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Automatic Alerting of Accidents and Emergencies: The International Standard Accident Number and Vital Sign Data Embedded in Future PACS

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ABSTRACT

Digital Imaging and Communications in Medicine (DICOM)-based picture archiving and communication systems (PACS) primarily collect data that health-care professionals acquire in hospitals for diagnostics or therapeutics, but integration of data from continuous health monitoring is not yet included. Smart wearables or smart clothes, but also smart environments such as apartments, homes, or vehicles collect such data. While cars already generate automatic alerts, for example the eCall system in Europe, smart homes or smart wearables will generate such alerts in near future, too. However, the response to automatic alerts still is operator-based. There is no technical link between the information technology (IT) systems operated by the rescue service, the emergency departments, and the hospitals. We suggest an international standard accident number (ISAN) that is created by the alerting system and supports communication between the systems of the rescue chain and secure data sharing. In this paper, we draw a scenario in which we enhance smart vehicles and smart homes with health-related unobtrusive sensing devices for vital signs and capture environmental, behavioral, and physiological parameters simultaneously from the shell-like private environment that cars and homes provide the humans. Via the ISAN, the data is communicated safely and securely to the hospital. We further analyze recent DICOM extensions on suitability to capture such data in the PACS of the hospital. The Vital Sign Template (TID 3510) extends DICOM Structured Reporting but captures such measures only at a particular point of time, rater than continuously. DICOM Waveform Data (DICOM 3.0 Supplement 30, added in 2000) was designed particularly for ECG data. It can store continuous recording of up to five sequence items of up to 13 channels. However, it does not cope with any information describing the capturing device, position, or other semantic information. In conclusion, vital sign monitoring cannot sufficiently handled with DICOM and its extensions of today.

Keywords: Diagnostic Space, Health Monitoring, Vital Sign, Accident & Emergency, Smart Environment, Ambient Assisted Living, Smart Home, Smart Vehicle, Smart Car

1. INTRODUCTION

In emergency medicine, possible illnesses or physical damages are derived from injuries, symptoms and the current state of health, measured by vital functions, as well as the available information on the emergency course of action. The diagnoses of the doctors are based on subjective knowledge and experience as well as incomplete information. In order to obtain further information, various examinations as magnetic resonance imaging (MRI) or computed tomography (CT) are carried out, in order to obtain further information about possible damage through image data analysis. This examinations can be very time-consuming and costly.[1] By including and analyzing information and medical data from many different sources in the decision-making process, faster diagnosis and treatment of the patient can be achieved and more targeted examinations can be provided.

Already today, important diagnostic information can be obtained in the private environment of the patient. Health monitor systems continuously monitor the vital signs of a person and send alerts if needed. Thus, in

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an emergency, they can provide important information about the patient's current state of health as well as the condition shortly before the emergency occurs. The data can be analyzed promptly and thus make rescue operations more efficient. In near future, not only health monitor systems – which are usually installed only for high-risk patients – will generate automatic alerts, but also smart wearables that measure the wearer's vital data by using eHealth sensor technology. Unfortunately, this alerts are still operator-based and the sensor data are not yet available to the emergency services to support diagnoses.

But not only eHealth systems can be useful in supporting diagnoses. With the increasingly widespread sensing devices that surround citizens in their daily lives, there is a huge data space that can provide information about accidents and emergency situations. Today's cars, for example, already contain a wide range of sensors. Although they do not provide information about the vital parameters of the occupants, they can provide useful information about the accident and possible injuries.

Even when the sensors and data are already available, there is no possibility to access this information during emergency operations or medical treatments in hospital. To overcome this lack of information exchange, we have proposed the International Standard Accident Number (ISAN).[2,3]

In this paper, we sketch a scenario in which we enhance smart vehicles and smart homes with health-related unobtrusive sensing devices for vital signs and capture physiological, environmental and behavioral parameters. Via the ISAN, the data will be transmitted safely and securely to the hospital. Since picture archiving and communication system (PACS) commonly use the digital imaging and communications in medicine (DICOM) standard for storing and exchanging medical images, we further analyze recent DICOM extensions on suitability to capture such data in the PACS of the hospital.

2. DIAGNOSTIC SYSTEMS

Sensing devices enable clothes, homes, cars, even whole cities to collect and share their data via various communication infrastructures. Due to the fact that more and more devices potentially can be connected to the Internet (Internet of Things, IoT), the amount and types of health care information is growing rapidly.[4] Not only eHealth devices that provide information on vital signs, but also environmental, movement or behavioral sensor data can provide useful information for medical treatment (e.g., in case of an accident). Basically, we distinguish three different levels for sensing devices that provide relevant diagnostic information about a patient: IN, ON and AROUND a person (Fig. 1).

2.1 Smart Implants

Smart implants are sensing devices that are implanted inside the human body, i.e., under the skin or near certain organs or vessels. Medical smart implants are mostly used to monitor certain vital or organ functions, to warn and intervene in case of critical or abnormal conditions to prevent or treat health-critical situations as early as possible. They provide valuable information from inside the person, such as the blood sugar level of diabetes patients. Smart implants have the great advantage that the data measured by the device comes from one and the same person. Therefore, data from a longer period of time can also be used for data analysis without having to take into account possible incorrect assumptions by the use of third parties.

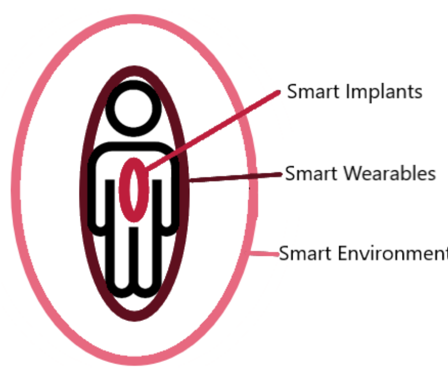

Figure 1: Levels of diagnostic systems

2.2 Smart Wearables

Smart wearables such as smart clothes, smart watches or smart health care devices like smart blood pressure meter are widely spread on the market. They can be worn or put on directly on the body. Especially smart watches and so called fitness tracker are commonly used by citizens today. By measuring various vital data – such as heartbeat, ECG or respiratory rate – they can provide important medical information. Details on wearable biosensor systems for health monitoring can be found in the survey from Pantelopoulos et al.[5]

2.3 Smart Environment

Homes, cars, public buildings or even an entire cities can be called smart environments when they provide information using sensor technology. In the domain of smart homes, various sensors are used to support ambient assisted living (AAL), such as motion and fall detectors. Intelligent algorithms for processing and evaluating sensor data from various devices can detect emergency events and trigger automatic alerts immediately after an event occurs.[5] Smoke detectors in smart buildings can detect house fires and provide information on how far the fire and smoke has spread. By using environmental sensors, a smart city can detect toxic gases and recognize catastrophes.

Even if smart environments do not yet measure eHealth data, they can provide meaningful information for the emergency and medical treatment. Today's car, for example, contains various sensors. Although the car does not contain eHealth sensors yet, which means that they do not provide information about the vital signs of the occupants, but rather driver assistance and control sensors, they can nevertheless provide information that can be used to determine the severity of the accident and the possible injuries to the occupants.

3. PRIVATE ENVIRONMENTS AND DIAGNOSTIC SPACES

As mentioned smart homes and cars are not providing vital-data yet, but there is a transformation ongoing to convert the private environment (the smart home or car) to a private diagnostic space. This transformation is described in the paper of Deserno.[3]

Smart homes as diagnostic spaces With the increased computing and storage capacities and the individual power supply that we face in the domain of smart homes there is the potential to replace diagnostic devices in public hospitals with individual data records for continuous health monitoring in the private space.[3] Antink et al.,[6] Blanik and Zaunsederet et al.[7] present different camera-based approaches of non-contact methods for vital signs monitoring. However, there is a lack of acceptance for video-based systems, especially in the private environment. With the help of sensors integrated into home furnishings such as armchairs or beds in which the user potentially spends a major part of the day, vital signs can be recorded unobtrusively.

Smart vehicles as diagnostic spaces Similar to the described armchairs in a smart home, sensors can be placed in automotives such as cars (e.g., in the seat or on the steering wheel) to measure vital data while driving. Leonhardt et al.[8] analyzed the unobtrusive monitoring of vital data in vehicles. Wang et al.[9,10] evaluated the performance of a seatbelt attached accelerometer for real-time monitoring of passenger respiration. Moreover, by monitoring the driver's state of health while driving, it is potentially possible to prevent car accidents caused by driver's attacks. Chowdhury et al.[11] discussed the potential of reducing car accidents by real-time monitoring of the heartbeat to detect heart attacks.

4. DATA EXCHANGE

Smart devices and environments as mentioned above can be used, to detect emergency situations and generate automatic alerts if needed. With the exception of the European eCall system, which sends out an emergency call when the in-vehicle system detects an accident, there is currently no integration of smart devices into emergency services. Health monitor systems that generate automatic alerts still use operator-based rescue services. Automatic triggered emergency calls could not only reduce the therapy-free interval (time between the event and the medical treatment) particularly when the person in distress is not able to setup the emergency call, but also support to customized the rescue operation by transmitting additional information about the emergency situation or vital data of a person in distress.

However, even by supporting automatic emergency calls, the parties involved in the rescue operation use their own isolated information technology (IT) systems. Currently, information flows one-way between the members of the rescue chain (Fig. 2). There is no technical link between the IT-systems operated by the rescue service, the emergency department, and the hospital. Furthermore, the information flow and data exchange between the parties is based on human interaction and disclosure of information. Information is exchanged usually by telephone, which means voice-based. The rescue team as well as the medical service in the hospital must rely on the information provided orally by the caller.

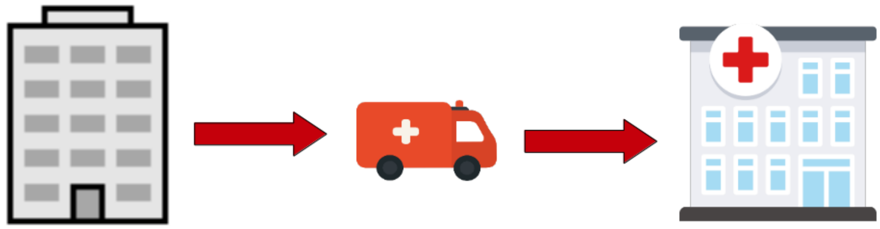

Figure 2: Current information flow in rescue operations

When a person is facing a heath-critical situation (e.g., heart attack, stroke), the person in need or a third person has to set up an emergency call. By making an emergency call, the rescue services will be informed about the emergency. By asking specific questions about the injured person, they try to get a first impression of the emergency situation. After the rescue team arrives, first of all they have to find the apartment and the person in need. This can be very difficult in some cases. Once they have found the person, the vital parameters are measured to estimate the patient's state of health and, if necessary, to initiate first medical aid. The patient must then be transported to the hospital, where further medical and therapeutic treatments are carried out. The hospital is informed about the incoming patient (again human-based). When the patient is handed over to the hospital, important information on the emergency case, the medical treatment given by the rescue team as well as state of health of the patient is provided to the hospital.

5. INTERNATIONAL STANDARD ACCIDENT NUMBER

Even when the data transmission could be technically realized today, currently there is no link between the isolated data silos. To overcome the lack of data exchange and to involve a variety of data sources into the accident and emergency medical services, we initiated the ISAN project. The acronym ISAN stands for the International Standard Accident Number (ISAN), an unique numeric identifier for accidents, emergencies and further medical events.[2] The ISAN will provide a link between the IT-systems involved in the rescue mission. From the alerting system (e.g., smart home) over the rescue service to the hospital. Also third parties, for example Toxicological emergency services, can be easily integrated.

With the proposed ISAN, we believe to overcome current limitations of one-way communication between systems of the rescue chain (Fig. 2) rowards a fully interconnected data exchange (Fig. 3). The ISAN support secure and bi-directional communication between all systems involved in the emergency treatment. The medical rescue service as well as the hospital interact in real-time with all other systems when requesting stored data. This transforms the information flow from a human-based conversation into a system-based communication.

Let us recall again the scenario sketched above. Here, an automatic emergency call informs the rescue team about the emergency. Since there is no human anymore that can answer to the operator, all required information must be uniquely coded and transferred automatically. The rescue service may also requests further information from the alert-generating system, for instance, a smart home. Based on the ISAN, the smart home verifies the request and provides the exact location (geo-location or civic address as well as floor plan indicating the room of accident), the number of persons involved, and the type of emergency. Furthermore, vital-signs that are monitored continuously, are provided in real-time. Arrival of the rescue team is signaled to the smart home, which then opens the door automatically or communicates a key-code to open the door.

In parallel to the rescue team, the medical team in the hospital is notified about emergency. In addition to the real-time data recordings, the team of the emergency room (ER) requests further data from the smart home, such as medical health records, medication lists, and allergies. During rescue and transport, the rescue service collects data, which includes initial findings, medical first aid treatment and again, continuous health monitoring data. This information as well as the real-time location of the ambulance is transmitted to the hospital. On

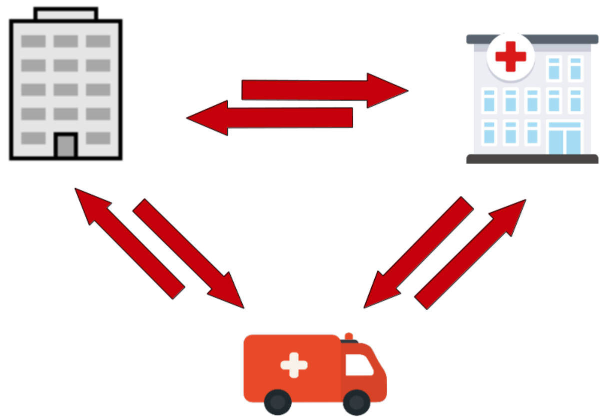

Figure 3: Future information flow in rescue operations via ISAN

patient's arrival, the ER-team is well prepared for instantaneous treatment of the patient. If necessary, the ER-team can request further medical examinations during the transport (as long as the rescue team and ambulance vehicle is equipped accordingly).

Furthermore, the ISAN is used not only for secure interaction and data exchange between the systems, but also to store all data collected during the emergency treatment. This emergency register is used for future data analysis.

6. HEALTH MONITORING AND FUTURE PACS

In near future, occasional diagnostics in PACS-based hospitals turns towards continuous health monitoring in private spaces, which are equipped with unobtrusive sensing devices. With that transform, medical curing turns towards event prediction and prevention. However, health monitoring systems will not replace PACS-based hospitals, but rather complement them.

The wide range of different digital storage and transmission formats is one of the main obstacles in order to build an integrated eHealth environment. This heterogeneous environment makes the medical related file exchange between different systems a challenging task. The integration of data from health monitoring systems into existing systems is an important factor for the interoperability of different systems.[12] It is therefore necessary to integrate eHealth data into a generally accepted format. PACS commonly uses DICOM standard to generate, store, and exchange images. In this section, we analyze the current DICOM standard on the suitability to additionally manage vital-sign data from health monitoring systems.

6.1 Vital Sign Template

The National Electrical Manufacturers Association (NEMA) has introduced the Vital Sign Template (TID 3510), specified in PS3.16, for DICOM-support of vital-sign data.[13] The template extends DICOM Structured Reporting (DICOM-SR). It belongs to the Hemodynamics Measurements Group. The specification describes the template as follows:

> *The Vital Signs Template consists of a CONTAINER containing the various vital signs measurements. These measurements may be acquired automatically from patient monitoring equipment, or may be entered based on manual measurements* (DICOM PS3.16 TID 3510).

In particular, the TID 3510 container is capable to store several vital signs (Tab. 1), which are commonly recorded by health monitoring systems. However, to the best of our knowledge, this template is rarely used so far. Although eHealth devices provide vital signs, they cannot fill DICOM-SR templates automatically. Furthermore, many eHealth devices, such as smart watches, measure the pulse rate but not the heart rate. Even though closely related, these are separate measurements, indicating a semantic gap for interoperability. Also,

Table 1: Vital signs contained in DICOM PS3.16 TID 3510. *The code 10:9232, for instance, indicates a normal sinus rhythm.

Vital Sign	Unit
Blood pressure (systolic/diastolic)	mmHg, kPa
Heart rate	beats per minute (BPM)
Body temperature	°C
Blood gas saturation	%
Respiration rate	breaths per minute
Pulse strength	range from 0 to 4
Pain score	range from 1 to 10
Cardiac rhythm	code*
Respiration rhythm	code

the position of the measurement device (e.g., wrist, chest, non-contact) must be coded in such a way that it supports automatic processing and understanding. Furthermore, it is not specified on which criteria the pulse strength is rated. To ensure interoperability and comparability, all devices should have a common rate scheme. But most importantly, the template is capable of representing the vital data at a particular time only. For a continuous health monitoring, several files must be transmitted.

6.2 Waveform Data

In 2000, DICOM Waveform Data (DICOM PS3.5) was introduced in the DICOM Waveform Interchange Standard (DICOM 3.0 Supplement 30)[12] for the exchange of encoded time-based signals or waveforms such as electrocardiography (ECG):[12]

> *It can handle waveform storage of data independent from sampling frequency, amplitude and system sensitivity.*

Since the Vital Sign Template can only represent the vital data at a certain time, the DICOM Waveform Data can be used for continuous health monitoring over a certain period of time. In DICOM Waveform Data, up to five sequence items with a total of 13 channels can be stored. This seems sufficient for ECG and other vital signs recorded by unobtrusive sensing devices within private diagnostic spaces. Anagnostaki et al.,[14] for example, have developed a codification scheme for a home care application to exchange waveforms and medical data based on the VITAL and DICOM standards.

In combination with the ISAN, cooperating system in the rescue chain might exchange data using DICOM. However, DICOM objects hold patient information such as ID, name, or gender. In case of an accident or an emergency, it can be difficult to ensure that an individual really is the person whose data has been entered into the system (e.g., guests in the smart home). Therefore, additional mechanisms are required to apply DICOM during the rescue operation.

7. DISCUSSION & CONCLUSIONS

With the transform of private environments into diagnostic spaces and the resulting shift from medical data recorded mainly in hospitals to continuous monitoring of vital parameters in private spaces, the way of collecting data for diagnosis and treatment is changing. We already presented the ISAN concept to link data between so far isolated IT-systems and to integrate medical data and information from different sources (e.g., smart home, smart vehicle, smart wearable, rescue service, emergency room) into the decision-making process of medical professionals. We sketched a scenario in which we enhance smart vehicles and smart homes with health-related unobtrusive sensing devices for vital signs and described, how the data can be exchanged between different parties and transmitted to the hospital. This additional data yield faster diagnosis and better treatment.

The Vital Sign Template and Waveform Data extend the DICOM standard towards vital signs. Nonetheless, several questions remain, as these DICOM extensions are not in use yet. However, in combination with the ISAN, DICOM-based PACS in hospitals and ERs might become suitable to store and manage vital signs recorded in private diagnostic spaces.

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