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The Adaptive Management and Security System for Maintenance and Teleoperation of Industrial Robots ⋆

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Abstract: Within the project "MainTelRob", we research the opportunity to support maintenance tasks over the Internet. We identified, that this requires a specific combination of services, e.g., video streaming, communication services and data transfer. By using the public Internet emerges the need to transfer all data in a secure and confidential way. However, there is no framework to provide these functionalities out of the box. This is why we developed the Adaptive Management and Security System (AMS), a multi-layer architecture and framework providing the building blocks to create tele-maintenance applications. In addition, the AMS measures the quality of an end-to-end connection over the Internet and adjusts the amount of data sent by the services, in order to use the given connection efficiently. In this publication, we provide a short overview of the state of the art and subsequently explain the architecture, as well as the structure and tasks addressed by each layer. We also provide insight into the first tests, in which a prototype implementation of the AMS was used to teleoperate an industrial robot over the public Internet.

Keywords: Data streams, Data flow analysis, Network analyzers, Network identification, Data compression, Data Transmission, System security, Human-machine interface

1. INTRODUCTION

In the current stage of globalization, new production plants are set up in emerging nations. The specialized machinery needed for these factories is often produced by special purpose machinery manufacturers residing in Europe or Northern America. The maintenance and repair of the industrial robots inside the factories require highly trained personnel, who are not always available on location. Here, Industrial internet solutions like telemaintenance can help bridge the gap. On the one hand, they enable manufacturers to provide assistance to their customers over the Internet. Removing the need to travel shall help to reduce downtimes in cases of breakdowns, and also create new business models and markets for the manufacturers. On the other hand, these solutions can, in combination with multimedia technologies, facilitate communication and transfer of knowledge between experts in the highly industrialized countries and the local repair personnel in emerging nations.

Within this publication, we regard the following use-case: There is a manufacturer's *telemaintenance center* from which an engineer, the *expert*, provides technical expertise to the local repair personnel, the *service technicians*, at the *facility*. The facility contains machines, a robot and telemaintenance equipment: a computer, multiple cameras for video streaming and a mobile device. Center and facility are connected over the Internet.

The main prerequisite is to provide the expert with a good view of the situation on-site. This insight can be offered by a specifically orchestrated combination of services: Remote access to machinery data in combination with video streaming and communication services, e.g. text chat and Voice-over-IP (VoIP). In addition, visual Augmented Reality (AR) overlays inserted into the camera pictures or video view are used to provide guidance. As the targeted environment includes the *service technician* repairing the machinery on-site, the industrial telemaintenance system should additionally provide modern means of communication. To enable the smooth operation of these desired services, four major challenges need to be addressed in the system: First, teleoperation needs modeling and remote control of industrial manipulators. Second, the teleoperation integrates humans in the control loop. There are no existing models for the human teleoperator, yet. To address this issue, we propose a strict user-centered approach. Third, there are different prevalent end user access technologies to the Internet, which differ in their expectable Quality of Service (QoS). Hence, our framework must be able to detect the characteristics of the provided end-to-end connection, and decide which services are ap-

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plicable. Fourth, it needs to orchestrate the transmission of data streams from multiple sources through a secured connection. This includes adapting the services to connection quality changes during ongoing telemaintenance sessions. In the next paragraph, we give a short survey of the state of the art in telemaintenance, while in the remainder of this publication, we present our approaches to the aforementioned challenges and offer insight into the first prototype tests.

2. STATE OF THE ART

The term telemaintenance refers to the integration of computer science and communication technologies into the maintenance strategy (Chowdhury and Akram (2011); Mouzoune and Taibi (2014)). We understand the challenges in telemaintenance as a combination of teleoperation and remote condition monitoring. In this publication, we focus on the teleoperation aspect.

In general, "a robotic teleoperation system allows to reproduce the actions of a human operator and to interact physically with objects and environments placed at a distance" (Melchiorri (2014)). Hence, it can be seen as a subcategory of human supervisory control (Sheridan (1992)). For example, visual feedback can provide information about the state of an industrial robot to the human operator in the control loop. For an overview of applications see Lichiardopol (2007); in this paper, we focus on teleoperation of industrial robots, which has been of early (Cederberg et al. (2002)) and late (Moradi Dalvand and Nahavandi (2014)) research interest. The application for teleoperation of industrial robots lies mainly in the context of hazardous environments (Pegman et al. (2006)), but in our scenario we cover maintenance scenarios similar to those for tunneling machines covered in David et al. (2014). As we aim to facilitate teleoperation via the Internet, the control perspective with time delay over the Internet (Slama et al. (2007)) has to be integrated as much as human perception of time delays (Vozar and Tilbury (2014)). There have been several proposals for teleoperation architectures, e.g. in Gray et al. (2007); Ortega et al. (2014). Our project partner Kuka Industries, former Reis Robotics, provides an architecture that includes basic teleoperation functionalities. However, there is a need for an enhanced architecture that also includes further services needed for human supervisory control, such as synchronized video feedback. The closest related work has been provided by Jia (2014), who covers multimedia streams, too (Elhajj et al. (2011)), but does not include other kinds of data needed for maintenance. To our best knowledge, there is no integrated teleoperation and maintenance architecture yet.

3. AMS ARCHITECTURE

The Adaptive Management and Security System (AMS) is designed as a modular multi-layer architecture, in which each layer provides functions for the layer above. Each layer comprises a manager component exchanging control information with the managers of adjacent layers. In the following sections, we explain the four layers of the AMS architecture top-down, as depicted in Fig. 1. We begin with the *Interaction Layer*, on which the work flows to be supported are specified. Subsequently, the *Application Layer* and its user interface concepts are explained. This is followed by an overview of the *Service Layer* providing the underlying functionality for the Application Layer. In the last subsection, we survey the *Telematics Connections Layer*, which resides, as depicted, above the OSI transport layer. It provides a single entry point into the center or facility for the secured data transmission.

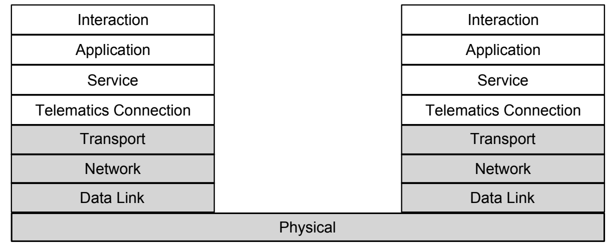

Fig. 1. Layers of the AMS architecture on top of the OSI transport layer

3.1 Interaction Layer

Top-down, the first layer of our architecture is the *Interaction Layer*, which follows an user-centric design approach. This layer serves as an adaption layer between our architecture and the business processes at the facility and center. We performed a broad contextual analysis involving interviews with managers, engineers, repair personnel and production workers. Based thereon, we modelled the workflows of experts and service technicians and identified use-cases and teleoperation scenarios (Sittner et al. (2013)).

For the *AMS* architecture teleoperation (as defined in Sheridan (1992)) is the key scenario. Here, the control loop is closed through the human and the control computer. We extend the model (as in Fig. 2) by the local *service technician*, which has a very important role due to safety issues. In Europe teleoperation of an industrial robot in an automation facility is only permitted if there is a local supervisor present. During our experiments, this service technician always has to press the dead man's switch to enable the external control. Therefore, he also performs human supervisory control and mirrors the conceptual structure of the main teleoperator (the expert).

As it can be derived from Fig. 2, communication mostly takes place between the expert and the service technician. Typical cases for maintenance calls are unknown problems at the production line, which need to be solved as quickly as possible. The expert knows the technical details of the robot quite well, but needs to get an impression of the periphery and the exact configuration of the robot in order to be able to analyze the failure. The *AMS* technology is designed especially for those questions by providing several cameras at the production line and a mobile camera in the tablet computer which the service technician carries as a *Local Human Interactive System* which can also serve as robot teach pendant (Aschenbrenner et al. (2014)).

3.2 Application Layer

The *Application Layer* provides the graphical user interface (GUI) to the user. This is also where the vendor