App-based System Diagnosis using Mobile Information Systems

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Abstract

This paper presents a study of the potential of integrated services for app-based system diagnosis using mobile information systems. First, a task and context analysis is provided for the application of integrated system diagnosis in the context of plant asset management (PAM). Second, exemplary scenarios are presented which demonstrate IT services for system analysis based on self-organizing maps, system diagnosis with a graph-based approach and support for therapeutic measures on defective assets. Third, a mobile information system is presented that allows users to list, describe, filter, and select assets, to browse through available diagnoses, and to follow step-by-step instructions for recommended therapeutic measures. The mobile information system provides a graphical representation, description, and selection of assets by using a P&I diagram as well as a chart visualization of process values. The system further provides access to both static and transient data sources such as engineering data of the plant, process data of the technical process and the results of complex analysis services. This mobile information system demonstrates the suitability of the proposed app-based approach. Finally, the results of a focus group workshop are summarized, showing the potential of mobile information systems in an industrial setting, barriers that still remain.

1. Introduction

Asset management is the management of the tangible and intangible property holdings owned by an individual or a corporation throughout the entire lifecycle of those holdings, the organization of their installation and maintenance, and the management of all asset-related information [1]. *Plant Asset Management (PAM)* refers to asset management with an explicit focus on the operative technique. PAM creates a data base that provides the necessary information for many integrated services for asset maintenance and system diagnosis. Dedicated *PAM systems* are used to collect, pre-process, and provide both static and dynamic data from various sources. PAM systems as a data hub for *mobile information systems* can provide service personnel in the field with a new level of support through mobile IT.

Integrated services could accelerate work processes, increase the quality of work, reduce the requirements for staff qualification and training, and significantly increase the quality of information about the digital plant. In order to use these services effectively, users need flexible, adaptive, and low-maintenance mobile information systems allowing them to access the PAM system at any time and any place under almost any condition. Due to the long lifetime of process plants, it must be possible to make enhancements and adaptations on the mobile information systems with little effort throughout the entire system lifecycle. It must also be easy to adapt them to continuously changing work processes. Updates need to be deployed automatically and resource-efficiently. Monolithic solutions have not been able to satisfactorily meet these demands, due to their size and complexity.

As an alternative, this paper proposes the *concept of orchestrated mobile apps*. Mobile apps are small applications that are optimized for a specific task on a specific mobile device. Due to the low complexity of each app, the system is easy to maintain. Using an app store infrastructure, mobile apps are easy to maintain and to deploy. The deployment of apps can be fully automated for any number of devices using appropriate update mechanisms. Mobile apps can be interlinked via the operating system's own mechanisms that allow them to call each other and to exchange data. Due to this loose coupling, it is very easy to update or replace single apps, and it is also easily possible to modify the app network if the underlying work processes changes. The process of setting up a network of interlinked mobile apps is called *mobile app orchestration*.

This paper demonstrates the applicability and suitability of mobile app orchestration based on the use case of PAM system based plant diagnosis. First, a task- and context analysis sets forth the essential requirements

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for a mobile information system. An appropriate mobile information system is then designed, which consists of four mobile apps to support the user in various tasks, enabling the workflow to become more effective and efficient. Finally, this paper presents the results of a focus group workshop with the developed system. During the workshop, the suitability of the proposed system, possible barriers to its deployment in plant information systems, and further areas of application for app-based mobile information systems were discussed in detail with industry representatives and mobile app designers.

2. Task and context analysis

2.1. The PAM model

VDI/VDE 2651-1 introduces a PAM model which provides function blocks for each stage of information processing. This generates status information on asset health on the one hand, and function blocks to evaluate, process, archive, distribute, and present information about assets on the other hand [1]. The PAM system is thus responsible for the data management including *retrieval, storage, provision, and presentation* of available data. It provides a bidirectional interface between asset and user, and can therefore also be regarded as a middleware between the two. PAM systems are used by human users as well as other IT systems. Four utilization aspects can be differentiated: *business economics, engineering, maintenance, and operation* [1]. PAM systems are used in three remits: *monitoring, diagnosis, prognosis, and therapy* including performance monitoring, condition monitoring, and alarm management; *provision and storage* of asset-related information; and *analysis, presentation, and dissemination* of all asset-related operator actions and other use-related information.

2.2. The workflow for app-based system diagnosis

Services in the remit *monitoring, diagnosis, prognosis, and therapy* have been merged into an integrated mobile information system in order to optimally support maintenance personnel on-site. The resulting system supports planning and self-organization of working tasks, provides procedural instructions for asset therapy, and provides a means to monitor and diagnose assets.

The workflow for PAM systems according to VDI/VDE 2651-1 has been adopted for the mobile information system. This begins with the continuous monitoring of the data sources, followed by the diagnosis of faulty assets and the prognosis of the fault consequences. Based on this, appropriate decision support is provided, along with recommendations for therapeutic measures to restore functional capability of the system. The resulting workflow model is illustrated in Figure 1. The expected results of each task also comply with the specifications given in VDI/VDE 2651-1. The following tasks are to be performed in the given order:

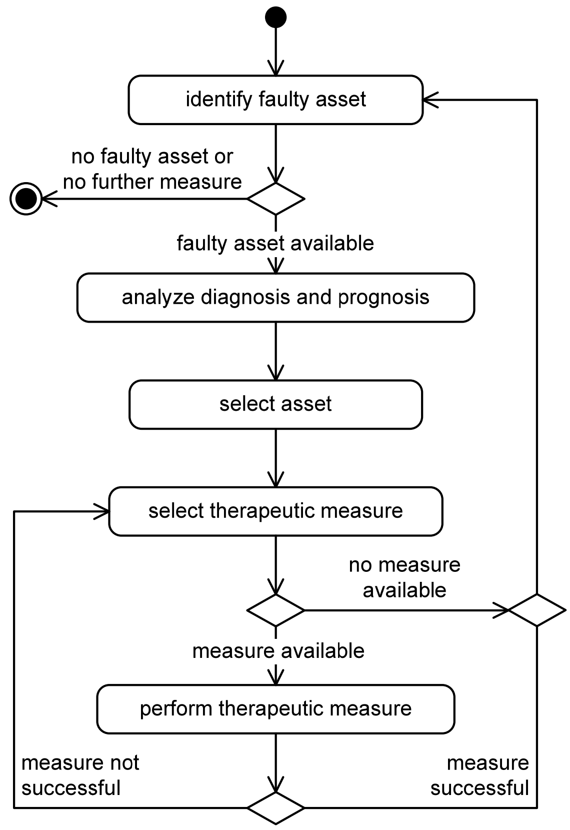

Figure 1. Workflow model for app-based system diagnosis.

1. **Monitoring** detects undesirable conditions of an asset (*symptoms*). Based on these, the user can assess the current state of the system.
2. **Diagnosis** provides the type, location, root cause and time of the first occurrence of influences that are responsible for the identified symptoms. The results are also evaluated in terms of reliability or probability of the diagnosis.
3. **Prognosis** provides forecasts on impending failures or disturbances and/or on the remaining service life.
4. **Therapy** makes proposals for therapeutic measures and gives procedural instructions to eliminate the root causes and to avoid negative consequences of asset faults. It provides strategies for the operation with the symptoms. Thus, the user can select a promising measure and perform this measure according to the instructions of the PAM system.

VDI/VDE 2651-1 summarizes feasible information exchanges under several aspects of use [1]. In this project, maintenance was considered as the most valuable area of use for mobile IT-supported work. Exemplary information has been provided in the areas of *operating data*, *equipment history*, *and condition recording* as well as *failure and failure forecast*. The PAM system has been equipped with a graph-based tool for state analysis, which allows the user to determine the current condition of the assets based on manifold input signals [2]. The information is provided to the user in a usable fashion by means of the mobile information system.

The PAM system provides a powerful tool for condition analysis that determines the current asset conditions in two stages [2]. In the monitoring stage, which is shown in Figure 2, current process data are compared with a fingerprint that was previously determined from self-organizing maps. In the case of major deviations, an investigation is done in the diagnostic stage to determine which asset and which error caused this deviation [2]. A graph-based approach is used for this purpose. Based on the results of the investigation, recommendations for appropriate therapeutic measures are derived, which lay the groundwork for the recovery or securing of the system functional capability.

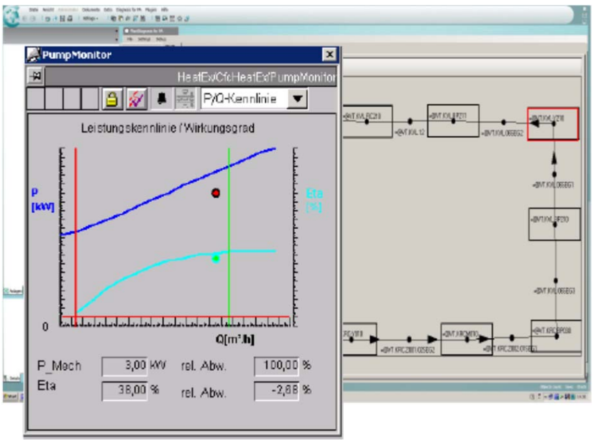

Figure 2. Fault detection with graph-based state analysis in SIMATIC PCS 7 and COMOS MRO plugin.

3. System concept

3.1. Orchestrated apps in the industry

Mobile information systems provide location- and time-independent access to the PAM system. They thus ensure that required information is instantly available. In contrast to paper-based data storage and management, data can be preprocessed and visualized as desired in order to ensure optimal task support. Also, the input of data by the user and the recording of user activities can be realized without media breaks. Furthermore, auto-ID techniques (for example QR-code or RFID) allow automatic identification of assets.

The orchestration of mobile apps allows a more flexible and cost-effective IT support for mobile work than prevailing monolithic applications. Each app supports a single task in the workflow. By linking the individual apps together according to this workflow, the whole workflow can be supported throughout. The network can be established using well-defined action requests and data transfers. Most mobile operating systems provide the respective mechanisms already. The resulting network eventually constitutes the mobile information system. Thus, apps can be replaced without having to modify other apps, and workflows can be modified without having to revise the entire system. The orchestration can be automated, which leads to a substantial increase in the flexibility and cost-efficiency of the app development [3].

3.2. Reference scenarios

Five reference scenarios have been developed and implemented in the *Siemens Smart Automation Research Facility, Karlsruhe, Germany*. The scenarios contain typical elements of the mobile plant diagnosis and are used to demonstrate the potential of integrated services for the app-based system diagnosis with mobile information systems.

1. **Fault-free operation of the plant:** the standard case; all the scenarios described below return to this scenario after successful treatment.
2. **Faulty operation - unambiguous error**: An intelligent field device detects a pneumatic leakage, and signals *function control* or *maintenance*. The detected fault is registered by the PAM system and transmitted to the mobile information system.
3. **Faulty operation - multiple error signals**: An intelligent field device and the pump monitor detect that gas is entrained in the piping system and they signal *out of specification*. The signals are collected by the PAM system, and the fault detection identifies a single root cause. This information is transmitted to the mobile information system.
4. **Faulty operation - ambiguous error signals**: Due to a (partial) blockade behind a valve, the system diagnosis signals *maintenance* for various assets. However, the self-diagnosis of intelligent field devices does not indicate a fault. The conflicting signals are collected by the PAM system, and the fault detection disambiguates the signals and identifies the root cause. This information is transmitted to the mobile information system.
5. **Faulty operation - multiple errors**: The system diagnosis and vibration monitoring detect vibrations in various assets and signals for this maintenance. The signals are collected by the PAM system, and the fault detection recognizes that there are indeed several errors. Thus, all faults are transmitted to the mobile information system.

3.3. Function allocation to the mobile apps

According to the workflow model presented in section 2.2, the mobile information system can be composed of four orchestrated apps. Each app supports one task in the workflow model, and can be reused in other mobile information systems with comparable functionality or used separately. The apps provide the following functionality:

1. The **Identification** app provides an overview of the status of the available assets in list form; it allows the selection of a faulty asset for subsequent therapy.
2. The **P&I_Diagram** app gives an overview of the status of the available assets by means of a piping and instrumentation diagram (P&ID); it allows the selection of a faulty asset for subsequent therapy directly from the diagram.
3. The **Therapy** app provides diagnosis results and therapeutic measures proposed by the PAM system. The user can give feedback about the success or failure of the measures that were carried out.
4. The **Time_Series** app provides relevant process values and their history through diagrams; it enables the user to perform a detailed analysis.

The necessary information for system diagnosis is provided by various source systems and collected by the PAM system. The PAM system, in particular the fault detection, analyzes the available data in order to generate a consistent, correct, and complete assessment of the current status of the plant. The mobile information system receives the data from the PAM system and makes it available in an appropriate user interface. The engineering data of the plant are stored in the planning tools, which usually provide appropriate import/export interfaces. In this case, the COMOS integrated engineering tool was used, which provides XML-based interfaces using the Enterprise Server Technique. Process data are available directly from the Process Control System (PCS), in this case SIMATIC PCS 7, which provides an OPC DA server to retrieve current and historical process values. SIMATIC PCS 7 can also be used to access a SIMATIC Process Device Manager (PDM) or an intelligent field device.

3.4. User interface concept

The user interface of the presented prototype was designed according to the design guidelines in the DIN EN ISO 9241 [4] series of standards and the general design principles according to Nielsen [5], Sarodnick and Brau [6], Shneiderman [7], and Tarasewich, Gong, and Nah [8]. Furthermore, domain-specific standards in the field of control engineering, in particular DIN 33414-4 [9] and VDI/VDE 3699-3 [10] were considered for the design. A tablet PC with a seven-inch screen and Google Android OS 4.0 served as target system. Therefore, the layout design of the apps follows the Android Design Guidelines [11]. The primary design goal for the mobile information system was to provide the available information “in a form understandable to the user and adapted to the context of use”, and “as quickly, as is required for a decision, action, or further processing” [1].

The user interface is kept consistent for all developed apps to ensure conformity with user expectations. Since processing of detailed information on a mobile device in an industrial context of use is cognitively highly demanding, data are aggregated and reduced, conforming to the task at hand. Thus, users can quickly and easily assess the status of the system and perform appropriate therapeutic measures. The mobile device is operated with the touch screen and the existing hardware keys. Input patterns also follow the Android Design Guidelines [11]. QR codes can be captured using the device camera.

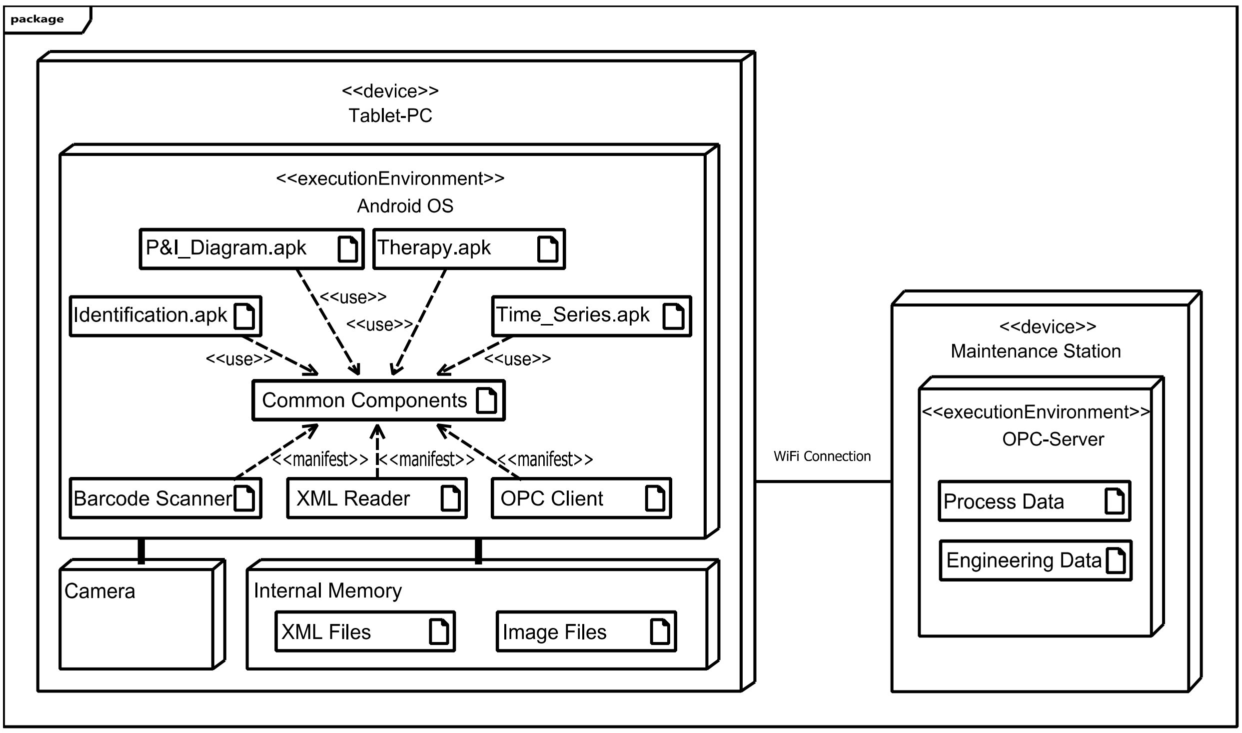

Figure 3. Deployment model for the proposed app-based mobile information system.

4. System design and implementation

4.1. System architecture

The mobile information system consists of six apps in total with five apps providing a user interface and one serving as a service provider. The apps call each other using the *Android OS*-specific *Intent mechanism*. This way, both system apps and self-developed apps can be integrated into the system. The user can also be offered a choice between several appropriate apps. The complete system architecture is illustrated in Figure 3. As can be seen, the mobile information system consists of the four apps – *Identification*, *P&I_Diagram*, *Time_Series*, and *Therapy* – which were introduced in section 3.3., and two support apps. The *Common_Components* app serves as content provider and can be used by all apps. It provides access to a remote OPC server and an XML-processor for received XML files, for instance from the COMOS interface. A *Barcode Scanner* app enables other apps to read barcodes and matrix codes. The latter app was retrieved from the Google Play Store and integrated into the mobile information system using an *Intent integrator* which also resides in the *Common_Components* app. Currently, the mobile information system requires a permanent wireless network connection to the PAM system.

4.2. Structure and layout design of the UI

The structural layout of the user interface is shown in Figure 4. It consists of five areas, four of them permanently available and one displayed if required. The status bar provides the company logo, the name of the application, and the currently registered user. The action bar displays all available actions in the current view. The navigation area visualizes the workflow and allows manual switching between apps. The working area provides application-specific maintenance data for monitoring, diagnosis, and therapy. The message bar moves from the bottom side into the working area when needed and provides system feedback. The structural layout was mandatory for all self-developed apps.

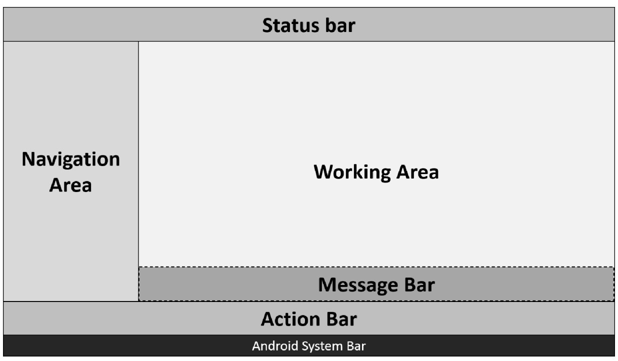

Figure 4. Structural layout of all apps.

For each structural element, an own *Android Fragment* was used. The same fragments behave equally in all apps they are used in. The mobile information system is operated with four possible inputs. A single short tap selects an item. A single long or double short tap triggers an action on the selected item (two-step selection), as does a single short tap on an already-selected item. In graphical elements, a double short tap is also used to change the zoom level. Scrolling through the list items and graphical elements are used to move the corresponding element. Multi-finger gestures are not used.

The *Identification* app shown in Figure 5 provides a textual list in the working area, with a description and the current status of all available assets. Filter and selection functions allow users to quickly get an overview of the current status of the plant. Each list entry contains the name, plant identifier, and status of the asset. If the status of the asset is "Alarm", it is highlighted by a similar text and a red bar at the right edge of the list item. The *Therapy* app for a faulty asset can be started by selecting the corresponding list item. Filter functions as well as the QR-code reader are available in the action bar. In case of reading a QR code which identifies an asset, the corresponding asset is selected in the list.

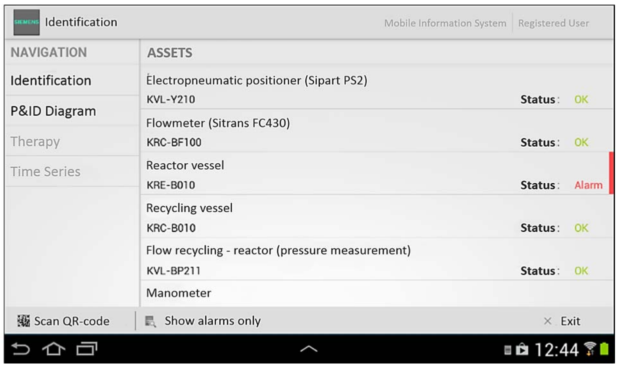

Figure 5. Identification app allows for easy identification of faulty assets.

The *P&I_Diagram* app shown in Figure 6 provides a graphical representation of the available assets by means of a piping and instrumentation (P&I) diagram in the working area. Based on their current state, assets are shown in either green ("OK") or red ("Alarm"). Two zoom levels are available: overview and detail view. Users can thus easily get a visual overview of the assets and their states. Double-tapping zooms into the detail view of the chosen section and allows selection of the assets. For faulty assets, the *Therapy* app is started by long single tapping an unselected asset or short single tapping on a selected asset. Using the action bar in the detail view, a small window can be displayed in the upper-left corner, showing the entire P&I diagram in order to simplify navigation in the diagram.

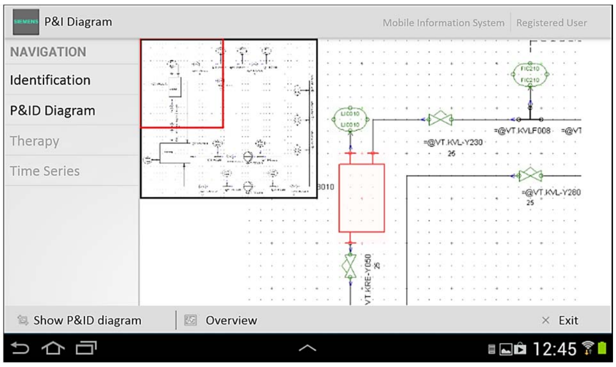

Figure 6. P&I_Diagram app provides diagnostic information embedded into the diagram.

The *Therapy* app shown in Figure 7 provides a textual description of the asset fault and recommendations for therapeutic measures which are arranged in a tab bar in the working area. Measures are sorted according to their probability of success. Once a measure has been selected by the user, the message bar appears at the bottom of the working area. After completion of the measure, the user can give feedback about whether the therapy was successful or not. In case of success, the user returns to the *Identification* app. Otherwise, the next measure can be selected. A button in the action bar allows the user to cancel a therapy. Cancellation must be confirmed in the message bar.

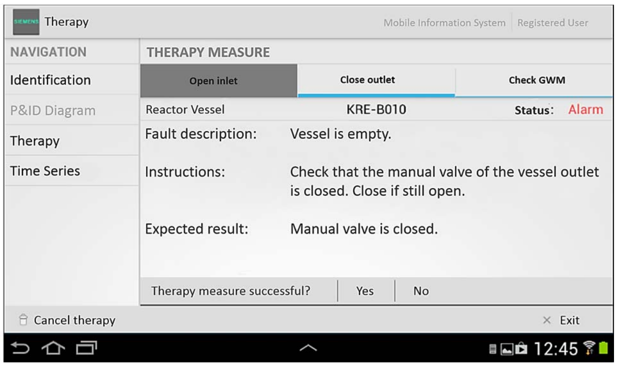

Figure 7. Therapy app gives users step-by-step instructions of possible therapies.

The *Time_Series* app shown in Figure 8 provides a series of process values via a bar chart. First, the process value of interest can be selected in the working area. The app then automatically acquires the process values from the OPC server and shows the resulting time series. The ranges are adjusted automatically. Given limits can be shown as well. Violations of the limits are highlighted by a red color change. The diagram can be reset using the action bar, which deletes previous measures and restarts acquisition and visualization. The small overview image from the *P&I_Diagram* app can also be used in this app to check if the displayed process value caused any error signals.

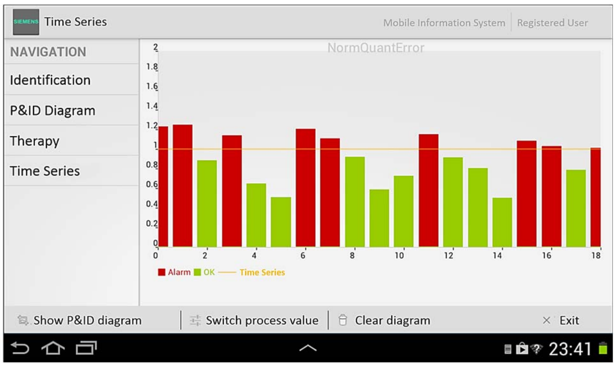

Figure 8. Time_Series app provides access to process values of the asset.

The *Barcode Scanner* app continuously captures QR codes with the device camera and returns IDs to the calling app. This is a third-party app that does not follow the design guidelines of the self-developed apps. Instead, the camera image is shown in full screen. Interaction follows the usual conventions for apps for camera control.

For the navigation design, a process-oriented approach was chosen, following the workflow model introduced in section 2.2. When starting the mobile information system, the user enters the *Identification* app. By selecting an asset, the user proceeds with the *Therapy* app. As an alternative, the user can also manually switch to the *P&I_Diagram* app in the navigation area and select an asset there, or read the QR code of the asset of interest. In the *Therapy* app, the user can choose from different recommendations for therapeutic measures and return the results of the therapy. With successful treatment, the user automatically returns to the *Identification* app or the *P&I_Diagram* app, depending on which one was the calling app. From the *Therapy* app, the user can also manually switch to the *Time_Series* app and view the trends of relevant process values of the asset of interest.

5. System evaluation and discussion

5.1. Experimental design

A focus group workshop [12] was conducted during which ten experts in the application domain and skilled user interface designers evaluated the mobile information system. Objectives of the workshop were to assess the suitability of the prototype for the given context of use, the identification of potentials for improvement and extension, as well as the identification of further applications for app-based mobile information systems. As stimulus, the reference scenarios were executed in the *Siemens Smart Automation Research Facility, Karlsruhe, Germany*. Subsequently, four question blocks were discussed: (QB 1) context analysis, (QB 2) evaluation of the concept for app-based system diagnosis, (QB 3) extension and integration aspects, and (QB 4) potential analysis. Data were recorded with handwritten notes and audio recording. The entire workshop lasted 170 minutes.

5.2. Results and discussion

For the interpretation of the workshop results, the *summary of central discussion aspects* method was applied [12]. The first step of this method was to identify the main aspects of discussion, based on the frequency and relevance of the statements. All statements were then categorized according to these aspects, and the content was reduced by eliminating redundant information. In addition, citations were selected to emphasize the key aspects. The result was a structured and aggregated collection of statements, sorted by the central aspects of the discussion.

The main aspect of QB 1 was the decreasing level of qualification in conjunction with an increasing fluctuation of future workers, resulting in an increasing need for support and supervisory control by mobile IT. The second aspect was the increasing demand for multi-vendor services for the assets throughout their entire lifecycle. The PAM system can serve as an information hub and central point of access to data for the mobile information system. This concept has proved suitable.

The main aspect of QB 2 was the preprocessing and presentation of faulty states, for which an additional fault history and an automated evaluation of the therapeutic success were proposed. Potential extensions could be the identification of assets with RFID, the navigation to assets in large systems, the integration of electronic shift books, and the integration of an EDD interpreter. The main aspect of QB 3 was the issue of a successful integration of the Google Android target platform in the IT systems of the plant. Here, the use of service-oriented interfaces (such as OPC-UA) was recommended. In QB 4, on-site commissioning, lifecycle monitoring, and operator training in the system were identified as potential additional applications in addition to the plant diagnosis. Thus, the enormous discrepancy between the lifetime of mobile devices and the lifetime of the plant, as well as the flexible adaptation of the mobile information system to varying workflows represent significant technical challenges.

6. Conclusion and outlook

This paper, has presented the potential of integrated services for the app-based system diagnosis with mobile information systems. It has analyzed the typical tasks and the context of mobile IT-supported plant diagnosis, and has presented a prototype of an app-based mobile information system for this purpose. The results have been discussed and generalized as part of a focus group workshop. The advantages of the proposed concept have been clearly worked out.

The next step is the creation of a development process and a technical framework for mobile information systems that is sufficiently efficient and sustainable, and also flexible enough to meet the demands of a long-term application domain in a highly dynamic technology landscape – particularly with respect to extensibility and adaptability of mobile information systems to varying work processes in long-term use. Initial research projects already provide promising approaches to these challenges [13]. Flexible data management using semantic networks, automated orchestration of individual apps to app networks on the basis of business process models, and the model-based generation of user interfaces are core concepts for future solutions [3].

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