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Applying Telemedicine for Stroke Remote Diagnosis: the TeleStroke System

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Abstract

In the healthcare context, one of the branches where we assisted in a remarkable evolution in the last decade is telemedicine. Enhancements in the ICT landscape have driven this evolution toward the current state of the art. Nonetheless, despite its undeniable benefits – both for patients health and local health authorities economics – nowadays, telemedicine has not been fully adopted as much as it could be. The recent COVID-19 pandemic has further strengthened the role and importance of telemedicine nowadays, also highlighting the existing gaps. This paper describes a telemedicine-oriented software system called TeleStroke to support the remote diagnosis of a possible stroke, applied to an Hub&Spoke healthcare organisation.

Keywords: Telemedicine; Teleconsultation; Neurology; Stroke; Smartglasses

1. Introduction

In 1998, discussing the trends in health at the threshold of the 21st century [1], the World Health Organisation (WHO) pointed out how telemedicine, among others, may represent a keystone in accessing primary cures, speeding up the whole healthcare process. Nowadays, the COVID-19 pandemic has highlighted again how telemedicine might play a crucial role in healthcare, not only limited to improve how healthcare services and assistance can reach people but also to increase physicians collaboration and reduce unnecessary costs and movements of people, practitioners and assets [2]. Simultaneously, in the last decades, Information and Communication Technologies (ICT) have been greatly enhanced. In particular, hardware and software technologies developed in the areas of Mobile and Pervasive Computing, Internet of Things and Wearable Computing are mature enough to be involved in designing novel cat-

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egories of software systems to support a wide range of healthcare services, in particular, to improve the impact of telemedicine in many medicine branches.

According to official and international definitions, telemedicine can have several embodiments: among others, one of these is *teleconsultation*. Briefly, teleconsultation refers to the circumstance where a practitioner calls for the support of a specialist in a particular medical field to reduce the amount of time needed to define an accurate diagnosis of a supposed disease. For instance, in a *Hub and Spoke* based health organisation [3], in general, specialised competencies are centralised into hub hospitals, while spokes one decentralised into the territory usually expose generic medical competencies. In this scenario, if the need to manage a complex disease in a spoke hospital arise, teleconsultation can offer an efficient way to rapidly transfer specialised competencies from the hub to the spoke avoiding the patient centralisation to hubs, reducing the costs of worthless transportation and, above all, increasing the efficiency of the whole health system.

In this paper, we propose a system called TeleStroke, born from the analysis of a real scenario, the Stroke Unit of the "M. Bufalini" Hospital in Cesena, Italy, where neurological emergencies are managed according to the Hub and Spoke model. Such a kind of pathology is time-dependent, meaning that prompt care is needed to ensure the best outcome possible. Moreover, it requires neurological specialists for the proper diagnosis. Although telemedicine has been recognised to be key in such a context [4, 5], its use is still limited. Nowadays, in our organisation, specialists are centralised in the Hub, and remote consultations are given via phone calls from a verbal description of the patient state obtained by nursers and caregivers physically in the Spoke, barely with access to diagnostic images. This risks compromising the precision of the diagnosis. The contribution of this paper is to conceive a system to improve the quality of care in this context by supporting teleconsultation for remote stroke diagnosis. Accordingly, TeleStroke has been designed to meet such requirements. Generally speaking, the TeleStroke system is a smart software system designed to reduce the amount of time required to define a diagnosis for a patient with a suspected stroke, allowing remote neurologists in supporting first-aid physicians using web-based audio/video streaming coupled with wearable devices.

This contribution is organised as follows. First, Section 2 offers background about state of art in telemedicine for healthcare with particular reference to the context of applications for time-dependent pathologies management. Then, Section 3 introduces the TeleStroke System, describing its architecture and the current state of the developed prototype. Finally, Section 4 concludes the paper by facing a first discussion about the current state of the project.

2. Background and Related Works

Telemedicine is one of the most promising and exciting fields of e-health that grounds on the idea to move information instead of people, and that is demonstrated to provide clinical benefits and to positively impact patient outcomes [6, 7] by providing more timely, effective and easily accessible care. It is defined as:

> the provision of healthcare services, through the use of ICT, in situations where the health professional and the patient (or two health professionals) are not in the same location. It involves the secure transmission of medical data and information, through text, sound, images or other forms needed for the prevention, diagnosis, treatment and follow-up of patients [1].

Telemedicine has been enabled and strongly bootstrapped by the diffusion of mobile and Internet of Things technologies, such as wearable devices, smartphones, body area networks, wireless communications. According to the vision of pervasive healthcare computing, it allows the broadest possible and more equal access to healthcare services towards care for everyone, everywhere and at any time [8].

Under telemedicine, a wide variety of services are included, among which it is worth mentioning telemonitoring, televisit and teleconsultation. Telemonitoring is a telemedicine service that enables remote monitoring of the health status of patients. Patients' vital signs and body measurements can be collected automatically through wearable devices or manually entering data through a mobile or web app. Data are shared with healthcare professionals who define treatment protocols, schedule televisit, ask for more measures without the need for the patient to move to a

[1] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0689:FIN:EN:PDF

healthcare facility. Teleconsultation refers to the interaction between two or more healthcare professionals regarding a certain medical issue to remotely provide diagnostic or therapeutic advice. In addition, Teleconsultation exploits a set of other telemedicine services, such as teleradiology, which involves the electronic transmission of radiographic images from everywhere on the earth to everywhere with the purpose to be interpreted or consulted.

Nowadays, telemedicine is already delivered in different contexts. For instance, telemedicine is diffused as a tool for managing chronic illness and the elderly, according to the view of patient empowerment and patient-centred care [9, 10] It is widely adopted in the context of emergency/urgency [11] It provides a channel to access highly specialised consultation and enables multidisciplinary brainstorming [12].

More specifically, in this paper, we present a teleconsultation application devised to support the Hub and Spoke model [3, 13] adopted in the care of stroke emergencies. The goal is to improve the quality and reduce the time of diagnosis since stroke is a time-dependent disease whose outcomes are strongly associated with decreased time from onset to treatment. A neurological teleconsultation in this scenario is beneficial in settings like spoke hospitals without a neurologist on duty. Moreover, teleconsultation might help select patients that should be directly centralised in the hub hospital instead of referred to a spoke centre. This is particularly true considering that the checklists defined as medical protocols for stroke detection lack specificity (lower than 50%) [14]. Hence, the need for neurology expertise to early detect a stroke plays a key role in optimising stroke patients' diagnostic and therapeutic pathways. Since neurologists usually are centralised into hub hospitals and are not part of the emergency team assisting patients in the pre-hospital setting, remote consultations are required.

To enable remote support, telemedicine systems based on mobile technologies have been applied to stroke management [4, 5, 14]. Generally speaking, systems available in the literature include devices to acquire and transfer video and audio information, mainly patient's history and examination, such as computed tomographic scanners, if the ambulance is equipped with, to enable teleneurology evaluation during patient transport. The camera is embedded into the ambulance or in the mobile device. In particular, literature reports pilot studies and systems that are often in early versions with few technical details on how the system has been developed [15, 13, 16, 17]. Moreover, their diffusion is still limited in our context, while some successful example demonstrates that TeleStroke is worth to be exploited [18].

3. The TeleStroke System

The TeleStroke system is conceived and designed in cooperation with the Stroke Unit of an Italian Hospital[2] — part of a Regional Local Health Authority where the Hub and Spoke model is pervasively adopted in the management of time-dependent pathologies. The system aims to make available to the physicians at emergency departments widely distributed throughout the territory a teleconsultation with specialised neurologists to perform efficacious stroke diagnoses.

3.1. Motivation and Requirements

The chance of curing a patient with a suspected stroke is proportional to the speed at which physicians diagnose and treat this critical medical condition for the patient. Although all physicians should identify a possible ongoing stroke for a patient, only neurological specialists are qualified to lead a fine diagnosis to identify the stroke severity and define a proper treatment for the patient. In other words, only after a neurological diagnosis, a patient with a stroke might be driven into the more suitable diagnostic and therapeutic pathway that may lead to the administration of drugs to reduce the stroke impact on the patient's life – technically, a thrombolytic treatment – and/or to decide for emergency endovascular treatment. Unfortunately, in those health organisations where the points of access to cares are pervasively distributed throughout the territory, it is possible that – beyond the major centres – a neurologist is not always available on site for a quick diagnosis in cases of a suspected stroke. In such cases, the amount of time requested to move a patient from the first-aid where they are to the nearest major hospital hosting the stroke unit can irreparably affect the patient conditions and their survival/recovery chances. In this context, telemedicine support

[2] Stroke Unit of the "M. Bufalini" Hospital, AUSL della Romagna, Cesena, Italy

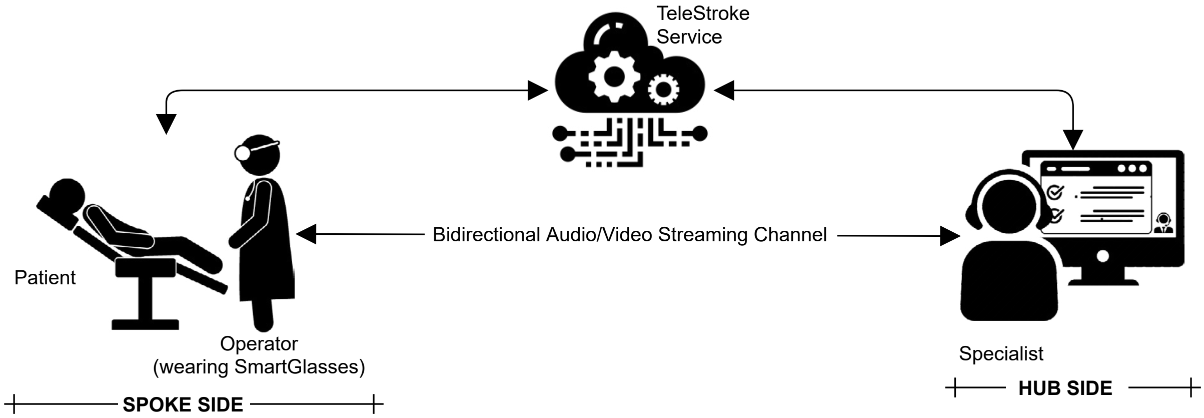


Fig. 1: Main elements shaping the TeleStroke system.

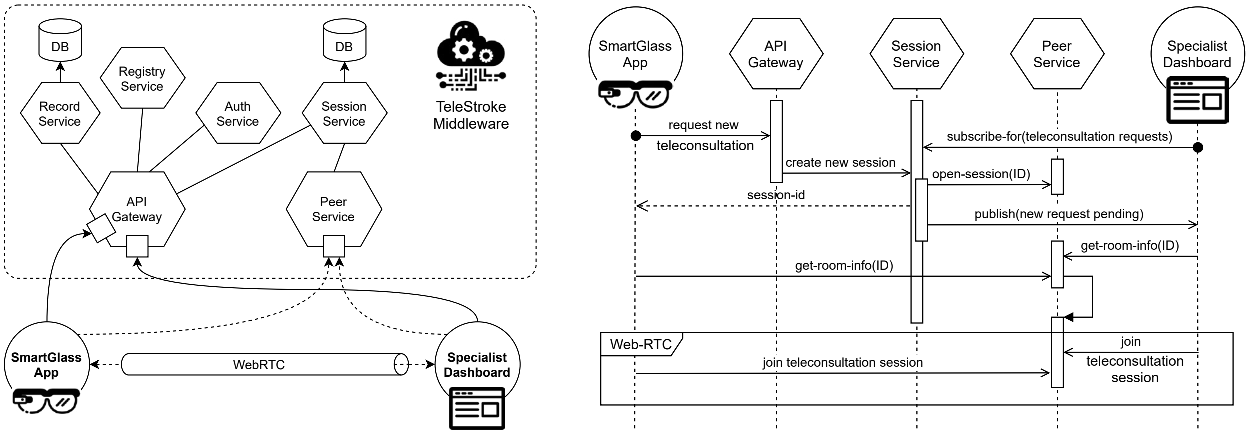
appears desirable, considering the need to increase the efficiency of the technological and functional links between the various hospitals, promoting the cohesion and homogeneity of corporate care paths regardless of the network access point.

The main objective of the TeleStroke system is allowing a physician to be remotely guided by a dedicated neurologist in performing an accurate stroke diagnosis. The remote neurologist needs to interact in real-time with the physician and simultaneously see reactions and responses of the patient according to the NIHSS (National Institutes of Health Stroke Scale) [19], a conceptual tool used by neurologists to quantify the impairment caused by a stroke objectively. The physician, vice-versa, following the instructions received by the remote neurologist, interacts with the patient to ask them to perform specific actions – e.g., how they respond to request about moving eyes, speaking, moving arms and so on. In this way, when a stroke is really diagnosed, its treatment can start immediately, avoiding waiting for the patient to move to the stroke unit. The benefits in terms of quality and success of treatment for most patients with suspected strokes are undeniable, being the stroke a time-dependent pathology. Secondly, advantages can also be observed in terms of cost reduction for the personnel and better resources management.

Generally speaking, the TeleStroke system is a software system exposing two distinct macro parts, as shown in Figure 1. These parts (subsystems) are respectively designed for the *operator* – the physician that is in charge to directly manage the patient with a suspected stroke, who acts at the spoke side – and the *specialist* – the remote neurologist that is in charge to make the stroke diagnosis, who works at the hub side. The following paragraphs explain the coarse-grained requirements of both parts.

The Operator Subsystem (Spoke Side). On the operator side, a physician wearing smart-glasses can ask for a teleconsultation of a remote neurologist. The motivation for the introduction of smart-glasses as a device with which the operator interacts with the system is twofold: (1) a hands-free interaction is more advisable because the operator during the consultation needs to touch/move the patient, and (2) the specialist needs to see in real-time what the operator sees. Furthermore, during the teleconsultation, the operator needs to talk with the remote specialist and to receive non-invasive messages on the smart-glasses display about the ongoing state of the teleconsultation (e.g., the step of the NIHSS under evaluation in a specific moment).

The Specialist Subsystem (Hub Side). On the specialist side, a neurologist – who is not involved in another teleconsultation – can answer the remote teleconsultation request by an operator. When the teleconsultation starts, the specialist needs to speak with the operator and simultaneously see the video captured and transmitted by the operator' smart-glasses. Moreover, the specialist should exploit an adequately designed interface to follow the NIHSS checklist and annotate both the patient's clinical picture and the results of the NIHSS steps. Finally, at the end of the teleconsultation, the system calculates the stroke severity, giving the specialist all the details to conclude the patient diagnosis.



(a) System Coarse-grained Architecture.

(b) Teleconsultation setup interaction process among services.

Fig. 2: TeleStroke Design and Development Details.

3.2. *Coarse-grained Architecture*

The TeleStroke system intrinsically is a distributed software system composed of two distinct parts, respectively dedicated to the operator and the specialist. Nonetheless, in the design phase, we devise the opportunity to introduce a third component to mediate the cooperation between the mobile app to be executed on the operation smart-glasses and the web app designed for the specialist. This third component runs as a back-end service and acts as a middleware to support the teleconsultation application logic (see Figure 1).

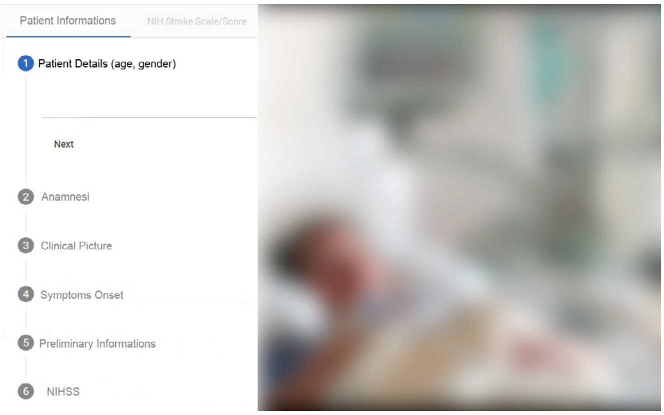
The middleware is designed according to a service-oriented architecture (SOA) – as shown in Figure 2a – and is in charge to enable both operator and specialist front-ends to initiate the teleconsultation, managing the whole process of authentication and data exchange. The middleware exposes a properly designed RESTful API, accessible through an API Gateway. It also enables the results storage (including the audio/video call recording) and allows subsequent data access. All the interactions among front-ends and the middleware exploits the HTTPS protocol—considering the nature of the exchanged data, aspects as privacy and security must be adequately considered. To allow the real-time audio/video streaming between the operator and the specialist, the design phase reflects the choice to establish a peer-to-peer (P2P) connection between the two front-ends to ensure adequate performances and robustness to the communication. For this purpose, the WebRTC[3] protocol is adopted and implemented.

Within the TeleStroke domain model, considering its functional requirements and uses-cases, when a specialist is logged into the system and properly authenticated, a subscription to the `Session Service` declares the availability of the specialist to receive teleconsultation requests. When a remote operator requests (and waits for) a teleconsultation to the `Session Service` – exploiting the APIs provided by the `API Gateway` – a new session with a proper ID is created by the `Peer Service` and, then, the first available specialist is notified by its dashboard. In the system, a properly defined session where both the operator system and the selected specialist one can join is called `room`. Details about how to set up the P2P Web RTC channel for a particular `room` are managed according to the Web RTC protocol requirements. An example of the interaction among front-ends and backend services to set up and manage a teleconsultation in the TeleStroke system is reported in Figure 2b, where details about the authentication process, teleconsultation audio/video recording, data storage and few others are omitted for simplicity.

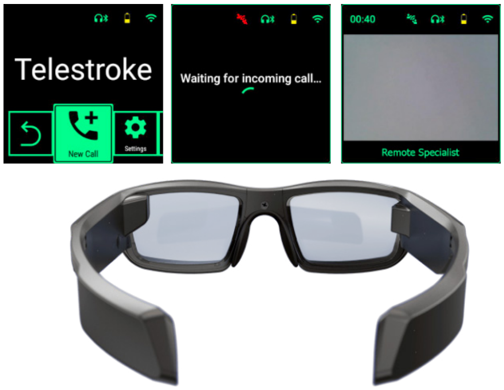
3.3. *Prototype Development and Technologies*

A first prototype of the TeleStroke system has been developed according to the described architecture. Currently, it is under experimental evaluations at the Stroke Unit collaborating to this study. For the operator subsystem, we

[3] WebRTC (https://webrtc.org/)



(a) A screenshot from the Specialist Frontend.



(b) Operator Smartglasses with several screenshots of the cards of the mobile app.

Fig. 3: TeleStroke system prototype' screenshots and elements (images from cameras have been blurred for privacy reasons).

adopted the Vuzix Blade Upgraded SmartGlasses[4] as a reference device. At the best of our experience, this device offers an appropriate degree of usability, ergonomics, and enough battery duration. We developed an Android app to be executed on this device, using Kotlin as reference language. In terms of user interface (UI) design, we followed the main guidelines for content positioning, colours, text dimensions and so on (a few screenshots are shown in Figure 3b) for smartglass-oriented mobile apps. Furthermore, considering the critical context where this app will operate, we refined the prototype's UI following the principle of reducing the number of interactions that the operator must do to activate and manage the teleconsultation. Instead, the front-end dedicated to the specialist is a web app developed using the Angular Framework and the TypeScript language. In particular, it is a responsive web app capable of rearranging itself according to the screen size (in our case study, the specialist can access the system from both a traditional PC or a tablet). Moreover, regardless of screen size, the front-end always ensures the specialist concurrently keeps tabs on both the video streaming coming from the operator and the protocol checklist for data entry (see Figure 3a). The backend has been developed using Vert.x as a reference technology for microservices implementation and the RESTful API definition. Moreover, we adopted MongoDB and Redis as reference technologies for the services data storage. Finally, to develop the WebRTC interaction, we introduce ad-hoc components based on PeerJS and PeerJS-Server libraries to create and manage the audio/video streaming channel and the RecordRTC library to record and store each teleconsultation call along with collected data and information.

4. Final Remarks

Telemedicine can have a meaningful impact on offering several health services to patients in the next future. Among this broad perspective, teleconsultation can immediately affect the actual cure processes in hospitals and, generally, local health authorities, offering – at the same time – health cost reduction and improvements of the health care quality and healthcare processes. The TeleStroke project presented in this paper represents the first result of a collaboration in a real-world case study about the remote diagnosis of a suspected stroke. Its logical architecture and its current prototype result from a domain-driven design phase, where we tried to incrementally produce a system as much as possible tailored to physicians needs. First simulations have been done in a supervised environment, with simulated patients. The first obtained results are encouraging, especially in terms of system usability and prototype stability. Our first evaluation aims were targeted to analyse system usability with the domain experts, the system's final users. In particular, we are interested in investigating the applicability of the wearable subsystem to support an adequate hands-free teleconsultation. Considering this perspective, we incrementally refactored the system user interface to minimise the impact of the system on the action the operator has to carry out. Accordingly, we also revised and

[4] Vuzix Blade Upgraded SmartGlasses (https://www.vuzix.com/products/blade-smart-glasses-upgraded)

refined the whole architecture and specialist front-end, introducing additional use cases as the possibility for the neurologist to personalise its NIHSS checklist and improve the management of the ongoing teleconsultation with the remote operator. Further steps in the evaluation and refactoring process will be devoted to using the TeleStroke system in a non-simulated scenario with real patients. Of course, additional precautions must be considered regarding the privacy and security of the audio/video transmission and the acquired data storage. For the system evaluation purposes, currently, among the data we store, there are also the patients' video shooting – kept for an a posteriori re-evaluation of each whole diagnosis process. So, a comparison with a traditional approach to stroke diagnoses can be appropriately carried out. For instance, whenever possible, performing a remote diagnosis and an on-place diagnosis by another dedicated neurologist. Finally, the introduction of Machine Learning (ML) techniques along with Computer Vision approaches are part of the research agenda related to the TeleStroke system. In particular, considering the video streaming of the teleconsultation as input, the aim is to evaluate if and how much such approaches can assist both the operator and the neurologist in detecting particular conditions to speed up the stroke diagnosis – towards a kind of computer-assisted real-time diagnosis.

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