# A Multifunctional Telemedicine System for Pre-hospital Emergency Medical Services

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***Abstract*—The paper presents the design and architecture of a multifunctional telemedicine system for real-time teleconsultation in pre-hospital emergency medical services (EMS). The application of telemedicine has shown to improve patient treatment quality and efficiency in various settings. Still, its use by pre-hospital EMS is lacking. Current technical, normative standards do not provide a sufficient framework in order to design a multifunctional telemedicine system for teleconsultation in pre-hospital EMS. Starting with a use-case driven requirements analysis, a telemedicine system usable in this setting is designed, realized and currently in use for evaluation by selected German EMS departments. This system uses commercial off-the-shelf medical devices, custom devices for communication and an individual system architecture, integrating the heterogeneous components as required by the defined use-cases.**

***Keywords*-telemedicine; teleconsultation; EMS; system architecture;**

## I. INTRODUCTION

Specialized telemedical applications have shown to improve patient care in different inner-clinical settings and its benefit has already been demonstrated for various preclinical uses [1]–[3]. Despite the rapid evolution of personal mobile communication devices with its current manifestation of power-full computing devices like smartphones, tablets or even wearable computing-devices [4], the use of telemedicine in pre-hospital environment is still in its infants.

Research efforts have been undertaken to develop multifunctional telemedicine systems which enable emergency medical service (EMS) teams to perform teleconsultation with remote specialists or more broad treatment facilities like hospitals [5]–[8]. These projects aim at creating pervasive assistance systems using different combinations of audio and video communication, transmission of biomedical data and access to existing medical patient records.

The above systems do only allow teleconsultation from inside the ambulance and the additional devices they introduce do not integrate well into commonly used, existing EMS team equipment. System architectures are proposed which require big parts of the created infrastructure to be classified as a medical device and as such pose a high burden on their realization from a regulatory point of view. Another concern neglected by these approaches is the user role which serves a teleconsultation request and thus guides the EMS team during patient treatment or supports them otherwise.

The German research project TemRas has developed the multifunctional telemedicine systems, described in this paper, which allows on-scene EMS teams to consult a dedicated EMS physician, hereafter called tele-EMS-physician, on duty in a teleconsultation center [9], [10]. This system's novelty is its level of integration into the EMS team's equipment and ease of use, enabling teleconsultation not only inside or close to the ambulance but from every location with suitable mobile network coverage, like inside a patient's home. On August 1st, 2012 the system was taken into service with initially three ambulances connected for teleconsultation in regular EMS missions. After a ramp-up during August, six ambulances from different EMS departments were connected to the system and operational since the beginning of September. Until October 4th, 60 successful teleconsultations have been performed using the presented system.

## II. METHOD

The system's design was created in a mainly linear process with strong user participation and close feedback loops between engineers and users. The original intent of a true iterative, agile development process could not be realized for the whole system, but was instead used to develop the individual user facing software-components. The whole process was agile in that it was not artifact centered and no sign-offs were performed like described by the waterfall-process [11]. Rather, all process activities were focused on the final system being usable for teleconsultation and fulfilling necessary safety requirements. Documents were only generated as basis for further discussion and swapping functionality in and out of development focus was possible during the whole process.

Involved into the system's design process was a team of experienced emergency physicians, most of which had already been working as tele-EMS-physicians during the former project Med-on-@ix [12]. On one hand they are users to the system as tele-EMS-physician, on the other hand they were user representatives for the on-scene EMS personnel. The participating physicians had used the system on-scene during Med-on-@ix evaluation and had regular contact to

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relevant EMS personnel during their work as regular EMS physicians. The system design itself was created by a small team of engineers which also realized most of the currently available prototype; other parts were sourced out to specialized hardware manufacturers.

The emergency physicians defined four main scenarios for the telemedicine system's usage. Together the emergency physicians and engineers described and detailed 21 use-cases as functional requirements descriptions to guide the system's design. These use-cases define which services the system has to provide in order to be usable for the main scenarios and roughly describe their usage and inter-relationship. The use-case's descriptions contain additional non-functional requirements like demands regarding robustness, reliability and data security. Service interface specifications were created in close iterations by the engineers and user facing functionality was created in a mockup-driven process with continuous user involvement. As single service's functionalities were available, users were involved in initial testing and requirements and further design was adjusted according to their feed-back.

Integration and system-tests were performed as early as possible in the process to unveil integration issues, missing necessary and planed unnecessary functionality early on. The early system-tests allowed for a good judgment about the actual relevant functionality for the systems intended scope and allowed the development team to react accordingly.

## III. System Design

The multifunctional telemedicine system's design is subject to some project related invariants which had influence on the development process and the overall system design:

- The system was designed and built during the project's first two years and had to be ready for use after that phase in order two allow for its evaluation in regular EMS missions.
- All medical devices used by the system are provided by the associated project partners Philips HealthCare and 3M. Devices from other vendors were not considered for initial integration.

### A. Use-Cases and Main Requirements

The defined use-cases can be clustered into three main groups which are further detailed in Figure 1:

- Audio Communication
- Data Transmission
- Common Activities

Besides these main use-cases multiple support use-cases were created to address aspects like user authentication or system administration and are not specific to this telemedicine system.

The prominent notion of audio communication related use-cases is based upon existing experience by the involved system users and user representatives, showing that an easy to use, reliable and robust method for bidirectional voice communication between the tele-EMS-physician and the on-scene ambulance team is the single, most important factor for a successful teleconsultation. Making regular phone calls is necessary for the tele-EMS-physician in order to support the on-scene team in administrative tasks or to contact external specialists like the poison control center. To provide a good usability, the tele-EMS-physician has only a single phone-like interface which integrates handling of internal calls (to the on-scene team) and calls to the public switched telephone network.

All use-cases describing the transmission of case related information between on-scene and the tele-EMS-physician are grouped together in the Data Transmission cluster of use-cases. This contains transmission of continuous real-time or discrete biomedical signals, auscultation streams as well as photo and real-time video transmission. The cardiotocography (CTG) is covered as a special form of biomedical signal transmission; it will only be used to perform a smaller study regarding its usability in pre-hospital EMS and does not have any impact on the current system design.

Common Activities mainly contains use-cases describing the electronic case documentation performed by the tele-EMS-physician and the handling of reports automatically generated from that data. The easiest method of delivering a case report to the receiving hospital, together with the treated patient, is by printing the case's summary report on a printer inside the ambulance. Using fax, a report can be sent to the hospital before the patient arrives. Direct integration with a hospital's information systems is currently outside the described system's scope.

The top four non-functional requirements defined for the system are:

- overall system usability
- security of transmitted data regarding eavesdropping
- data correctness
- robustness of both data transmission and audio communication.

Overall system usability is a very fuzzy formulation. This requirement targets at providing an integrated system experience in order to enable simple workflows during patient treatment. To further concretize this requirement, the system's two main usage locations, on-scene and teleconsultation center, are addressed in separation:

- On-scene the ambulance team's current workflows and carrying pay-load should be influenced as little as possible. The system must seamlessly integrate with the devices used on-scene and be usable for a regular two-person team during potentially stressful patient treatment.
- From the teleconsultation center one tele-EMS-

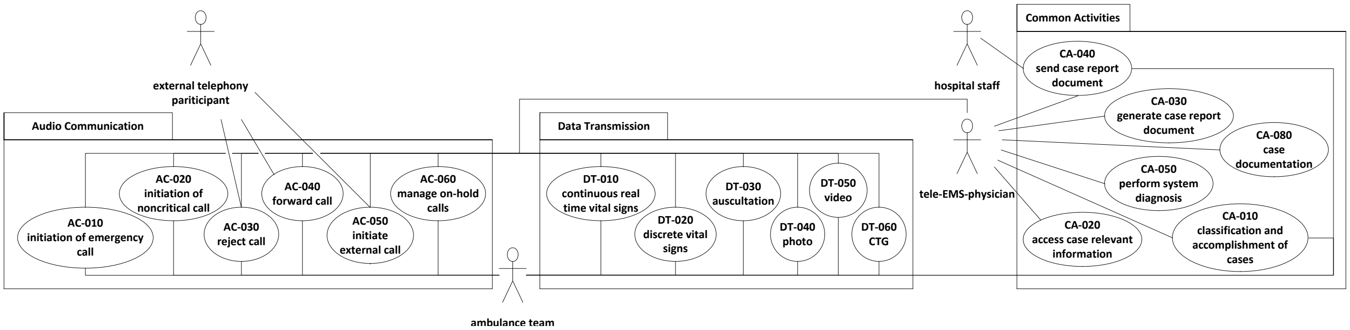


Figure 1. The main use-cases defined for the telemedicine system described in this paper.

physician only interacts with one ambulance team at a given time. All related services must ensure that data only from that team is displayed. The different services must integrate seamlessly into one working environment in order to reduce the burden posed onto the tele-EMS-physician by the system's usage.

Data correctness covers two main concerns:

- Information must not be altered between its acquisition on-scene and presentation thereof to the tele-EMS-physician. If data is transformed in any way it must be ensured that the information it presents is not affected by that transformation.
- It must be ensured that data which is presented to a tele-EMS-physician is at any time associated to the correct ambulance and thus the right patient respective case.

### B. System Architecture Overview

Various harmonization and standardization groups have defined different standards and interoperability profiles, a collection of specifications often with accompanying restrictions and definitions, for a multitude of data-interchange and device integration scenarios: Health Level 7 (HL7), Integrating the Health enterprise (IHE), Continua, IEEE 11073 [13]–[15]. The amount of different, sometimes competing, sometimes complementary specifications and usage profiles makes it hard to know where to start when looking for the right design for a system which does not fully fit the existing use-cases. At the same time the harmonization efforts mainly target the hospital or consumer market. A market survey regarding pre-hospital EMS devices shows that by now first manufacturers begin selling telemedicine enabled devices, with each vendor creating an independent, proprietary solution [16], [17].

Based on the use-cases, additional requirements and project constraints, a system architecture was designed. This process started by choosing the devices which compose the on-scene system. This device-centric view onto the system is depicted in figure 2 in which the system is divided into the three locations: consultation center (top), ambulance/in-car (left) and on-scene (right). All data transmission from

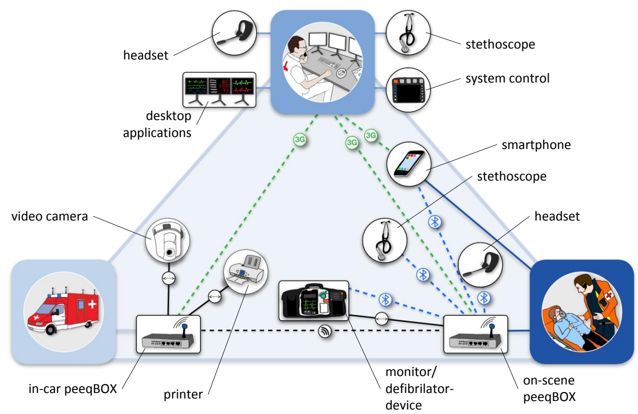


Figure 2. Device-centric view on the telemedicine system's system architecture; adapted from [9].

inside the ambulance and on-scene is relayed to the consultation center via a special data transmission unit (peeqBOX, designed and manufactured for use in this system by P3 Communications GmbH, Aachen, Germany).

The in-car peeqBOX acts as gateway for the Local Area Network (LAN) inside the ambulance, enabling TCP/IP network traffic between this and the consultation center's LAN. The following devices connect directly to the ambulance LAN:

- A network enabled video camera (SNC-RZ50P, Sony, Japan) is mounted at the ambulance's ceiling. It is fully controlled by the tele-EMS-physician who can tilt, pan and zoom its view. The video is streamed using a H.264 video codec, eight frames per second, a Bit rate of 128 kilo Bits per second and an image resolution of 384 times 288 pixel.
- A thermal printer (PocketJet PJ-623, Brother, Japan) with 300 dots per inch using a print server (TL-PS110U, TP-Link, China) for its connection to the network.

The on-scene devices all use Bluetooth to wirelessly connect to the on-scene peeqBOX. This peeqBOX itself is housed inside the right pocket of the monitor-

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Figure 3. An early development prototype of the on-scene peeqBOX fitted inside the right pocket of the monitor/defibrillator-device's bag. The bag's right pocket was later adjust to provide space for patient therapy equipment.

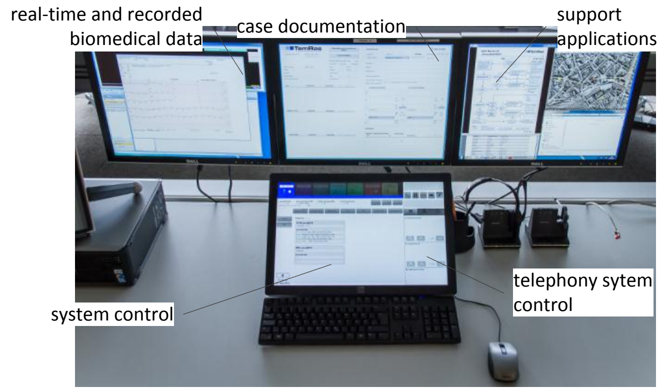


Figure 4. Photography showing a tele-EMS-physician workplace with the three top monitors showing the main applications (besides video) used during a consultation and the lower centered touch-monitor with the system control interface and the integrated telephony system controls to the right. Keyboard and mouse are connected to the desktop computer to interact with its applications on the three top monitors.

ing/defibrillation device, as shown in figure 3. The following devices comprise the on-scene location of the system:

- A monitor/defibrillator-device (HeartStart MRx M3535A, Philips, Netherlands) configured with the options SpO2, NBP, EtCO2, 12-Lead, 12-LTx Bluetooth, Pacing, Q-CPR, Q-CPR Data, 75mm Printer, EventSum Bluetooth, IntelliVue Net and Per Data Tx.
- Two headsets (Plantronics Voyager Pro HD, Plantronics, USA) used by the ambulance team to communicate with the tele-EMS-physician. This communication link is delivered via a regular voice call established by the on-scene peeqBOX using public circuit switched mobile telephony networks.
- A smartphone (HTC Sensation XE, HTC, Taiwan) serving two purposes: In regular operation it is used to take photographs on-scene which are automatically transmitted to the consultation center. In case of the loss of the regular audio connection via the peeqBOX during a case, the ambulance team can directly call the tele-EMS-physician with this phone, increasing the chance for safe termination of a consultation instead of its interruption.
- A stethoscope (3M Littmann electronic stethoscope 3200, 3M, USA); this device's integration is still in its conception phase and is not used by the currently running system.

In the consultation center a tele-EMS-physician's workplace is comprised of the following user-facing devices, as shown in figure 4:

- A wireless headsets (Savi W710/W730, Plantronics, USA); the tele-EMS-physician can choose out of two available models which one to use or switch the headset if the first one runs out of battery power.
- A stethoscope (3M Littmann electronic stethoscope 3200, 3M, USA); this device's integration is still in its conception phase and is not used by the currently running system.
- A desktop computer (OptiPlex 780 DT, Dell, USA with main memory: 4GB; processor: Intel Core 2 Duo E8400, Intel, USA; graphics-card: NVIDIA Quadro NVS 420, NVIDIA, USA) with three monitors (UltraSharp 2007FP, Dell, USA) attached running Microsoft Windows 7 operating system hosting the different applications used by a tele-EMS-physician during consultation.
- A dedicated control computer (OptiPlex 780 USFF, Dell, USA with main memory: 4GB; processor: Intel Core 2 Duo E8400, Intel, USA) with a single touch monitor (Elo 1900L APR, Elo, USA) attached which is used to control the telemedicine system, shows data for system diagnostics and offers an integrated user interface for the telephony system.

### C. Device and Service Integration

Classifying the devices by the Continua Alliance's Reference Architecture, the monitoring device and stethoscope are Peripheral Area Network (PAN)- or LAN-devices whereas the on-scene peeqBOX is an Application Hosting Device [14]. All services provided by the tele-EMS-physician relate to WAN-devices. Storage of patient related information could be delegated to a Health Record Device (HRD), but such a service's primary intend of "... offering a broad overview of a person's health status in a central location [18]" is out of the scope of the current system design.

Current state of the art would suggest realizing the connection between said PAN-devices and the on-scene peeqBOX by following IEEE 11073 family of standards [15], [18]. Two current facts prevent this choice:

- Only a subset of the necessary device profiles exist as approved standards: blood pressure monitor and pulse oximeter, whereas basic electrocardiogram (ECG), using 1- to 3-leads, is still in final draft status by ISO [19]–[21]. Communication of 12-lead ECG or stetho-

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scope connection has not been addressed by this family of standards at all. (reason might be focus of use-case)

- None of the devices in question for use supports an open standard for communication. The only way to interface with them is by means of proprietary software provided by the devices vendors.

Instead a common integration approach is used by building a message driven middleware layer following common Enterprise Integration Patterns [22] using individual adapters to control the used third party applications. This middleware layer is comprised of different Java services hosted on a Java application server (Glassfish v3.1.2, Oracle, USA). Messaging is performed via the Advanced Message Queuing Protocol using a single message broker (RabbitMQ v2.7.1, VMware, USA), enabling service adapters to be implemented in different programming languages. The system's user interface presented to a tele-EMS-physician is composed of both preexisting local applications running on the desktop computer and rich web applications specifically implemented for this setting.

The web applications displayed in a special viewer application instead of a regular browser, allowing tight control over them and preventing the user from accidentally navigating away from an application. These viewer applications as well as the other local applications are controlled by an application controller service running on the desktop computer, allowing the middleware services to launch, close or otherwise remote-control them.

All but the system's audio communication functionality uses IP network technology to connect the ambulance (in-car) and on-scene location to the consultation center [23]. This IP network is provided by each of the peeqBOX-devices, simultaneously using multiple third generation mobile telecommunications network links, up to three on-scene and up to five in-car to connect to a special router, called Stationary Communication Unit (SCU), in the consultation center. Additionally the in-car peeqBOX offers a Wireless LAN (IEEE 802.11a) inside and close to the ambulance which is used by the on-scene peeqBOX to relay all its IP network traffic via the in-car peeqBOX and its roof-mounted antennas. All IP network traffic between the peeqBOX-devices and the SCU is distributed among the available mobile network connections and encrypted using AES-265 encryption. This approach enables direct integration of IP network capable services (video-camera, printer) and at the same time ensures a high robustness against the full loss of their network connection.

On top of the IP network each peeqBOX offers a file transfer service using the standard File Transfer Protocol. Via this service files are delivered to ambulance specific inboxes where they are further processed by the middleware layer and handed to consuming services in the consultation center. Access to this file transfer service is offered by additional peeqBOX service adapter:

- The photo adapter queries pictures taken with the smartphone via the Bluetooth File Transfer Profile (Bluetooth FTP), having the smartphone act as server. As soon as the adapter has handed a picture to the file transfer service, it deletes the picture on the smartphone.
- The biomedical signals adapter accepts Bluetooth FTP connections from the monitor/defibrillator-device which uses this method to publish files containing periodic trend data and recorded 12-lead ECGs, both in a proprietary data format.
- System diagnostics data concerning a peeqBOX is collected into a small sized (less than 600 Byte) XML-file every ten seconds and handed to the file transfer service. This data includes: battery level (only on-scene), device temperature, voice and data connection overview, detailed mobile connection link data, headset status, time-stamp and global positioning system (GPS) coordinates.

To enable continuous real-time biomedical signal transmission from on-scene the peeqBOX uses an OSI Layer two network bridge to connect the monitor/defibrillator-device to the clinical network provided by an IntelliVue Information Center (Philips, Netherlands) in the consultation center [23]. The monitor/defibrillator-device's integration will be discussed in more detail in a future publication.

The audio communication between on-scene and a tele-EMS-physician is realized in two stages. The on-scene peeqBOX is used as multi-SIM mobile phone with additional control logic. The user interfaces to this function only by using the single button on its headset, which initiates an emergency call to the consultation center via the best available, circuit switched network. In the consultation center a private branch exchange based on the open-source Asterisk framework answers the call by putting it into a separate conference room. The tele-EMS-physician which accepts such an incoming call is connected to this conference room via a voice over IP client, remote-controlled via the system's middleware layer. Using the touch monitor's telephony interface, the tele-EMS-physician can itself initiate calls either to an on-scene peeqBOX or to an external telephony participant.

## IV. Conclusion and Future Work

A multifunctional telemedicine system using commercial off-the-shelf medical devices, which is suitable for use by a regular EMS team, has been presented in this paper. The lack of existing standards for the required integration of medical devices results in an interoperability issue which prevents the creation of open systems and common frameworks or platforms for such a telemedicine system. The current situation requires integrating each device or product line independently. Solving this interoperability issue should therefore be a primary target of future research and regulatory efforts.

The presented service integration approach using a simple message broker enabled a rapid system implementation and proved suitable for creating an integrated telemedicine system. Its capability for delivering sophisticated, automated workflows, e.g., for advanced reporting or data-exchange with external entities, however is limited. The use of concepts like Enterprise Integration Bus might be a viable option to address this issue and is left for future work.

Integrated information exchange with receiving hospitals or electronic health records is not covered by the scope of the presented research. The IHE and Continua Alliance efforts generally address this concern. Assessing their existing guidelines regarding suitability for this integration use-case remains for future work.

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