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Special Issue: Innovations in Medicine and Healthcare

Research Paper

Design of a real-time emergency telemedicine system for remote medical diagnosis

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ARTICLE INFO

Article history:
Published online 23 April 2015

Keywords:
Telemedicine
Real-time emergency
Remote medical diagnosis
Blood coagulation
International normalised ratio

In routine clinical practice of emergency care, it is very difficult to perform diagnostic procedures during ambulance transport. This can lead to a delay in the patient's diagnosis and, consequently, in the patient's treatment until arrival at the hospital. Although this situation does not imply notable risk in the majority of pathologies, in anticoagulated patients, this delay can be fatal. In this study, a system is discussed that would minimise the response time before the medical administration of anti-haemorrhagic or antithrombotic treatments that would mitigate or even eliminate the dramatic consequences of the progression of intracranial haemorrhage. The aim of this study is to design a real-time emergency telemedicine system for remote medical diagnosis and to demonstrate that it is possible to perform haematological tests in an ambulance in terms of an international normalised ratio (INR) using wireless transmission, accurately and in real-time, to the referral hospital. The main and novel component of our system is a hybrid network that enables secure long-distance communication from an ambulance. The results of the tests in the ambulance are such that there were no significant differences between the values obtained from the samples analysed during travel in the ambulance and those analysed in the laboratory. Transmitting this information immediately to the hospital may involve administering early treatment during the transfer as prescribed by the medical staff that have access to both the data and to the patient's clinical history. In conclusion, the telemedicine system designed for real-time emergencies opens new perspectives for remote medical diagnosis.

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http://dx.doi.org/10.1016/j.biosystemseng.2015.03.017
1537-5110/

Nomenclature

Acronym	Definition
ADSL	Asymmetric Digital Subscriber Line
AF	Atrial Fibrillation
AVF	Augmented Vector Foot, peripheral leads of the electrocardiogram
AVL	Augmented Vector Left, peripheral leads of the electrocardiogram
AVR	Augmented Vector Right, peripheral leads of the electrocardiogram
BP	Invasive Blood Pressure
DVT	Deep Venous Thrombosis
ECG	ElectroCardioGram
ECGx	x Derivative of the ElectroCardioGram
EDC	Error Detecting Code
FFP	Fresh Frozen Plasma
GPRS	General Packet Radio Service
HCT	Hospital Complex of Torrecardenas
ICT	Information and Communication Technology
ICU	The Intensive Care Unit
INR	International Normalised Ratio. It is referred to as the measuring of prothrombin time in the plasma clot after the addition of the tissue factor
IP	Internet Protocol
ISI	International Sensitivity Index
NBP	Non-invasive Blood Pressure
OAT	Oral Anticoagulant Therapy
PT	Prothrombin Time
RESP	Respiration
RS232	Communications interface with Recommended Standard 232
SCADA	Supervisory Control and Data Acquisition
SPO2	O_2 saturation
SPSS	Statistical Package for the Social Sciences
TCP/IP	Transmission Control Protocol/Internet Protocol
UAL	University of Almeria
UDP	User Datagram Protocol
VKA	Vitamin K Antagonists
VTE	Venous ThromboEmbolism
WHO	World Health Organization

1. Introduction

Information and communication technology (ICT) is providing technical solutions in many fields with social purposes, such as healthcare, allowing the application of new ideas for improvements in the welfare of consumers (Yu, Stoelting, Yi-Tao, Yi & Sarrafzadeh, 2010). Telemedicine is an umbrella term that encompasses any medical activity involving an element of distance (Wootton, 2001). In telemedicine, the client is separated from the expert in space (Craig & Patterson, 2005). Telemedicine is changing the classical form of healthcare delivery by providing efficient solutions to an increasing number of new situations (Gómez et al., 1996). The development of sensing systems with low-cost sensors and wireless transmission capabilities provides an economic and versatile system for this area of research. Advances in telecommunication technologies have created new opportunities to provide telemedical care as an adjunct to the medical management of patients (Anker, Koehler, & Abraham, 2011). Telemedicine can be useful when there is adequate monitoring, and the system has a direct impact on the fundamental aspects of patient management (Domingo et al., 2012). One of the earliest recorded uses of ICT in telemedicine was when Einthoven, on 7 February 1906, transmitted electrocardiogram (ECG) tracings over telephone lines (Hjelm & Julius, 2005). Telemedicine potentially holds great promise in facilitating emergency medical practice (Amadi-Obi, Gilligan, Owens, & O'Donnell, 2014). However, mobile telemedicine applications need to overcome several problems associated with vehicle mobility. In the past, wireless communication technologies have limited the quality of telemedicine services. Considerable research has been performed in this regard, and several systems have been tested and implemented; however, in those studies, mainly 2G mobile or a satellite were used for the transmission of ECG and sometimes images (frames) and audio (Kyriacou, Pattichis, & Pattichis, 2009; Novas, Gázquez, & Noguerol, 2013; Sørensen et al., 2011). In recent years, the advance of mobile 3G and 4G has spurred new projects (Laetitia et al., 2014; Liman et al., 2012; Wu et al., 2014), e.g., transmitting video, audio and medical data in real time (Bergrath et al., 2012; Ogedegbe, Morchel, Hazelwood, Chaplin, & Feldman, 2012) or transmitting haematological data such as INR (Ebinger et al., 2014; Walter et al., 2010).

The transfer of critically ill patients requires good coordination to provide the diagnostic tools and the most appropriate treatment for their conditions. Emergency ambulances have two basic objectives: to move the patient to a hospital, where the patient can be treated more effectively than *in situ*, and to ensure adequate assistance to maintain the patient in the best possible condition until arrival at hospital (Noguerol et al., 2010).

Anticoagulation with vitamin K antagonist drugs is indicated and controlled in an increasing number of patients. In fact, the number of anticoagulated patients exceeds 1% of the general population (Fang et al., 2010; Navarro et al., 2008). The cause of the growth experienced in recent years is mainly its use in atrial fibrillation (AF). The prevalence and benefit of anticoagulant therapy is that disease increases with age (Krishnan, 2005). Although prescribing in venous thromboembolism (VTE) is usually temporary (Agnelli & Becattini, 2005; Nieuwlaat et al., 2008), in most anticoagulated patients diagnosed with AF, it is indicated indefinitely (Agnelli et al., 2003; Fang et al. 2010; Nieuwlaat et al., 2008), usually for life. Therefore, this is an acquired hypocoagulability by factorial deficit, with characteristics of a chronic situation (like a chronic disease).

It is important to note that despite the emergence of new oral anticoagulants, which act as inhibitors to coagulation (not by factor deficit) (Connolly et al., 2009; Jerry Avorn, 2011), their