Remote Engineering Solutions
for Industrial Maintenance

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Abstract — This paper presents the NDT (Non Destructive Testing) concept and process in combination with the OMA system (Online Maintenance Assistance) for remote service support. The system is used to support complex maintenance processes by assistance from remote experts in an online video conference with integration to inspection workflow and devices. The system operates on Commercial of the Shelf (COTS) hardware and in standard Web Browsers. It allows flexible integration into the enterprise IT e.g. in existing role and authentication concepts and is compliant to standard enterprise security regulations.

Keywords — Non Destructive Testing; NDT; Online Maintenance Assistance; Remote Control; Workflow Support; Ultrasonic Testing; Maintenance; Audio; Video; Remote Service; Expert Guidance; Workflow Optimisation

I. INTRODUCTION

Aircraft maintenance services are highlighted by many industries. The number of maintenance operations increase with the number of aircrafts in service. Nowadays, Non Destructive Testing (NDT) operators and experts are lacking. It is sometimes necessary to send an expert on-site to investigate, if an aircraft is ready to fly or not. These operational costs could be decreased thanks to a remote maintenance mean. A way of improving operations maintenance is investigated by Airbus, the University of Applied Sciences Osnabrück, Testia and EADS Innovation Works. This kind of enhanced NDT enables a remote expert to pilot an inexperienced operator on-site to do the NDT operations. This working group is proposing a technique of advanced ultrasonic data solutions in the context of remote maintenance, detection and quantification of damage on aircraft structures. The objectives are:

- Enabling full or partial control of a remote ultrasonic inspection
- Enabling a remote expertise function in order to judge the acceptability of the identified damage or its reparability (suggestion of a repair), or to give restrictive flight instructions

The general objective is to improve aircraft availability with minimum logistical means, manpower and resources. Therefore the members of the working group create tools for an optimised work procedure, which should be combined to a comprehensive solution.

II. RELATED PROJECTS

The work in [2][3][4][5] describes the early concepts of an aircraft maintenance solution operating on touch panels. While [6] focusses on interactive multimedia support for tele-engineering, [7] addresses the issue with remote control of distributed equipment in real time and introduces an own model to address given problems in this area. In [9], as an example for a NGN service, a web based approach for sharing documents in an online conference is illustrated. [10][11][12] describes an enhanced system to perform knowledge based mobile remote inspections called OMA [13] system (Online Maintenance Assistance). [14][15] describe an integrated approach to provide access to different ultrasonic systems within one software instead of using multiple manufacturer-specific versions.

III. REMOTE ENGINEERING AND MEASUREMENT AS AN EXAMPLE

In Remote Engineering, technical tasks are carried out partially or completely from a remote location. A typical task, which requires the presence of an operator, can be found in maintenance. Inspection tasks are one common example for maintenance processes. NDT is an inspection method to ensure that health of structure components is reliable. Many kinds of inspection techniques exist e.g. visual, x-ray, penetrant testing, eddy currents, ultrasonic, etc. The objective is to perform the inspection of a structure without altering it. In the aerospace industry, NDT is part of the fabrication and also maintenance processes of structural components. This paper focusses on the
ultrasonic technique. This technique utilises high frequency (MHz) sound wave propagation. An ultrasonic piezoelectric transducer is excited by the Smart NDT Tools to produce an ultrasonic wave into the material on which the transducer is applied on. If the wave meets a discontinuity in the material, the echo measured by the transducer will be different from the echo measured on a defect free zone. Such discontinuities can be delamination, cracks, porosities, etc.

IV. SMART NDT TOOLS AND NDTKIT CONCEPTS

EADS Innovation Works and Testia did research for several years on the concept of the Smart NDT Tools. The tools are NDT devices designed like USB computer peripherals, which makes it possible to integrate many additional components, which deliver several functions. This hardware can obviously be useful for the maintenance. This was shown within the framework of the INDET project in the 5th Research & Development Framework Program of the European Commission and also presented as publications at national or international conferences [14][15]. The objective of these means is to provide low cost, portable, versatile and easy to use NDT solutions shown in Fig. 1.

Smart NDT Tools allow the NDT operator to focus on the diagnosis, to increase NDT operation traceability at company level, and to enable aircraft manufacturers for proposing its products with better maintainability. NDTkit is an innovative software package dedicated to Non Destructive Testing ultrasonic data analysis and automatic diagnosis. It has been developed to respond to aerospace composite production needs for cycle and cost reduction, but it is also very helpful for maintenance operations, when a diagnosis on an in-service aircraft structure is requested. The industrial version of NDTkit is now distributed by Testia under the name Ultis [16]. Based on application-specific modules with built-in assisted diagnosis, they can be used by non-expert operators in a basic mode and specialists in an expert mode. They offer e.g. dedicated tools for thickness measurement, corrosion detection or drilled holes. In parallel, EADS Innovation Works and Testia have also worked together for over ten years on Smart NDT Tools, an ultrasonic signals post-processing software [17] shown in Fig. 2 and Fig. 3.

V. REMOTE MAINTENANCE CONCEPT

The OMA system is used for visual assistance and remote support of industrial service. It is designed for collaboration between mobile operators and supporting experts. The focus of this system is to improve the maintenance of complex industrial equipment and to support technical departments, suppliers and manufactures to cooperate in several areas:

- Remote visual NDT inspection
- Context aware maintenance of complex equipment
- Damage inspection
- Structure and material testing
- Remote data acquisition

In an OMA session an operator at the maintenance site needs support from an expert in a service centre. The operator carries a (ruggedised) Tablet PC with an attached camera and a mobile phone. The Tablet PC is connected to the company’s or a public network through a wireless connection, such as Wi-Fi, EDGE, UMTS or LTE. After the login, the operator and the expert are connected to the OMA system. The operator can call the expert to establish a connection. By accepting the call, a live video connection is established between both sides. A typical usage scenario is shown in Fig. 4.

Fig. 1. Multiplexed 8*32phased array ultrasonic Smart Tools associated to a rugged Panasonic CFH2 Tablet

Fig. 2. The general user interface of the Smart NDT Tools

Fig. 3. The dedicated module for drilled holes
One of main features of OMA is the possibility to connect measuring devices with a video output and to transmit the live signal to the remote expert. Sometimes it is necessary to view the test process itself and the results of the measuring devices simultaneously. Both streams are transferred at the same time and the expert receives them in a synchronised view.

Potential inputs for the video signal are:
- A software module which allows capturing the screen of the computer.
- The VGA screen output that can be captured using additional hardware.
- Other analogue video outputs, which are often the best solution to integrate older equipment.
- If no video output exists, a second video camera can capture the screen activities.

For very dynamic diagrams or in cases where an installation of software modules is not allowed due to restrictions, a remote viewing function using the described VGA or analogue video input can be used. The acquired signal is compressed and transmitted by means of a second video channel. Beside the option to stream multiple synchronised video sources, the expert has also the possibility to control the connected equipment remotely. For this, the equipment has to support one of the following modes:

- Type I: The device is connected to the network and implements a remote protocol for desktop sharing e.g. RFB [20] or RDP [22] or other protocols. Depending on the signal characteristics, the compression parameters are adapted to reach the best Quality-of-Experience (QoE) at the observers’ side.
- Type II: The measuring device is connected and controlled with a PC software client and the operating system supports a remote protocol for desktop sharing.

In the first case the remote expert connects directly to the device and controls it via OMA. In the second case the remote expert connects to the PC client of the operator by using a remote desktop protocol and then gets access to the software of the device.

For interactive cooperation in remote service sessions it is possible to create, share and manipulate camera snapshots. Both sides can annotate important parts of images with pointers and freeform lines in a shared virtual workspace. An upload function allows editing and preparing important results before establishing a conference. To combine distributed competences OMA comes with a multi-conference feature to invite additional experts to the remote service session. By combining distributed competences, most complicated cases can be solved efficiently.

VI. REMOTE SECURITY ARCHITECTURE

To secure the connection a concept has been developed, which consists of several security layers. It can easily be integrated into an enterprise structure and is shown in Fig. 5.

A. The Group/User Management Layer

The highest/forth layer is the Group/User Management Layer. Generally OMA users need to have an account, which can be linked to an enterprise Group/User Management system (e.g. LDAP, Active Directory, Siteminder). To give access to completely nomadic users, the administrator can create a temporary account. The nomadic user can then use a smsTAN to authenticate with the system, which is send out automatically over the public cellular network to his phone.

B. Video, remote control and data layer

The third layer enables the specified main features video and remote control. Additionally it enables the data and audio connection between the participants.

To add enhanced security to the remote control, two additional passwords and a separate data tunnel inside the encrypted channel are used. The first password is used, when the separate data channel is being established. The software component displays a six-digit key, which is communicated via speech. In addition, the remote control component allows access only, if its (second) password is inserted. After the connection is established, the screen data is transported inside the encrypted channel. In the future it is planned to limit the control to certain windows/applications. Fig. 6 shows the sequence diagram of this scenario. A universal abstract data connection allows the transfer of snapshots and the exchange of whiteboard annotations. Further data services like a document conference (see below) will also be based on it.
To achieve a minimised delay and to guarantee the best possible voice/video quality, the audio is transported separately from the data channel by using the Public Switched Telephone Network (PSTN). After establishing an OMA conference the system initiates a separate phone call between the participants by using a telecommunication service provider.

C. Transport/Tunnel Layer

The second layer is used for transport of the overlying layer. Depending on the type of network connection it operates in the transport or tunnel mode. Within enterprises and other connections without firewall restrictions, the transport mode is used. This guarantees the best transmission with minimised overhead. When connections cross enterprise boundaries, firewalls are often blocking several TCP/IP ports and protocols making the transport mode unusable. To enable communication in this case, the layer is operated in the tunnel mode by using the standard HTTP(S) port 443 which is typically available.

This layer was implemented by enhancing a standard commercial video conferencing framework [23]. It covers some standard modules of a web based conferencing solution and a generic and encrypted data channel. Therefore the tunnel mode operates by using an encrypted multi-protocol streaming [24].

VII. REMOTE CONTROL OF SMART NDT TOOLS

One of the goals during the integration process was to determine, whether the OMA integration provides advantages for remote control of NDT. There are several standard tools for remote control of PC based software like Smart NDT Tools. By expert interviews the following requirements were identified:

a. At least 70% of the screen should be used for video. The other 30% for the control components.

b. Viewing two video signals at the same time should be possible to see the NDT measurements and the inspection location simultaneously.

c. Support of digital and analogue video input via adapter.

d. Support for remote maintenance inspection including a remote monitoring of results from measurement equipment.

e. Integration with enterprise’s IT esp. with authentication and group/role systems like LDAP, Active Directory etc.

f. Adaptable to corporate identity.

g. Extensible with additional functions.

In addition to OMA, the other products available on the market, which are potentially suitable for remote maintenance as well, are listed in Tab. 1. The Table illustrates the products and evaluate if they meets the set requirements with “fulfilled (+)”, “partially fulfilled (o)” and “not fulfilled (-)” and shows the suitability of the systems for Remote Engineering.

VIII. REMOTE MAINTENANCE CONCEPT

It was noted that OMA meets the requirements listed in the previous chapter. Next the preliminary findings in this paper are combined to a solution. In detail these are the NDT operations previously described and the usage of the Smart NDT Tools to perform such processes.

A trained NDT operator needs to detect some corrosion and/or impacts on an aircraft’s wing. He has difficulties to perform cartography of the part with the default settings recorded on the system and does not have the knowledge to change them. Fig. 7 illustrates the workflow in this case.

1. The operator connects to OMA and calls the Expert.
2. The audio connection is automatically established.
3. The operator shows the whole area with the two video streams. One fixed video camera records the whole wing, while another wireless video camera is used to focus on details of the part and on the ultrasonic system (probe and acquisition unit).

4. The expert takes control of the ultrasonic software and changes the settings appropriately (delay laws, frequency, differential gain…).

5. The inspection is performed. The operator moves the probe on the wing area. The expert can observe the probe (with the video stream) and the signal (with the remote mode) at the same time.

6. The operator and the expert proceed to the diagnosis. If needed, the expert can take control of utilities to analyse the results, calculate the surface of the defects and detect porosity.

7. End of communication.

Ultis’ Smart NDT Tools were designed to operate on small Tablet PCs. Like OMA, the software was optimised for low screen resolutions and the buttons were designed for finger/touch operation.

IX. POSSIBILITIES TO EXTEND REMOTE CONTROL SESSIONS

This combination of the Smart NDT Tools and OMA brings up many new additional possibilities helping in maintenance scenarios. Typically an inspection follows a specific context which contains e.g. meta data or technical documents. This context can be used in remote inspection scenarios to simplify the inspection workflow even more.

In general the context of an inspection includes:

- The type of object which is inspected and is characteristics
- The type of the measurement equipment and its technical properties
- (Maintenance) organisation and the current location
- Responsible inspector and his affiliation
- Associated user model including network connectivity and the device executing OMA (e.g. a Tablet PC)
- Technical documents / manuals / files (PDFs, DOCs, images, configuration files)
- (Previously) created associated inspection Reports

After determining the given context data above, it has been analysed how this data can be utilised. There are typically manuals and technical documentations available for the inspected object and the measurement equipment.

Additional meta data can be obtained from the location and the inspection history, which is personal to the operator or specific to the inspected object. Examples for the inspection history are filled reports of previous inspections. With the given maintenance context, specific documents can be preselected automatically for an easy access. In a remote maintenance session it can be useful to view such documents together. For this it is possible to use the joint document viewer of the OMA system. The collaboration service contains an image viewer including a synchronised view of a document for the participants (see Fig. 8). This allows to discuss maintenance situations and documents.

X. RESULTS

The successful integration of NDT into OMA can be seen as a starting point for the integration of further systems. In parallel, a new security concept with reduced user interaction and compliant to the requirements of large enterprises was introduced.

The integration of a general Remote Engineering system with application specific systems shows a good potential to improve the workflow in maintenance processes. The authors are interested in other application scenarios, which could benefit from integrated Remote Engineering.

In spring 2013, several tests were performed between Singapore (expert) and Toulouse, France (operator) and between Osnabrueck, Germany and Stanford, CA, USA. By using OMA, the experts were able to successfully remotely control the operators Smart NDT Tools over a distance of <10000 km.

XI. OUTLOOK

Ongoing research will address automatic adaptation of compression parameters of all signals (video, screen) to different mobile networks using prior knowledge. In general, compression and bandwidth management will be optimized to
further reduce of network utilisation, which requires about 150kBit/s for parallel remote control and a slow video stream.

Further inspection and monitoring systems are currently being integrated. An example is a Structural Health Monitoring system, which allows the interpretation and post-processing of active sensor networks used in airplanes and building structures.

It is planned to replace the existing video conferencing framework by camera, video and communication support currently introduced to HTML5 [25]. However, the standard is not finished yet and web browsers are slow in integrating the required additional features. It is also foreseeable, that industrial companies will limit the choice of new web browsers making the current approach necessary for some more time.

The extension of the document sharing function will provide pre-filled inspection reports using available context data.

Another possible and important scenario to extend remote control sessions is the usage of Augmented Reality features. Current research of the project focuses on providing a 3D model of a real world inspection object.

The integration of Smartphones as remote clients for remote inspection is part of another work.

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