the whole set of wearable system design that we present is kind of a model in electric power inspection[10]. Vertically, the system can access to more different manufacturers and inspection equipment, as well as enrich the inspection means; horizontally, the system can make concurrent replication and then can be promoted to more operational units, so as to guarantee the safe operation of the power grid equipment.

Acknowledgement

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References