Naoto Kume and Mikko J. Rissanen. Towards Ambient Communication Support for Power Grid Maintenance and Repair. In: Proceedings of 2nd International Conference on Ambient Systems, Networks and Technologies (ANT), Niagara Falls, ON, September 19-21, 2011, pp. 98-105. Procedia. DOI: 10.1016/j.procs.2011.07.015

DRAFT

Towards ambient communication support for power grid maintenance and repair

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Abstract

In the power industry various companies have a crucial responsibility of sustaining infrastructure for electricity service. Maintenance and repair of electrical devices out in the field is potentially dangerous and sometimes complicated in nature. Effective and safe fieldwork requires clear and accurate communication between fieldworkers repairing and maintaining devices outdoors and operators monitoring and controlling the power grid in a control room. Operators and fieldworkers have to synchronize their activities for maintaining steady electricity service. Current ICT support for fieldwork consist of mobile phones, mobile software applications and workforce management systems, but much of the necessary communication is still conducted orally over the phone. We propose ambient communication support that improves communication between operators and fieldworkers. The concept is based on mobile navigation and work order management application, image-processing techniques for detecting target devices and wearable sensor based activity recognition methods. We present work-in-progress in form of preliminary prototypes and discuss the technological advances needed to make the concept real.

Keywords: Mobile application; Wearable computing; Activity recognition; Motion sensor; Communication support; Power industry.

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1. Introduction

The electricity infrastructure is a highly transparent service. Usually, electricity service is expected to continue without interruptions so that ordinary consumers do not notice if a failure in the infrastructure occurs. Critical accidents which threaten the continuity of the service are not acceptable, because our society depends on it. A power outage affecting a hospital may have direct life-endangering impact, whereas in other cases the impact is mainly economic. Preventive, high-performance maintenance and effective repair are the cornerstones for avoiding critical interruptions in the service. Fieldworkers of maintenance organizations around the world are constantly alert and ready to fix problems before they become critical as in the 2003 blackout incident [1] in the United States.

The fieldworkers handle high-voltage electrical equipment which in the worst case can cause death if handled without proper training and compliance to standard safety procedures. For safety reasons it is usually mandatory to have two persons fixing complex electrical equipment. This reduces the risk of fatal accidents, which however still

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happen sometimes. On the other hand, the requirement of two person repair teams keeps the headcount of service personnel steady whereas in several technical domains, the tendency is to do less human work and automate more of it. Much of the electric infrastructure is already automated by power generation companies and Transmission and Distribution (T&D) companies with the support of electric hardware and software vendors. Various supervisory control and data acquisition (SCADA) systems collect information from all the electric devices, such as transformers, substations and other elements of the power grid, and send them to a control room where power grid operators monitor the status of the electricity service. Data shown in SCADA to operators is either time-stamped values from the devices or alarms that are triggered when certain values exceed a predefined threshold. The operators have the overall view to the power grid and aim to detect problems before they become critical widespread outages, send fieldworkers to the problem site to fix the situation and verify effectiveness of the repair. Operators are responsible for coordinating fieldworkers' activities in the outdoors by assigning Work Orders to them. Communication between operators and fieldworkers is crucial for effective maintenance and repair and for the safety of the fieldworkers. For instance, every time a fieldworker is approaching a substation, there has to be absolute certainty that the substation is not energized and thus is safe to enter without a risk of high-voltage electrocution.

In the era of smartphones, tablet PCs, 3G networks and iPhone Apps, it is expected that productivity is continuously increased by ever more capable ICT. Currently, ICT support for power grid maintenance and repair consists of workflow management systems and mobile phones, which have limitations in efficiency for maintenance and repair. For example, a fieldworker working in the outdoors whose work progress should be known by operator sitting in the control room, has to either keep the phone line open all the time or pause the work to adjust work progress on a workflow management system running on smartphone. Much of the communication is still analog in nature, whereas a digital solution would provide for more accurate communication and therefore safer operations.

We believe ICT of the future can provide more comprehensive and ambient support for efficient maintenance and repair of the power grid. In this paper we describe relevant aspects of communication between the fieldworkers and the control room operators and present a concept and work-in-progress towards a prototype of an ambient communication support system which consists of:

- mobile interface for Work Order management and navigation to the worksite,
- detection of target electrical devices to be repaired by image processing techniques, and
- activity recognition for recognizing status of work automatically.

2. Communication Between Operators and Fieldworkers

The following describes understanding acquired during several years of research and development projects that have focused on providing ICT support for control room operators and fieldworkers. In typical projects the target groups have been operators and fieldworkers as well as their managers that have been interviewed in workshops and individual interview sessions. Usually operators are required to have adequate background as fieldworkers in order to guarantee understanding of devices behind controls in the control room and efficiency of communication with fieldworkers. Here, we summarize relevant aspects of the nature of communication between control room operators and fieldworkers.

2.1. Role of phone calls, work artifacts and safety procedures

Operators receive information about an outage either from customers in forms of failure reports or they see it in the SCADA. If the cause for the outage is not obvious or can be subject to misinterpretations, fieldworkers are sent out to the worksite by writing a Work Order and a clearance. The Work Order contains information about how

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switching electrical devices on and off in this case should be done. Clearance determines that the worksite is clear for execution of the work. Switch order is defined, recorded in SCADA applications and validated afterwards to be effective and shared between the operator and the fieldworker. If switch order requires communication when the fieldworker is inspecting the situation on the worksite, the switch order is written in haste during the fieldwork.

Currently, many operators do not know where exactly the field crews are at the moment. Although the current control rooms are equipped with conventional paper maps or a digital GIS system, locations of individual fieldworkers and field crews are not known without coordination over the phone. Despite the technological advances in outdoor positioning such as GPS, few companies seem to have employed them in practice. Although the work can be conducted over the phone, operators say that an interactive map is not essential, but it would definitely make the work faster. Every single time fieldworkers are about to enter a worksite, e.g. a substation, they call the operator to confirm that the area is de-energized and therefore safe. Usually to indicate that fieldworkers are on a worksite the operator attaches a note to the SCADA system, for example a truck icon, to ensure that other operators do not energize the worksite by accident. Every time the fieldworkers leave the substation, they call the control room to let the operator know if the site can now be re-energized or not. These kinds of issues are embedded in safety checklists and electrical safety standards (see e.g. [2]) to ensure safe maintenance and repair.

From the operator's point of view, there is not much information coming from the field between calls. The operator does not really know if the fieldworker is progressing or even alive at a specific moment. Despite the large amount of communication including repetitions and responsibilities to prevent human errors do occur. Operators say that human errors happen several times a week, but severe accidents happen once in a decade.

After getting a clearance from the operators, the work on the electric devices starts. Before starting to work on the device, fieldworkers have to verify its identity and type to be sure they are working on the device the operator gave clearance to work on. In case a wrong device is suspected, a phone call to the control room clarifies the situation. Many human mistakes in the past have been due to careless validation of target devices for maintenance or repair.

In some cases alarms from substations may be false positives caused be a malfunction in the alarm system instead of the actual electric device. In these cases fieldworkers and operators have to verify orally that the condition of the physical site matches with the condition shown in SCADA. Since a normal phone offers only audio connection, it is often difficult and even frustrating to spell device names and numbers. This sets demands on clear articulation, which is often part of the on the job training of operators and fieldworkers. Sometimes quality of the phone connection maybe low and human mistakes in communication happen. To support accurate communication, fieldworkers sometimes take a photo of the worksite by a smart phone and send it by email to the operator. Still, much of the communication involves spelling values from the system by the operator to the fieldworker out at a substation, or vice versa.

Problem solving is another aspect of communication between control room operators and the fieldworkers. In some crisis situations operators reported to have called the field crew instead of looking the data in the system. When the operator suspects a bunch of alarms to be due to a previously occurred device fault, it can be faster to ask fieldworkers to tell the status orally rather than do analysis digitally by using the system. Unfortunately in a real crisis, there is little time for an operator to answer all the phone calls, which requires information about each phone call before answering so that most urgent calls can be prioritized and others simply postponed. Many control rooms are equipped with a special hotline for the most urgent calls.

In short, phones and radios play a very significant role in the T&D industry. Especially in areas where the infrastructure is growing and all the automated functions of SCADA systems have not yet been put to full use, a large portion of maintenance and repair jobs is confirmed by phone calls. The need for phone calls is smaller in regions of more static infrastructures. As an example of frequency of phone calls, we have witnessed a period of 1h 40min of an exceptionally busy morning shift during which one operator had to deal with 22 separate phone calls, that is, one every 4½min. Short phone calls take just a few seconds of acknowledging starting or ending of a work in field, which is usually done by simple "OK." Longer phone calls typically take around a minute. Sometimes even longer discussions are conducted over the phone. All phone calls are recorded on tape, so that e.g. communication in crisis situations can be traced back for analysis (as conducted e.g. in [1]). The need for saving all communications in digital archives is imminent.

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2.2. High level information requirements and state-of-the-art ICT support

The current state of the technological support for fieldworkers and operators does not utilize all the potential of ICT. Knowledge of what is happening in the field is difficult to share with the control room. These challenges can be broken into separate information requirements that an advanced communication support system would fulfill:

- Location: Where is the work being conducted?
- Time: When is the work taking place?
- Worker: Who is executing the work?
- Work: Which work order is being executed?
- Target: Which target device is being worked on?
- Process: What kind of procedure in terms of target devices and safety procedures?
- Status: What status of progress in comparison to the process? How much time the work is expected to take?

As the first three requirements have been solved with GPS equipped smartphones and the fourth requirement with workforce management systems, the rest of the requirements have been proven to be technically challenging. The following summarizes today’s practice in the T&D industry (see also Fig. 1: Today):

- Target: Work orders in normal T&D companies are becoming digital. Paper reports printed out from the control system are still the most standard practice. Workforce management systems that support operators for managing fieldworkers have emerged and available on various smartphone platforms. Currently, tablet PCs are becoming popular. In short, there is digital information about the target devices. However, digital detection of target device outdoors is limited to bar codes and bar code readers, which requires tagging of those devices beforehand and is thus cumbersome for most companies. Typically the fieldworker has to find a serial number or such identifier to be sure that the correct device is in question.
- Process: Safety standards are specific to each country (e.g. [2]) yet very similar on higher level. All work on electrical devices has to obey the standard safety procedures in order to guarantee worker’s safety and minimize the risk of damage to the device. To maintain or repair each type of electrical device requires training. It is up to the fieldworker’s skill and competence to conduct correct and safe fieldwork. Currently, the process can only be explained orally over the phone by referring to shared competence between the operator and the fieldworker.
- Status: Status of the work progress is communicated orally over the phone. Technically it has been long possible to let the fieldworker sign off each individual step in the process on a smartphone application, but since the work requires two hands and full mental focus, pause in the work for submitting status information to the control room has not been found acceptable. In short, currently status information is not at all digitalized.

3. Ambient Communication Support: Concept and Prototypes

A system that would solve the above-mentioned challenges of sharing target, process and status information between the fieldworker and the operator, would improve efficiency of communication in the T&D industry. Fig. 1 illustrates the concept and its impact. Three major stages from the overall process of managing outages can be reduced by the proposed system. The system enables the operator to know that the fieldworker is starting work on validated target and the status of work in the field. By automating recognition of the status in comparison to the process the fieldworker is freed from user interventions and can therefore proceed with the Work Order using both hands and full focus on the task without ever having the need to pause the work or even open phone connection to the control room. Thus, trivial communication and especially the short “OK” messages become fully automated by the system, which saves time for both the operator and the fieldworker. Moreover, all information about the process and status can be saved in a permanent log, which enables analysis of incidents afterwards. The concept enables one operator to manage and coordinate more fieldworkers than today, which leads to significant savings in the T&D

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industry. Fig. 2 illustrates the high-level architecture and functionality of the system. In the following sections we present work-in-progress towards a prototype of the ambient communication support.

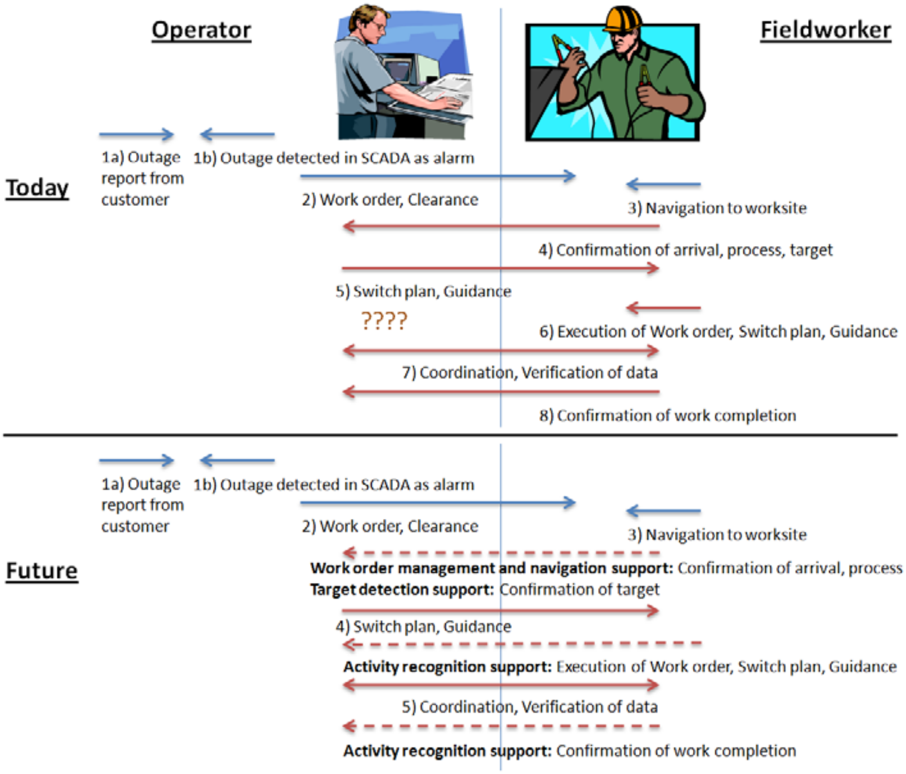

Fig. 1. Ambient communication support concept and its impact. Work order management and navigation support eliminates the need for confirmation messages about arriving at the worksite, selecting correct process. Target detection support eliminates the need for communication about target electrical device. Activity recognition support allows information sharing about status of the work execution, which is today not known by the operator.

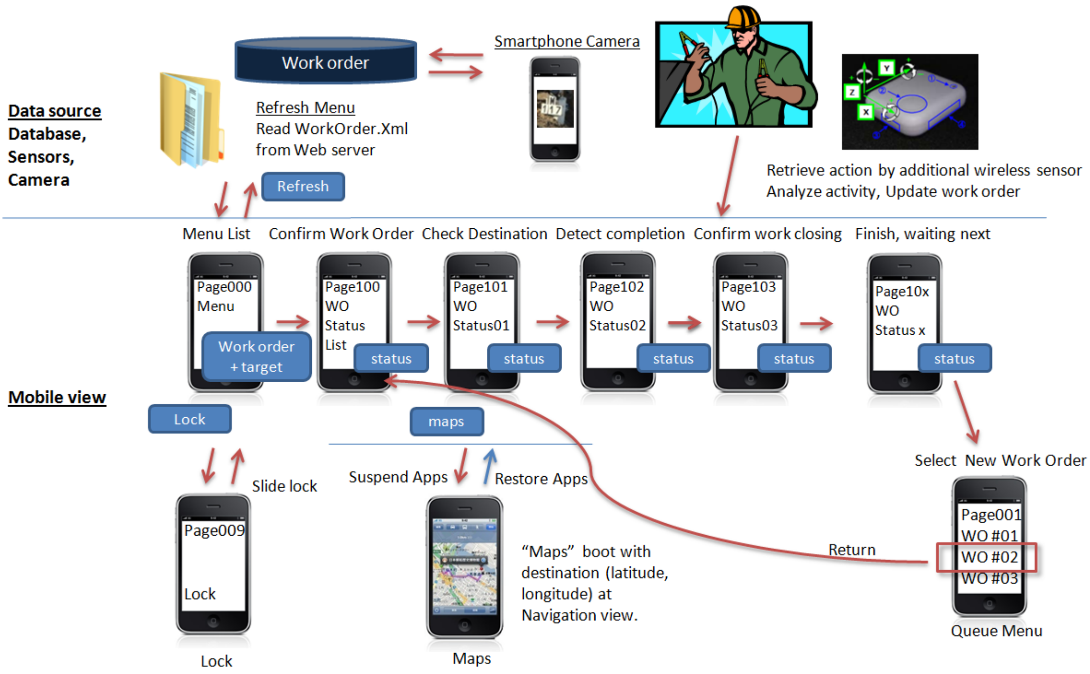

Fig. 2. Overall system architecture. Fieldworker carries a camera-equipped smartphone and wears acceleration and gyro sensors on upper arms. Work Orders are retrieved from the control system's database. Activity recognition enables state transitions and triggers status alerts.

3.1. Mobile navigation and work order management interface

A mobile interface enables the fieldworker to receive Work Orders sent by the operator. Normally, deployment of fieldworker to a specific worksite is decided by operators considering the fieldworker's expertise and current location. An operator makes a combination of Work Orders to a closest fieldworker who is a known expert in solving certain kinds of technical problems. Work Order is distributed to any fieldworker on demand to a mobile device. For the planning of deployment, an operator could refer to a personnel database which contains characteristic information based on experiences about each fieldworker.

Current prototype is implemented as an iPhone App as shown in Fig. 3. The work Data structure of communication is designed as Queue, Work Order and Status. Queue contains several Work Orders and typically contains a list of problems having different target devices and location. Work Order is defined as a combination of Status data, which are steps of repair procedures. For example, Status consists of deployment order, confirmation order, recording order and reporting order. Status is described with exact procedure manual in each step. Repair order or deployment order are contained in each status. Simple task management server placed in a control room is also developed as a web server connecting via HTTP. iPhone application has been developed as a task viewer connected to 3G wireless internet and as a GPS positioning function. Work Order is retrieved via HTTP from task management server to iPhone application. Work Order is to be extracted to a Status list. Completion of each Status can be checked on the list. Map viewer and site pointing from Work Order are expected to reduce time the fieldworker needs for starting the work as compared to paper maps and paper Work Orders. The iPhone application can display an alert by popup text box, beep sound and vibration.

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Fig. 3. Smartphone application for locating worksites and managing work orders. Work orders describe repair and maintenance activities step by step, which are updated in real-time by activity recognition methods. In addition, conventional navigation aids for finding the worksite are embedded in the application.

3.2. Automatic detection of target devices

After the operator has assigned the fieldworker a Work Order and the fieldworker has arrived at the worksite, it is required that the target device is verified by some means. The ambient communication support system supports also this part of the fieldworker's job. We propose and easy-to-use camera-based "hand scanner" that can be used for taking a photo of the target device and matching the photo with the Work Order. The hand scanner is part of the mobile interface which beeps if the target device in a photo taken by the fieldworker matches with the content associated to the Work Order. Result of image matching is sent to the control room. Once matching is done the operator immediately knows that the right target has been reached by the fieldworker and that the work is starting. As long as serial number or other ID information is visible on the device, image processing techniques can be used for identifying which of all the installed devices is being worked on. Therefore, the system provides for safety in the fieldwork.

For detecting target devices for repair and maintenance we are considering to apply the image recognition methods used in the Flashscope prototype [3], which uses SURF algorithm [4] for image matching. Currently, integration of the Flashscope concept to an iPhone App has not yet started, but the technical components and methods exist. It is only a matter of development effort to integrate Flashscope functionality to iPhone's camera, since several applications implementing advanced image processing algorithms for augmented reality services on smartphones have been realized [5, 6]. A simple pointing of the suspected target device can trigger image recognition, which after a successful or unsuccessful detection of the work order target provides simple audio and/or vibration feedback using the smartphone's output capabilities.

3.3. Activity recognition of work status

The fieldworker is equipped with wearable motion sensor device that recognizes maintenance and repair activities. The activity recognition automates communication about status of work in the field and enables both the fieldworker and the operator to share the information in real-time without user interactions. Sampled audio messages provide feedback to the fieldworker of each step that has been executed successfully, so that awareness of information sent to the control room is known all the time. The fieldworker and the operator can therefore be kept up to date about the progress in real-time fully automatically.

Fig. 4 shows a communication model between in an initial prototype of a mobile client, a local PC and the control room server system. Our current implementation does not support computing of activity recognition part on the mobile client, an iPhone. Therefore, connection is established to a MacBook that can provide local data communication support from fieldworkers' vehicle which is usually left in the vicinity of the worksite. Currently a simple flag control realizes automatic and manual alert display by activity recognition or remote operator's interruption.

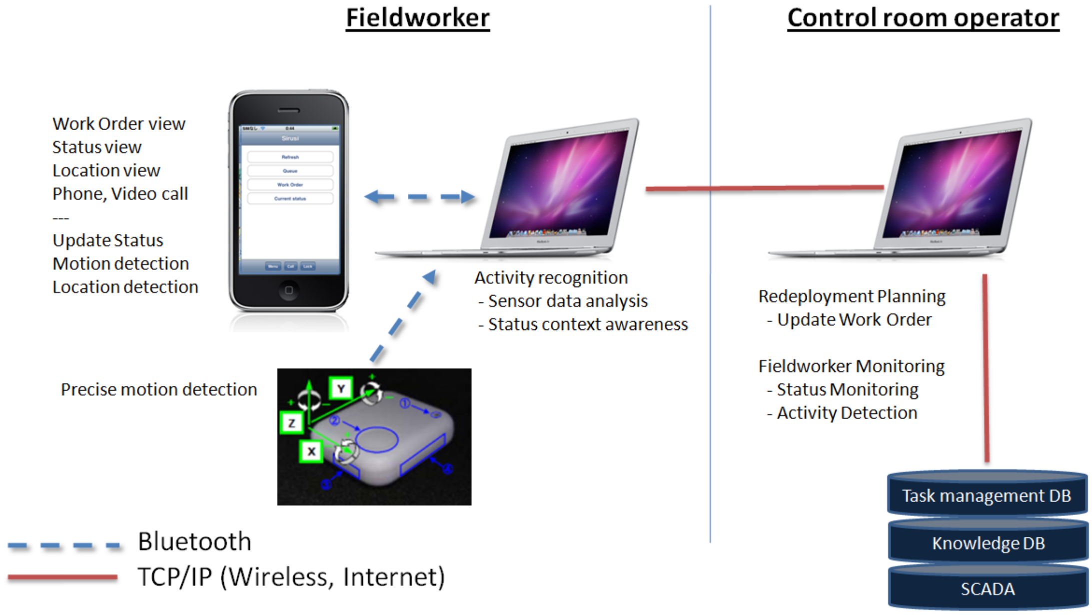

Fig. 4. Architecture of the activity recognition system. Motion data from the acceleration and gyro sensor is sent to a local laptop for analysis, which then forwards feedback to the fieldworker via the smartphone and to the control room.

Activity recognition engine runs on a MacBook and utilizes acceleration and gyro sensors built in B-Pack model WAA006 [7]. The B-Pack sensor is connected to a local PC via Bluetooth. The local PC receives motion sensor data and analyzes activity using the methods originating from the E-Nightingale project [8] which demonstrated successful recognition of nurse's hand washing procedures at acceptable success rate. The same methodology is expected to apply to activity recognition in the T&D industry. When the local PC detects specific activity related to Status, the local PC sends message to both iPhone and control room server. Applied activity recognition method is window-based tracking which requires master data of a specific motion. As a tentative implementation, we constructed an activity recognition system which can distinguish wrenching and screwing activities that consist of swing and rotation motion of the upper arm.

Even if retrieved motions from the sensor in the current prototype cannot yet be called an activity database, the retrieved activity is looked up in the Status information which contains activity list to complete an order. When an activity is recognized in the proper sequence in comparison to the work process, the application sends a signal to update Status. If an activity is recognized a mismatch with work process is detected, the application sends an alert signal to iPhone the fieldworker receives a feedback on right time before performing incorrect activities.

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To make the system reliable in real use, we have also implemented a backup function for making sure critical state transitions cannot be missed. In case of recognition failure, a simple snap of fingers triggers the next state transition, thus, making the system reliable for real fieldwork without too much disruption to the work process.

The current limitation is the requirement of vicinity of the laptop used for computations, but purely mobile sensor data analysis is expected to be possible in the next versions of the prototype as an iPhone app. Moreover, integration of all functionality that for now is implemented on separate devices is future development.

4. Conclusion

We have proposed that ambient communication support could improve communication between control room operators and fieldworkers for maintaining and repairing the power grid. The work-in-progress presented here indicates potential of the concept. We presented an interface design for navigation and work order management, discussed suitable image processing techniques for detecting target devices and presented a prototype of activity recognition methods for automating transmission of work status to the control room.

Future research will focus on developing the activity recognition application further with real data from real fieldworkers and making the concept practical in future years. Realization of the concept is expected to provide safety to fieldwork and make repair and maintenance in the T&D industry more efficient.

Acknowledgements

This work was fully sponsored by Industrial Software Systems, ABB Corporate Research. The authors thank Fredrik Alfredsson (ABB Corporate Research) for valuable input, Haruo Noma (ATR Labs) and Tomohiro Kuroda (Kyoto University Hospital) for technical guidance, and Martin Naedele and Magnus Larsson (ABB Corporate Research) for their support to the project.

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