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# A Patrol Robot for Electric Power Substation

Rui Guo, Bingqiang Li, Yutian Sun, Lei Han

*Electric Power Robotic Technology Laboratory of State Grid Corporation of China*
*Shandong Electric Power Research Institute*
*Jinan, Shandong Province, China*

guoruihit@yahoo.com.cn

***Abstract* - This paper describes the development of a patrol robot for the detection of equipments fault inside an electric power substation. The robot, carrying an infrared thermograph, automatically moves around the substation and positions for collecting images of possible critical points. It is fully featured with autonomous navigation, autonomous battery charging and autonomous equipments recognition. It is also remotely supervised by a wireless system. The robot is successfully applied in several substations to demonstrate its performance.**

***Index Terms* - *patrol robot, magnetic guidance, autonomous battery charging, equipments recognition***

## I. INTRODUCTION

The use of the infrared thermograph for fault detection is becoming a common practice in the maintenance routines of the different substation components. In an extra high voltage substation, the reliability required from these components is critical [1-3]. This is the main reason for the development of a system in which the infrared thermograph could be automatically moved inside the substation and positioned for collecting images of possible critical points.

The objective of this paper is aiming to develop a patrol robot for inspection of substation equipments. It is featured with robustness, so as to withstand the region's high temperatures and air humidity; and autonomy, so as to avoid the presence of a specialized professional in situ. Experiments have also been carried out to verify the functionalities of the system.

## II. ARCHITECTURE OF THE ROBOT

New PC based open architecture robot controllers and the demand for increased flexibility, and lower purchasing and operating costs are forcing a paradigm shift in the design, integration, and servicing of robotic work cells. Lower purchasing and operating costs can be achieved along with increased flexibility by using standard hardware and software components. The use of standard PC components in a robot controller opens the door for third party venders and allows for new work cell development and customization opportunities. On the other hand, Linux offers powerful and sophisticated system management facilities, a rich cadre of device support, a superb reputation for reliability and robustness, and extensive documentation. Best of all, Linux is available at no charge and with completely free source code. What's more, Linux is inherently modular and can be easily scaled into compact configurations -- barely larger than DOS -- that can even fit on a single floppy. Therefore, it's not surprising that open-source Linux has created a new OS development and support paradigm in intelligent dedicated systems and apparatuses. Therefore, the robot controller system in this paper is built around the PC hardware and the Linux operating system.

### A. *Hardware architecture of the robot*

Figure 1 demonstrates the hardware structure of the robot. It carries a visible light camera and an infrared thermograph which is used to detect invaders and equipments fault respectively. The camera and the thermograph are dynamically directed to different substation components through a pan-tilt system.

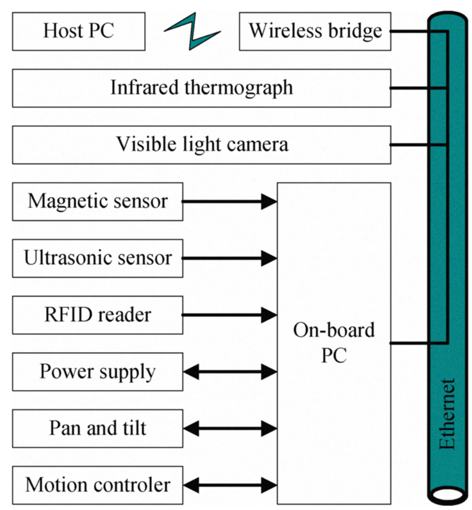


Fig. 1 Hardware architecture of the robot

There are two PCs in the system. They are communicated through a wireless system, operating at a frequency of 5.8 GHz. The on-board PC controls the behaviours of the robot, such as movement, obstacle avoidance and positioning. The host PC plays a supervisory role, such as reading the status from each sub system, recognizing the equipments from the thermal image, planning the patrol path and displaying the 3D map.

### B. *Software architecture of the robot*

Figure 2 describes the software structure of the robot. A distributed object-oriented software architecture has been designed that facilitates the coordination of the various components of the system.

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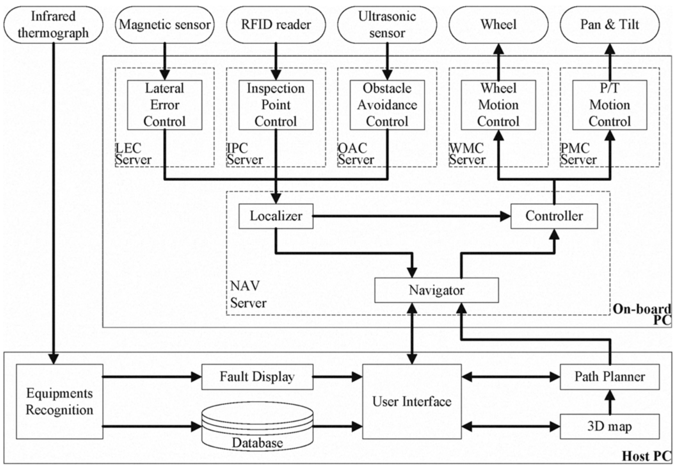



Fig. 2 Software architecture of the robot

The main building blocks are concurrently executing distributed software components. Components can communicate with one another within the same process, across processes and even across physical hosts. Components performing related tasks are grouped into servers. A server is a multi-threaded program that handles an entire aspect of the system, such as navigation control or robot interfacing. Each server has a well-defined interface that allows clients to send commands, check its status or obtain data.

The hardware is accessed and controlled by 5 servers. A designated server, called NAV Server builds on top of the hardware servers and provides localization and motion control services as well as a higher-level interface to the robot from remote hosts.

Components that are too computationally intense (e.g the equipments recognition) or require user interaction (e.g the user interface) reside on remote hosts and communicate with the robot over the wireless network link.

## III. KEY TECHNIQUES OF THE ROBOT

### A. *Autonomous navigation*

Because the motion is easy to program and can be well controlled, the robot is differential wheeled. The movement is based on two separately driven wheels placed on either side of the robot body. It can thus change its direction by varying the relative rate of rotation of its wheels and hence does not require an additional steering motion. Two omni-directional wheels are added in the rear for additional balance, shown in Figure 3.

The magnetic guidance system is not affected by falling or accumulated rain or snow and has been tested and proven to be robust under a wide variety of operating conditions. The patrol robot works outdoor for 24h all-weather situation; therefore a magnetic guidance system is better than a sensing system based on an optical technique [4-5].

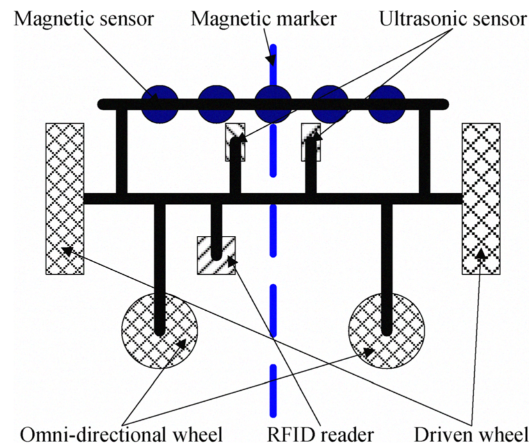



Fig. 3 Autonomous navigation system

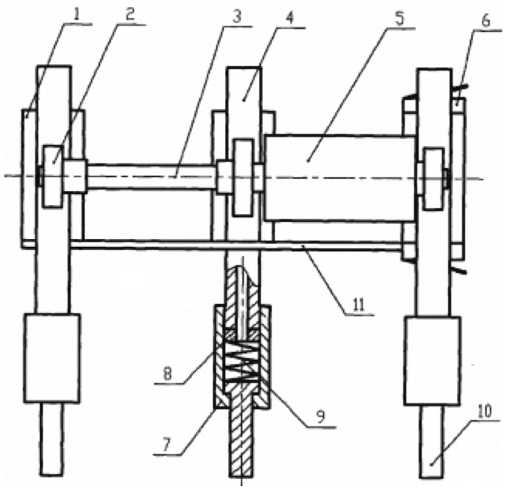
The magnetic guidance system consists of a series of magnetic markers that serve as a roadway reference, plus vehicle-borne sensing and processing units that obtain information from the markers. When the sensors detect the signal from the magnetic markers, they will show different values owing to the different distance to the magnetic marker. The sensors can be arranged according to their output values and there is a peak which is the strongest magnetic field among these sensors. From the sequence of these sensors, the sensor which is the nearest the magnetic marker can be found, and the lateral deflection can be calculated.

Positioning is implemented by using RFID technology. The robot equipped with an RFID reader communicates with the tags on a road. While driving, the robot constantly monitors the presence of a tag. Once detection, the reader retrieves the information from the tag including coordinates of the location. If the location is inspection position, the robot also retrieves the angle of the pan & tilt and the focus of the camera. If the location is charging position, the robot goes to the docking station for recharging.

### B. *Autonomous battery charging*

Currently very few mobile robots have the capability to recharge without manual intervention [6-7]. In this paper, a battery charging mechanism is designed, which allows for large misalignments in both position and orientation (less than ±5cm and ±5°).

Figure 4 demonstrates the charging mechanism. The charging plate is placed on the ground. When the robot arrives at the charging position, the motor rotates and the gear rack moves down along the slot. The contactor is connected to the battery by a conductor through the hollow gear rack. And the contactor and the gear rack are insulated by using an insulated bushing and washer. The two limit switches determine if the robot has physically connected and disconnected with the charging plate.




1. slot, 2. gear, 3. shaft, 4. gear rack, 5. motor, 6. limit switch, 7. insulated bushing, 8. insulated washer, 9. spring, 10. contactor, 11. base

Fig. 4 Battery charging mechanism

Dirt on the charging plate and the contactor may interfere with the supply of electrical current from the battery charger and therefore cause eventual failure of the automated recharging process (particularly in industrial environments). This can be easily overcome by occasional cleaning of the contacts by a human. However it should be noted that if the robot is expected to operate completely unaided and autonomously for long periods, then this may be an eventual reason for failure.

### *C. Autonomous equipments recognition*

The robot is automatically moved inside the substation and positioned for collecting images of possible critical points. And equipments have to be recognized from the thermal image to distinguish an exact fault. This is done by using interest points matching. We first detect the interest points to represent the significant visual characteristics of the input images. A small region around each interest point is denoted as an image patch. Next, we extract the low-level features, which include color and texture features, to describe each image patch. Finally, we utilize the technique of geometric hashing to index the patches into a hash table. During the query stage, we detect the image patches out of the query image as similar as in the indexing stage. Then, we calculate the number of matching between the patches and the hash table entries to measure the image similarity [8-11].

#### 1. Interest points detection

Interest points are pixels that capture significant local features of an image, and usually locate around corners and edges of images. In the application of image retrieval, the ideal interest points should be invariant to illumination change and geometrical transformation. That is, once an image undergone lighting change or geometric transformations, we expect the interest points can still indicate the same local features. Moreover, when only partial information of an image is available, using interest points is advantages over other features (such as edges or regions) to capture local information.

In this paper, we use Harris algorithm for interest points detection. The Harris corner detector is a popular interest point detector due to its strong invariance to: rotation, scale, illumination variation and image noise. The Harris corner detector is based on the local auto-correlation function of a signal; where the local auto-correlation function measures the local changes of the signal with patches shifted by a small amount in different directions.

#### 2. Feature extraction, description and matching

After detecting the positions of interest points, the local features of interest points have to be indexed for retrieval. However, interest points are merely isolated pixels and are insufficient to represent the characteristics of an image. Therefore, we select a 16*16 region around each interest point as an image patch and extract color and texture features within each patch to represent the local feature of an image. Thus, the similarity between two images is converted as the similarity between two sets of image patches.

In this paper, we extract color and texture features to describe each patch. We measure the average color as the color mean of each patch, and the degree of smoothness as color variance of the patch. In addition, we measure the texture feature to describe the structural arrangement of the image patch. Four texture properties from co-occurrence matrix are extracted in this work: energy, entropy, contrast, and inverse difference moment. In combination of the color and texture feature, we could define the feature descriptor of each image patch. To measure the distance between two image patches, we simply measure the weighted Euclidean distance between their feature vectors.

#### 3. Indexing by geometric hashing

After extracting the feature vector for each image patch, we will record not only the feature vector but also the location of the image patches. By considering the interrelationship of image patches, we aim to match the image patches even when the image is geometrically transformed or only partial image is present. Geometric hashing is a technique developed for matching spatial features against a database. The basic idea of geometric hashing is that arbitrary two interest points of an image are selected as a basis, and then the other interest points are processed by the same geometric transformation and indexed into the corresponding hash table bins. When all combinations of the bases have been selected, the resulting hash table records the locations of interest points through all possible geometric transformations. Therefore, when processing a query, we can find the most similar object by sequential searching the hash table. When a two-point basis is used, the matching is invariant to translation, rotation, and scaling. For a three-point basis, the matching is invariant to affine transformations. While a four-point basis support the perspective-transformation invariant matching. However, using more points as a basis for geometric hashing increase the computational complexity rapidly.

In this paper, in order to retrieve images invariant to translation, rotation, scaling and partial occlusion, we utilize the geometric hashing technique to index the spatial information of images patches. To reduce the computation complexity, we use two interest points as a basis to achieve the translation-, rotation- and scaling-invariant image retrieval.

4. Test

We use 130 images which contain current transformers, potential transformers, lightning arresters for test, shown in figure 5. The results show that 123 images have a successful recognition.

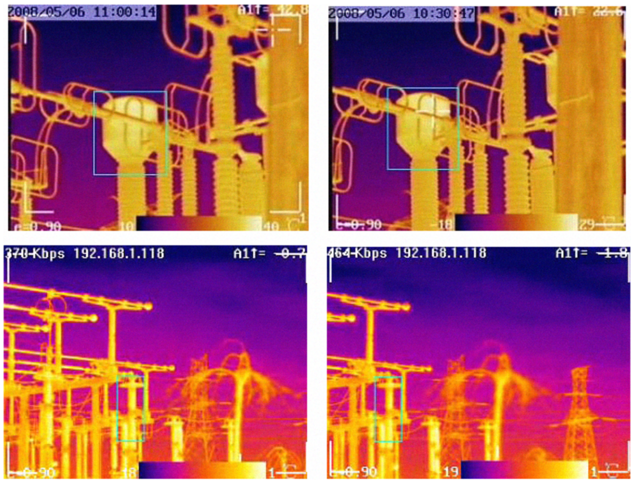


Fig. 5 Equipments recognition

## IV. EXPERIMENTS

The robot is successfully applied in several substations to demonstrate its performance. Table 1 describes the specifications of the robot. Figure 6 displays a photograph of the robot. Figure 7 and figure 8 show the user interface and 3D map running in the host PC respectively.

TABLE I
SPECIFICATIONS OF THE ROBOT

| Item | Specifation |
|---|---|
| Dimension | Length: 1000mm<br>Width: 600mm<br>Height: 600 mm |
| Weight | 100Kg |
| Speed | 1.44km/h～2.88 km/h |
| Gradeability | 15° |
| Ingress Protection Ratings | IP53 |
| Positioning Accuracy | Lateral: ±10mm<br>Longitudinal: ±10mm |
| Battery | 24V/38AH lead-acid battery |
| Movement of the Pan & Tilt | 360° in the horizontal axis<br>180° in the vertical axis |
| Wireless Communication | 5.8GHz in frequency<br>50Mbps in bandwidth<br>10Km in transmission distance |
| Infrared Thermograph | ±2° in accuracy<br>0.08℃ in NETD |

Fig. 6 Self-developed patrol robot working in a substation

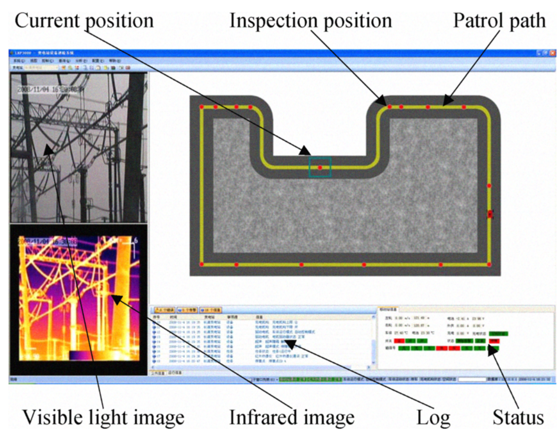



Fig. 7 User interface running in the host PC

Fig. 8 3D map running in the host PC

## V. CONCLUSION

The patrol robot presented in this paper can be an efficient tool for fault detection and its subsequent prevention during the operation of a substation. It is featured with robustness, so as to withstand the region's high temperatures and air humidity; and autonomy, so as to avoid the presence of a specialized professional in situ. Applications of the robot will improve security and automation level of substation maintenance.

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