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MOBILE & WIRELESS HEALTH

Intelligent Wearable Occupational Health Safety Assurance System of Power Operation

Xiaona Xie[1] · Zhengwei Chang[2]

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Abstract
To improve the capacity of emergency control over on-site operation risk and effectively guarantee safety of operators in a complicated environment, a wearable safety assurance system framework for power operation is proposed. The framework centres on a wearable information processing gateway for single man and provides standardized access for vital signs monitoring, human-machine interaction and other equipment in a form of wireless ad hoc network. Using wearable vital signs monitoring equipment, the physiological parameters such as heart rate, body temperature and blood pressure can be monitored in real time. By extracting physiological parameters and SVM machine learning method, the operator's health condition is judged. Practical application shows that the wearable safety assurance system can evaluate the life status of workers in complex environment in real time, and can detect the risk of personal safety accidents caused by abnormal physical condition in the process of operation in advance.

Keywords Wearable vital signs monitoring · SVM life status assessment method · Portable information processing gateway · Occupational health safety

Introduction

Power transmission and transformation operation involves high altitude, hot-line, adverse weather and other high-risk operation environments. Operators face many practical problems, such as heavy tasks, broader safety responsibilities and more elaborated requirements for skills. At present, safety monitoring for on-site operation environment and operators mainly depends on labour and other conventional ways. It is difficult for on-site people in charge and operation assistants to know about current health status of operators and status of surrounding environment on site and to judge effectively whether risks of high-voltage electric shock, induced electric shock, falling from a high altitude and other accidents will be increased when relevant operation is conducted securely.

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✉ Zhengwei Chang
changzw@ustc.edu

1 School of Control Science and Engineering, Chengdu University of Information Technology, Chengdu, China

2 State Grid Sichuan Electric Power Research Institute, Chengdu, China

With the development of intelligent wearable technology, some power-related entities have already carried out some work in the field of wearable equipment [1–4]. However, there is a severe lack of application study on wearable safety assurance in grid operation risk control. A wearable system framework, wearable orientation and implementation method, where various safety assurance equipment are integrated, is presented in this paper. Wearable equipment are used to perform real-time monitoring for vital signs of operators and life status is assessed by Support Vector Machine (SVM). Intelligent pre-warning for potential safety hazard is fulfilled by means of life status of operators and in combination with their location, weather and environment, grid operating environment and other information, so as to stop operators from working with disease and fatigue and from getting close to hazardous area unintentionally and to enhance intelligent safety level of on-site grid operators.

Design of wearable safety assurance system

In a scenario of power operation, additional load brought by safety assurance equipment to operators is required to be reduced to the maximum. Safety assurance equipment are characterized by easy carrying, automatic monitoring, intelligent interaction, prompt pre-warning and etc. Firstly, wearable integration method is designed for power operation safety assurance system; secondly, safety assurance data are interconnected and intercommunicated and information processing system is built to perform multi-source information integration; thirdly, life status assessment model is built by machine learning so as to fulfil intelligent pre-warning for potential safety hazard.

Wearable integration method

Common product forms of wearable equipment include [5]: clothes, helmets, backpacks, necklaces, belts, armbands, watches, and etc.; however, those applicable to operator mainly are clothes, helmets, belts, backpacks and watches. Besides, hand-held form has becomes interaction terminal carried by operators. Intel, together with Honeywell, introduces a wearable firefighting on-site safety management system. In such system, belt of firefighting clothes is provided with a wearable sensor hub and carries helmet, watch and other wearable monitoring equipment. American WPSM system [6] is a set of physical and medical sensor equipment that collects and monitors a wide variety of signs of the human body for US combat troops, and reports the status of soldiers to commanders and paramedics when soldiers are injured or extremely tired.

Generally, during power operation, safety assurance equipment to be used include intercom, fence, hand-held terminal and etc. In this paper, wearable integration method is designed for power operation scenario, major wearable forms include backpacks, belts and watches and portable set includes handheld PDA. Backpack may be used to carry standby power, environment monitoring equipment and tools used daily. Belt may be used for GPS monitoring equipment and environment monitoring equipment. Watch may be used for vital signs monitoring equipment and man-machine interaction equipment. Handheld PDA be used for voice intercom, man-machine interaction, environment monitoring, information processing gateway and etc.

Safety assurance for power operators mainly relies on vital signs monitoring equipment, GPS positioning equipment, environmental monitoring equipment and voice intercom equipment. Vital signs monitoring equipment can be designed as a wearable watch to perform real-time monitoring for vital signs of operators. Operators can summarize process and transmit data by hand-held PDA terminal. Especially, as a man-machine interaction terminal, hand-held PDA is also able to integrate voice intercom, GPS positioning and built-in environment monitoring & sensing to increase level of integration. Design of additional equipment shall be minimized in the system.

Design of system framework

Design of the system framework is shown in Fig. 1.

The whole framework is divided into three parts. The first part is wearable information acquisition equipment, the second part is the information processing gateway, and the third part is the application system. Wearable information acquisition devices and information processing gateways are connected in wireless form, such as ZIGBEE, Bluetooth and Wi-Fi, and have high versatility and scalability. The wearable information acquisition equipment is mainly used to monitor information about vital signs, including electrocardiogram, pulse, body temperature, blood oxygen and blood pressure. The information processing gateway is not only a wearable gateway, but also a human-computer interaction terminal. It contains voice intercom module, GPS positioning module, environment acquisition module and 4G communication module. It collects, processes, manages, stores and forwards all kinds of information. The application system is used for operators' health management, virtual fence, information assistance and coordinated decision in hazardous area.

Information processing gateway

For the power operation safety assurance system studied in this paper, the information processing gateway is the key equipment for data aggregation, processing and output. Monitored information can be divided into vital signs information, location information and environment information, which includes different specific indicators and comes from different wearable equipment. For example, vital signs information includes ECG, pulse, body temperature, blood oxygen, blood pressure and other indicators. Characteristic factors are required to be extracted and then life status is assessed and classified by machine learning method.

Extraction of characteristic factors of life status

Physiological signals of human body are divided into two types, periodic physiological signals and non-periodic physiological signals. Periodic physiological signals, such as PPG and ECG, occur in sympathetic and parasympathetic activities of automatic nervous system. Automatic nervous activities can reflect fatigue and stress of human body. Non-periodic physiological signals, such as body temperature and blood pressure, are key data reflecting status of vital signs. Non-periodic physiological signals can characterize life status and they are characteristic factors. Periodic signals, always in a large data size, are required to be pre-processed in time domain and frequency domain so as to obtain characteristic factors.

Taking ECG data for example, characteristic factors of time domain are selected to be ECG R wave number HR and R

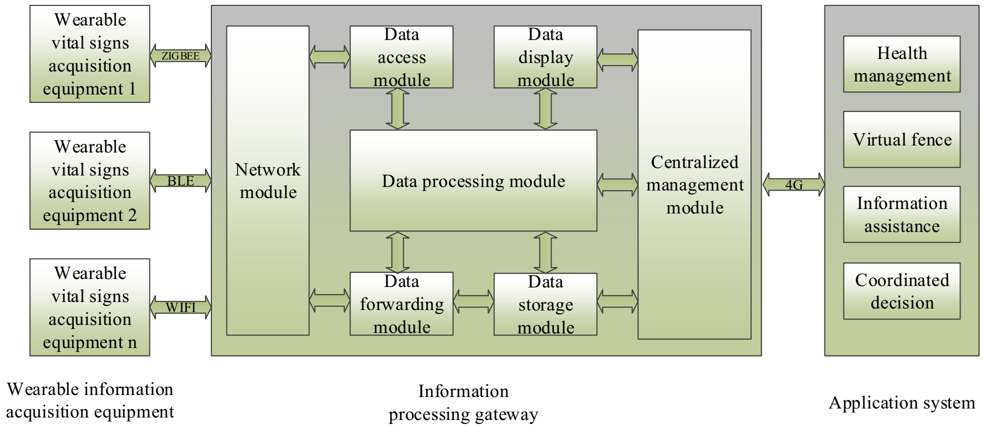


Fig. 1 Framework of wearable power operation safety assurance system

wave interval standard deviation SDNN. Characteristic factors of frequency domain are High frequency power value HF, low frequency power value LF and Very low frequency power value VL. Especially, multi-scale entropy characteristic factor SampEn is selected [7].

SVM life status assessment

The wearable equipment integrated with physiological sensors can be used to perform real-time monitoring for the basic physiological parameters, such as heart rate, ECG, respiration and blood pressure of operators. Operators' health status is judged by means of physiological parameters and SVM classification [8] method so as to discover in advance risk which incurs personal safety accident during operation due to abnormal physical condition. Idea of implementation is shown in Fig. 2.

As shown in Fig. 3, one or more of the feature factor vector(s) extracted from the pre-processing is (are) divided into a training sample set and a test sample set. The optimal multi-classification hyperplane algorithm calibration module is defined by DAG-SVMS in accordance with training sample set [9]. The multi-classifier model is used to process the test sample set, complete the feature classification of the sample data and finally obtain fatigue status assessed from vital signs of operators [10], such as very fatigue, relatively fatigue, fatigue, slightly fatigue and good status.

Standardization and expansion of system

There is a variety of wearable monitoring equipment. In order to improve expandability of the entire system, the information processing gateway provides the corresponding standard SDK for networking, processing and data forwarding so as to fulfil standardized access and expansion. Networking via ZIGBEE, Bluetooth, WIFI interface is standardized, providing an easy access for various wearable equipment (such as wearable oximeter and AR glasses). In data forwarding, once a piece of new equipment is accessed, the gateway will automatically start a new data forwarding thread, making it convenient for communication with backstage.

In practical application, wearable oximeter is accessed to the system via WIFI. Data interface provided by wearable oximeter manufacturer is connected via standard SDK so as to be accessed to the system. After the access is completed, the blood oxygen index is taken as one of the characteristic factors and is also input to the DAG-SVMS. Vital signs status is classified by means of training sample. In addition, TCP client service is started, backstage connected and information flow of oximeter uploaded so as to access and manage new data in mobile application system.

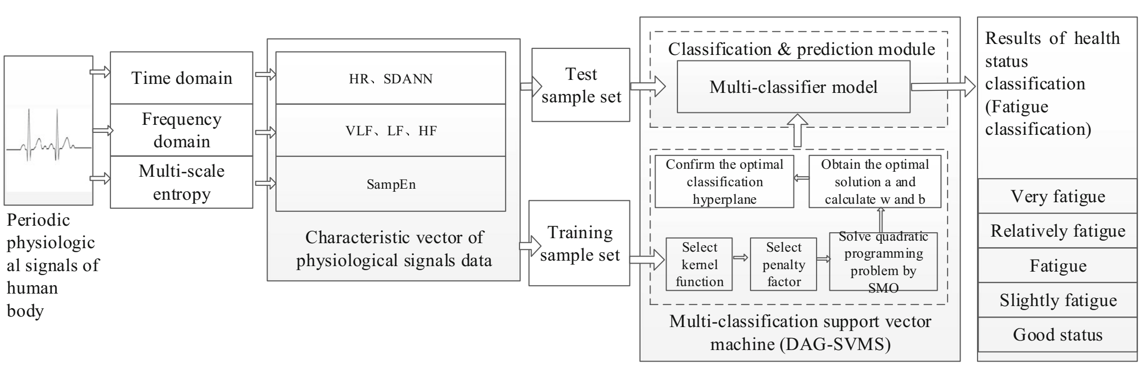


Fig. 2 Idea of SVM implementation of life status

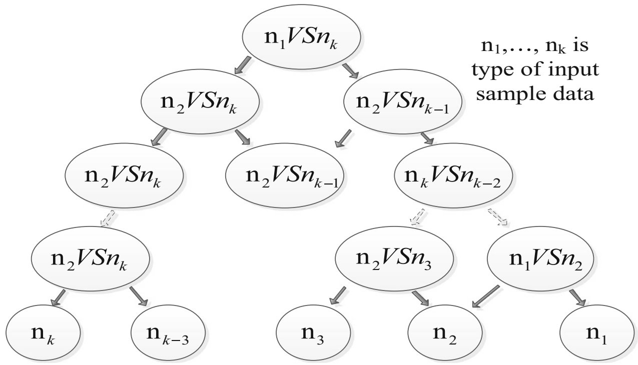


Fig. 3 DAG-SVMS analysis method for fatigue signs of operators

Wearable orientation of equipment

The wearable examples of vital signs monitoring watch and information processing gateway are proposed in this paper and they have been implemented successfully.

Wearable vital signs monitoring watch

The hardware platform of mobile embedded computer based on SOC, which is suitable for electrical production, shall be designed to meet the requirements of wearable integration and the CPU output, resource development sharing and feedback information of users need to be taken into account at the same time. According to the demand analysis and platform selection of the power network patrol, the research scope of the hardware platform for wearable wrist strap can be selected as the proposal of the related intelligent wrist strap recommendation platform such as MTK or Ingenic, etc. In practical applications, when the Ingenic M200 application processor is applied, the architecture plan of overall hardware platform displayed by it is as shown in Fig. 4.

There is the interface of MIPI used for switching in display screen, the interface of I2C used for switching in touch control screen, the interface of SPI used for switching in gyroscope sensor, the interface of SPI used for switching in electrocardio sensor (ECG), analogy front-end of pulse sensor and nine-axle IMU, the interface of AD used for switching in body temperature sensor, the serial port of UART used for switching in accurate positioning and Bluetooth module and the interface of I/O used for switching in vibration motor and buzzer in M200. Among them, NJL5310R double LED green light shall be chosen for PPG sensor and TI AFE4400 shall be chosen for the analogy front-end. What's more, ADS1292 shall be chosen for ECG [11].

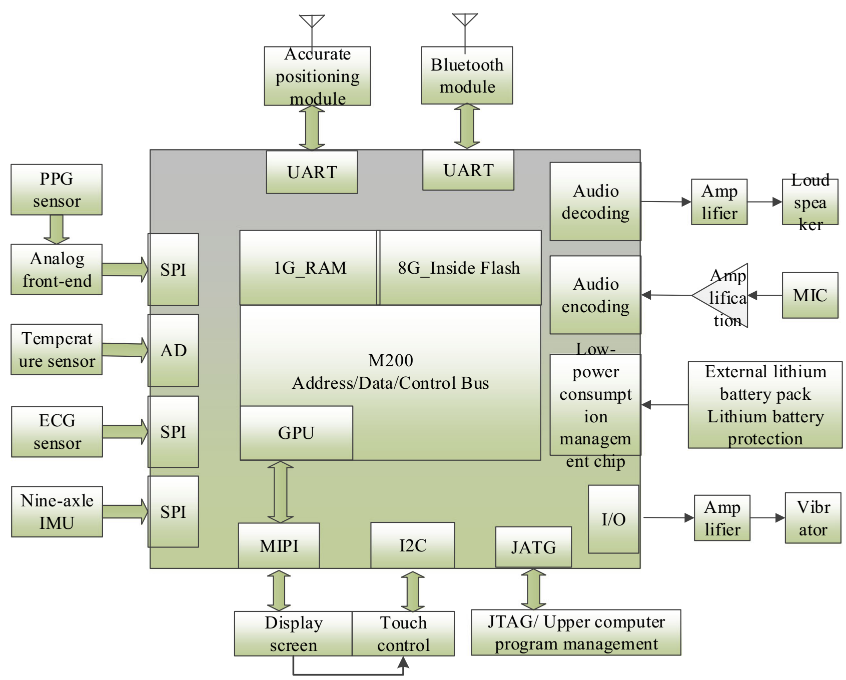
The real product is shown in Fig. 5.

The technical parameters of physiological signal are shown in Table 1.

Portable information processing gateway

As shown in Fig. 6, the portable information processing gateway is mainly classified into three parts: power module, voice talkback module and information processing module. The power module is powered by 12 V lithium battery, with the voltage stabilization of power supply and charge-discharge

Fig. 4 Design sketch for architecture of wearable embedded platform M200



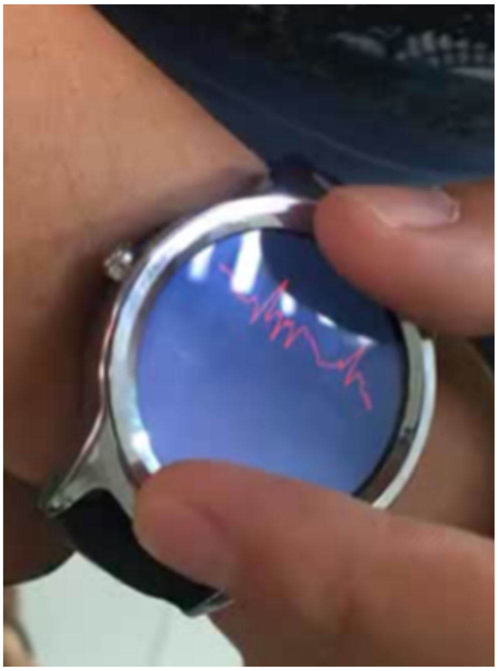


Fig. 5 The product of wearable vital signs monitoring watch

management of the system, which directly provides power for voice talkback and information processing module. The near-field communication in team work is mainly finished by the voice talkback module. MTK6735 is selected for information processing module master and the rest part can be classified into four parts: sensor, network transmission, near-field gateway and basic information. The environment sensing module and GPS are integrated in the sensor, by which the geographic location information of the operator can be located and the local environmental condition (temperature and humidity, atmospheric pressure, ultraviolet) can be collected; the 4G module is mainly used in the network transmission, which is used for the interaction between local information and the backstage; the Bluetooth and the Wi-Fi module is used in the near-field gateway, which is mainly used for the integration and the expansion of wearable equipment; NFC as an individual identification, which can be scanned to read its personnel basic information by the watch, what's more, some local historical data will be archived by the storage module.

The real product is shown in Fig. 7.

The related technical parameters are as in Table 2.

Table 1 Technical parameter of wearable vital signs monitoring watch

Performance index	Technical parameter
PPG peak catching rate	99.6%
CMRR(ECG)	96 dB
Body temperature accuracy	0.2 °C

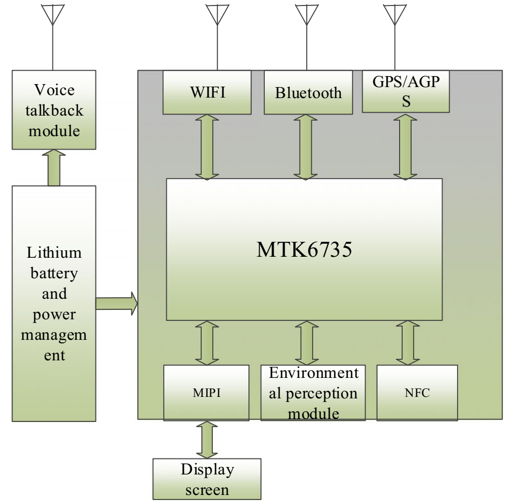


Fig. 6 Architecture design sketch of information processing gateway

Practical application

The work site of State Grid Sichuan Electric Power Research Institute includes plateau above 4000 m above sea level. Therefore, workers often have altitude sickness, which affects their occupational health. We have applied the proposed system in such a harsh environment.

Through the practical application in electric power operation of a plateau substation, the operator carries the wearable vital sign watch and its information processing gateway and the safety assurance is carried on without affecting its normal operation. The application condition on operation site is as shown in Fig. 8.

Fig. 7 Portable information processing gateway

Table 2 Technical parameter table of portable information processing gateway

Performance index	Technical parameter
Main frequency	2G Hz
Standby time	72 h
Distance of voice talkback	3Km
Positioning accuracy	3 m
Temperature	−20 to 65 °C
Humidity	0 to 99%
Atmospheric pressure	50 to 110Kpa
Ultraviolet	0 to 13 UVI

As shown in Fig. 9, the electro cardio, pulse, respiration, heart rate and body temperature of operator can be monitored in real time by wearable smart watch which can transmit information to wearable gateway via wireless communication. There is the function of voice talkback in wearable gateway to ensure the normal communication in the process of team cooperation. In addition, the built-in environmental monitoring system of wearable gateway can react to harsh environment and the plateau temperature and humidity, ultraviolet, atmospheric pressure can be reflected by it, so that attendance in bad weather, sunburn, altitude reaction and so on can be prevented. Accurate position positioning can be provided by GPS system which will give an alarm in the way of virtual fence in case the operator intrudes in the dangerous areas.

Fig. 8 Practical application of wearable safety assurance system

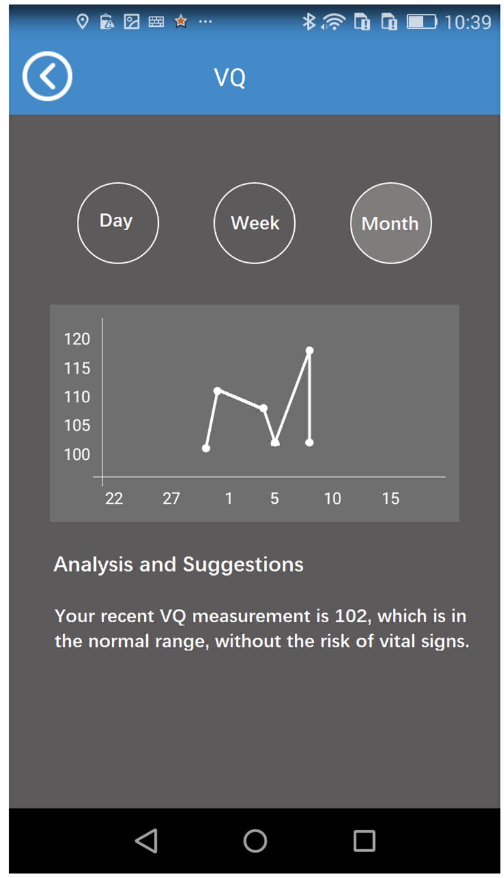


Fig. 9 The analysis and suggestions of the application

Normal work for 48 h can be supported by charge of the whole system for one time, which can meet the demand of the electric power operation for whole day. After the system is applied, the early warning rate of altitude reaction, vital signs and environmental conditions are displayed, so that the safety protection level of the working scene is greatly improved.

Conclusion

A series of wearable power operation safety assurance system is designed and implemented, and a safety assurance method based on vital sign condition and environment information for operators is proposed in this paper. An open standard networking interface is designed in the whole wearable safety assurance system, so that the wearable monitoring equipment with different technical means can be supported to be switched in to unify the networking management, machine learning and forwarding.

In this paper, the wearable examples of wearable vital signs monitoring watch and portable information processing gateway are given. Under the precondition of guaranteeing each function and performance index, it is more suitable for complex electric power operation scene, especially in wearable electrocardio monitoring, and the traditional 12-lead electrocardio monitoring is made wearable, so that there is the certain advancement in the equipment.

The intelligent safety protection level of electric power operation is greatly improved by the wearable power operation safety assurance system and the surface and qualitative evaluation is transformed into refined, quantitive and measurable direction. Wearable is the trend of the future and there is a model in the whole wearable system design for electric power operation given in this paper. Vertically, more different manufacturers and kinds of wearable monitoring equipment can be switched in the system to rich safety assurance information; horizontally, more operation scenes can be replicated and expanded by the system to improve the control level of electric power operation risk.

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Compliance with Ethical Standards

Conflict of Interest Xiaona Xie declares that she has no conflict of interest. Zhengwei Chang declares that he has no conflict of interest.

Ethical Approval This article does not contain any studies with human participants performed by any of the authors.

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