

# Assessment and analysis of territorial experiences in digital tele-echocardiography

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**Summary.** Nowadays digital ultrasound-cardiovascular devices are able to send out directly digital images and films. Thanks to the large adoption of such devices, the echocardiographic world is facing new ways of exchanging images and collaborating. What we present in this paper is a review of the experimental projects carried in Lombardy, meant to support the work of specialists by means of second opinion and telemedicine services. On the medical point of view echocardiography is a widely used activity where operators are perfectly accustomed to do repetitive operations and steps. Tele-echocardiography (T-E) introduces new methods and technologies into stable and everyday medical practice, causing disruptions either on the side of the specialists' way of working or on the new opportunities and service. Introducing such a service means to properly model it in order to reduce the changes in the operators' way of working while maximizing the benefits. A proper method of modelling the operators' needs is then a key factor which must be correctly addressed. This paper will present some successful projects and the assessment procedure but it will also discuss a possible service modelling method, which has been adopted for the described experiences.

*Key words:* technology assessment, echocardiography, telemedicine.

**Riassunto** (*Valutazione e analisi di esperienze territoriali in tele-ecocardiografia digitale*). Oggigiorno gli strumenti digitali per la ecocardiografia ad ultrasuoni sono in grado di produrre immagini digitali e filmati. Grazie al largo impiego di questi strumenti il mondo della ecocardiografia sta affrontando nuove modalità di scambio immagini e collaborazione. In questo lavoro è presentata una revisione su progetti sperimentali realizzati in Lombardia, con l'obiettivo di supportare il lavoro di specialisti per mezzo di consultazioni di tipo *second opinion* e servizi di telemedicina. Da un punto di vista medico l'ecocardiografia è una "pratica medica" ampiamente usata, dove gli operatori sono perfettamente in grado di fare delle operazioni ripetitive e dei passi ben prestabiliti. La tele-ecocardiografia introduce nuovi metodi e tecnologie in "pratiche mediche" ben stabilizzate causando da un lato disagio dal punto di vista del modo di lavorare dello specialista, dall'altro portando nuove opportunità e servizi. Introdurre un tale servizio implica una opportuna modellizzazione dello stesso in modo da ridurre i cambiamenti nel modo di lavorare dell'operatore e massimizzando i benefici. Un opportuno metodo di modellizzazione dei bisogni dell'operatore è pertanto un elemento chiave e deve essere opportunamente preso in considerazione. Questo lavoro presenta alcuni progetti realizzati con successo ed i relativi metodi di valutazione ma discute anche i possibili metodi di modellizzazione del servizio che è stato adottato per le esperienze descritte.

*Parole chiave:* valutazione tecnologica, tele-ecocardiografia, telemedicina.

## INTRODUCTION

The large diffusion of last generation of echocardiography instruments stimulated research on new applications able to exploit their digital image handling features. T-E is thus becoming an important new instrument for the echo-cardiologists, but its potentials are still not completely exploited.

Nowadays, the transmission of images and films is greatly facilitated by the diffusion of digital ultrasound-cardiovascular devices able to send out

directly JPEG images and MPEG videos (still and loop modes). The diffusion of Digital Imaging and Communication in Medicine (DICOM) [1] also encourages the migration of the echocardiography world to the digital era, enabling the integration of either portable or stationary ultrasound devices in a unique informatics network, both with wired and wireless connections. An interesting scenario could be so depicted: distant physicians, with different ultrasound devices, able to collectively share

images and clinical information. The only problem is that this scenario must be supported without adding complexity to the work of professionals and, at the same time, the work must be guided. Literature reports several studies about the impact of T-E in the clinical life [2-10]. These studies are characterized by a difficult geographical situation in which the afferent centres can be hardly reached and are relatively far one each other. Most of these studies have been supported to evaluate the possibilities of having correct echo-cardiographic images, even in case of tele-consultation and tele-presence (tele-guided acquisition from distant equipments).

According to published papers by the clinical point of view the most promising sectors, in which a telemedicine tool can greatly improve care quality, seem to be the cardiological emergencies [8, 9], the paediatric cardiology [2-7] and the adult congenital cardiopathies [10].

In any case the greatest advantages of telemedicine and distant collaboration tools are the availability of a tele-diagnosis at any time, the possibility of treating correctly the patient only after a proper consultation, the reduction of morbidity connected to transportations and the reduction of hospitalisations costs.

On the medical point of view echocardiography is a widely used activity where operators are perfectly accustomed to do repetitive operations and steps. T-E introduces new methods and technologies into stable and everyday medical practice, causing disruptions either on the side of the specialist's way of working or on the new opportunities and service. Introducing such a service means to properly model it in order to reduce the changes in the operators' way of working while maximizing the benefits. A proper method of modelling the operators' needs is then a key factor which must be correctly addressed. This paper will present some successful projects and the assessment procedure but it will also discuss a possible software and service modelling method, which has been adopted for the described experiences.

## TERRITORIAL EXPERIENCES

Building a T-E service consists of different steps: efficient modelling of the software service collecting requirements of physicians (see chapter "The modelling process for an efficient development of T-E services"), design of the proper media transmission channel and setup of the proper discussion instrument (setup of the community). The two following experiences focuses on these two latter aspects, the first digress on several transmission and image compression methods, the second discuss a web based virtual community of experts and introduces the software modelling discussion of chapter "The modelling process for an efficient development of T-E services".

### *Low-cost, ubiquitous T-E combining high-grade video compression and low-bandwidth transmission lines: from pilot studies to clinical use*

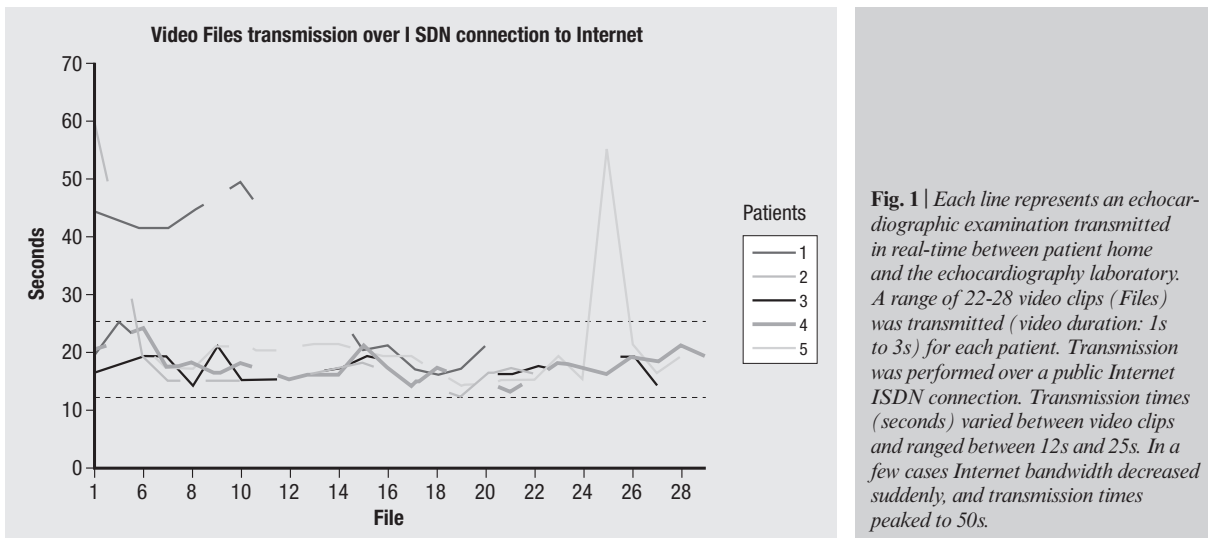
The cornerstone of echocardiography is combined motion video 2D and colour Doppler imaging. Modern echocardiographic machines produce digital motion video imaging which is compressed (low grade lossy method) using an MJPEG codec within the standard DICOM protocol. However, because of the limited compression, (*i.e.*, large video files), T-E would need high bandwidth transmission lines (*Table 1*) which are expensive and not widely available in our country, especially in remote areas where T-E would be needed the most. The use of (small) still frame images as a surrogate for full motion video transmission does allow remote transmission of echocardiographic information, but diagnostic content is reduced to such an extent that this modality is acceptable only in extreme, isolated scenarios.

Alternative applications for T-E are tele-consultations between a first or second-level and a third level echocardiography laboratory, and remote education programs.

To overcome these limitations, a project was started in 2003, with the aim to create a software ([www.emedstream.com](http://www.emedstream.com)) which would simplify acquisition and transmission of echocardiographic motion video clips utilizing high grade motion video compress-

**Table 1** | *Transmission and image compression methods in T-E*

Connection	Description	Transmission velocity		MPEG4	MPEG4	DICOM
POTS	Analogic modem	56 kb/s	56 kb/s	20"-40"	14'	2h (6h)
GPRS	Cell. phone	56 kb/s	56 kb/s	20"-40"	14'	2h (6h)
ISDN	Integrated service digital network	128 kb/s	128 kb/s	8"-16"	6.25'	1h (3h)
UMTS	Cell. phone	64 kb/s	384 kb/s	20"-40"	14'	2h (6h)
ADSL	Asymmetric digital subscriber line	768 kb/s	768 kb/s	1.5"	1'	9' (27')
T1	Cable	1.5 Mbit/sec	1.5 Mbit/sec	0.8"	32"	4.4' (13.2')
LAN	Local area network (Ethernet)	10 Mbit/sec	10 Mbit/sec	<1"	5"	40" (2')
T3	Fiber distributed data interface	45 Mbit/sec	45 Mbit/sec	<1"	1"	9" (27")
		100 Mbit/sec	100 Mbit/sec	<1"	<1"	4" (12")
ATM	Asynchronous trasmission mode	>500 Mbit/sec	>500 Mbit/sec	<1"	<1"	<1" (2")



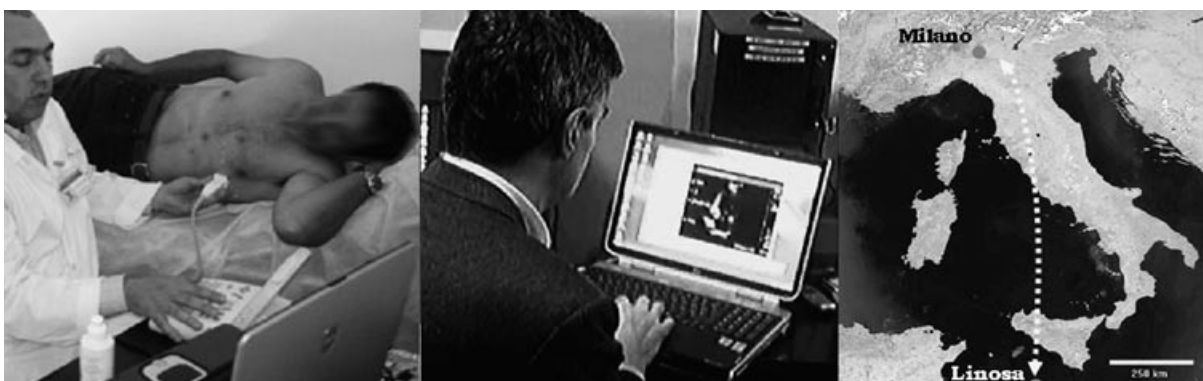
sion with royalty-free MPEG-4 codecs and the widely available and tested IP transmission protocol. The software, available with both a point-to-point and a client-server architecture, connects an echocardiographic machine to a remote notebook that receives the compressed and transmitted video clips. All MPEG-4 codecs produce files with a very high grade compression (up to 1:1000), allowing transmission of short video clips over low-bandwidth lines (from analogical modems 56 kb/s to ADSL 768 kb/s) at acceptable or even real-time transmission times (Table 1). A recent multicenter study – a part of the present project – has established acceptable clinical quality for transmitted MPEG-4 video [11].

Pilot clinical experience with the acquisition/transmission software has included:

- 1) real-time transmission of complete echocardiographic examinations obtained with a portable echocardiographic equipment (SonoHeart Elite, SonoSite Inc., WA, USA) between patient homes and an echocardiography laboratory, uti-

lizing an ISDN (128 kb/s) public Internet connection (Figure 1), after coding of patient data. Notwithstanding the low bandwidth, transmission times of each motion video files (duration: 3 s) ranged 10-25 s such that transmission could be defined as “pseudo-realtime”, and occurred within the duration of the study. Other studies adopted faster transmission methods such as HDSL [12];

- 2) transmission of sample echocardiographic studies (a sequence of 3 s motion video clips), within the GILDA (Gruppo Italiano Linosa Diabete e Sistema Nervoso Autonomo) echocardiographic substudy [13], between the Mediterranean island of Linosa and the Ospedale L. Sacco in Milano (Centro Ricerca Terapia Neurovegetativa) in May 2003, using a low-bandwidth satellite VPN connection (range: 80-128 kb/s) (Figure 2);
- 3) transmission of sample short motion video clips (duration: 1 s) from echocardiographic studies performed on the Italian alpinists participat-



**Fig. 2** | Left: Acquisition of video files with a portable echocardiographic machine (SonoHeart Elite, SonoSite Inc.), connected to the transmitting notebook computer, in the echocardiography laboratory on the island of Linosa. Center: Display of the echocardiographic motion video files on the receiving notebook in the Sacco Hospital in Milano. Right: Geographic locations.

ing in the "K2" Italian celebrative expedition in July 2004 (<http://k2.planetmountain.com>). The transmission occurred over an ultra-low Internet bandwidth (9 kb/s of a portable satellite telephone) connecting the Himalayan base camp of the expedition (altitude 4500 m) in Pakistan with the hospital Centro Cardiologico Monzino, IRCCS in Milano.

The best example of a present day successful clinical application of tele-consultation in echocardiography is the T-E consultation project of the Istituto Geriatrico "P. Redaelli" (R.S.A.) in Milan, which was started in January 2007. Within this project, the T-E software connects an echocardiography machine operated by a first level physician (specialty: internal medicine) in the echocardiography laboratory of the Redaelli Institute with the remote notebook of a third level cardiology consultant specialist, located in the Milan urban area. Consultations are made both in real-time (urgent consultations) or scheduled on a regular basis. The connection is based on the IP protocol and a VPN connection (ADSL). Video files are originally compressed using a Windows Media Video 7 codec [11].

During the first 17 months of the clinical project, there have been 101 T-E consultations involving 95 patients (age range 22-96 years, mean 74). A clinical utility (*i.e.*, change in clinical management of the patient following the T-E consultation) was found in 40.6% of the cases. A total of 4617 video files have been transmitted (2669 motion video clips of 3 s duration and 1948 still frames), totalling 1.4 GB of low-bandwidth transmitted data. A mean of 45 video files totalling 13.8 MB was transmitted over a 10 minute period for each patient. Duration of transmission was 23 minutes for real-time (23.8% of cases, transmission occurring during the echocardiographic examination) and 6 minutes for scheduled tele-consultations (76.2% of cases). To the best of our knowledge, this is the only clinical adult T-E project in Italy based on remote transmission of complete echocardiographic studies using low bandwidth.

In conclusion, real-time T-E of complete echocardiographic studies is feasible and clinically useful using custom made software and off-the-shelf hardware using very low to low-bandwidth Internet connections and validated MPEG-4 compression of echocardiographic motion video files.

#### ***Echo-cardiography on the web, virtual community of experts***

Starting from the experience of TeleRegions SUN [14] we created a tele-consultation tool among different level hospitals, called CAROLIN (Cooperatives Application for Remote On-Line Interactive diagnosis) [15, 16] that has been further developed in the TeleRegions SUN2 IST Projects [17]. CAROLIN is a multimedia application for cardiology teleconsulting that is currently used as the main instrument of the CARDNET Network [18]. Members of CARDNET were 12

hospitals in Lombardy (Italy) with and without cardiology dept. (6 cardio-surgery and 6 cardiology depts) and 3 in Catalunya (Spain). The primary aim of CAROLIN was to facilitate and streamline remote exchange of clinical information [19] among the various hospital levels of the CARDNET Network, reproducing the characteristics of a real consultation as closely as possible.

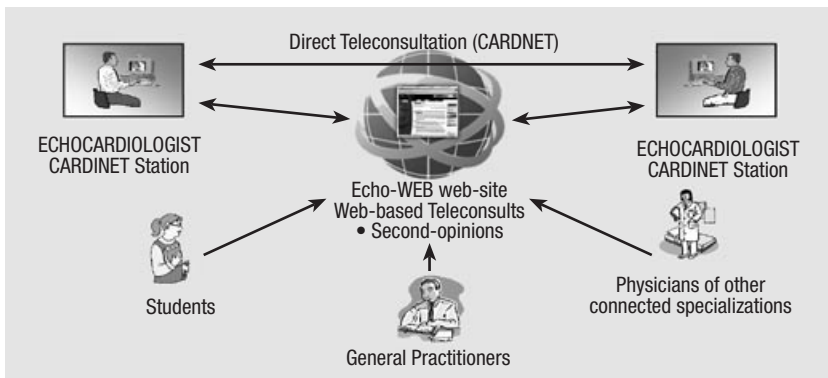
Despite this system was originally studied for angiographic needs, to transmit angiographic films, at the time the most urgent needs were the possibility of using it to transfer echocardiographic films among echocardiographers and cardiologists. A large community of cardiologists was already used to CAROLIN, thus the main idea behind is still present in the system here presented, so as not to lose already accumulated expertise. We modified CAROLIN to handle efficiently echocardiographic images too and share them through the web to create an open community of experts exchanging their knowledge.

The working torque formed by the web site and CAROLIN allows CARDNET users to still consult in the already accustomed way (through CAROLIN), and at the same time to be part of a larger virtual community of experts (through the web site), with great advantages of single members (*Figure 3*).

#### **THE MODELLING PROCESS FOR AN EFFICIENT DEVELOPMENT OF T-E SERVICES**

The modelling process for such a complex application domain is extremely important. In an ideal situation physicians (customers) show their needs and requirements mostly at the beginning of the project and developers (providers) must translate them into a program. Further steps are only refinements or enhancements of the initial requirements list. In our case, instead, the requirements definition was not so simple, mostly due to application field newness. Echocardiographers were not aware of the technological possibilities and unready for this new way of working, thus they were not able to define their targets and wants so far to start the developing. This situation implied a more complex requirements definition process, a repeated series of interactions and some full turns.

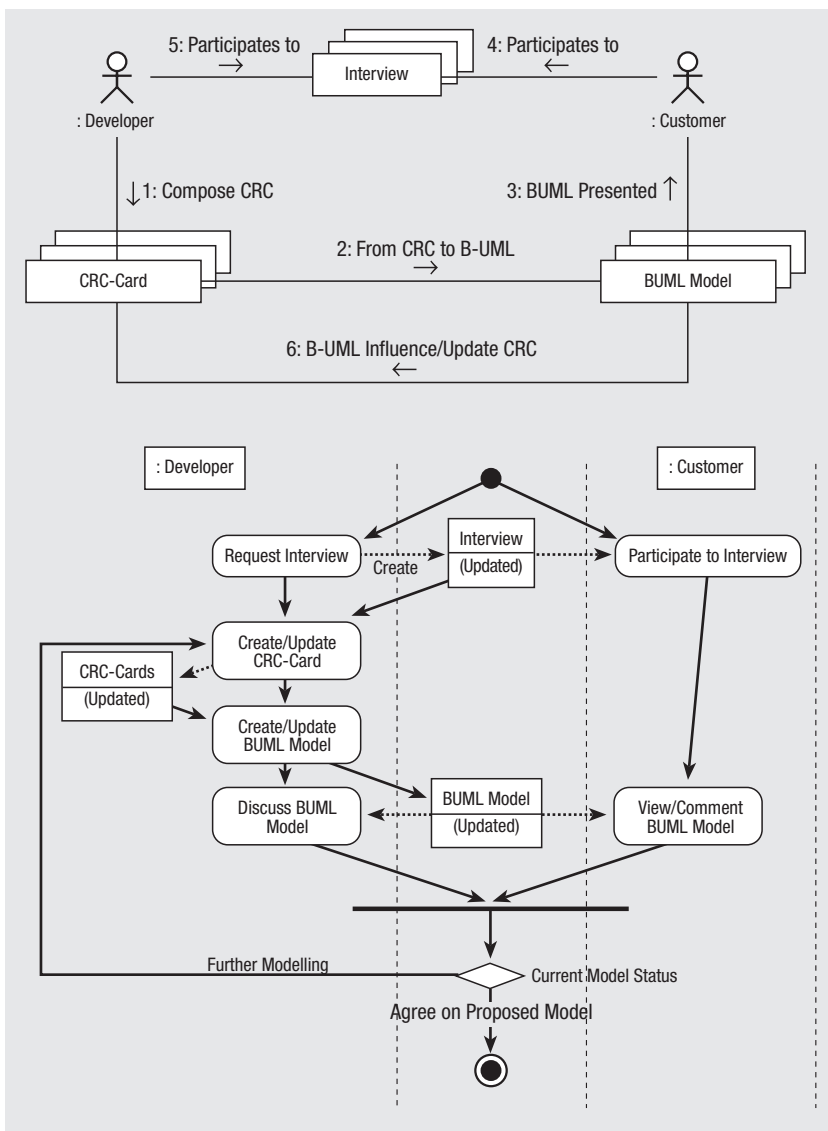
The process on which we based our work is the RUP (rational unified process), that splits the work in different phases and for each one defines targets, artefacts and methodologies, using UML [20, 21]. RUP is a quite generic modelling process and must be customized to fit into specific application domains. A strength key of the RUP approach is that early business modelling phases follows the same principles as object modelling for software development; the use of common principles makes the resulting business model easy to be understood even by the customers. The main target of our inception phase [22] was to stimulate physicians' collaboration and curiosity, to let them freely contribute to the requirements definition with their experience.



**Fig. 3** | Overall view of the digital echo-lab system. CARDNET users can work involving or not the web, directly teleconsulting or sharing cases.

First of all we helped physicians to understand problems and possibilities of the web and in general of telemedicine. Later we proposed several detailed usage scenarios (based on our experience and on existing literature) and discussed them through

interviews and comparative analysis of real operative situations. We focused physicians' attention on how their current way of working could be modified, underlining enhancements but also possible errors and risks.



**Fig. 4** | Schema of the interview-CRC-BUML modeling process used to create the system. It is shown as a collaboration diagram on the left to emphasize process's structure and as an activity diagram on the right to emphasize process's steps in the time.



In this phase the main used instrument has been the Interviews, but the problem was to define a common language being technical enough for the Developers and descriptive and simple for the physicians. We adopted the CRC-Cards (class responsibility and collaboration) [23, 24] and the Business UML diagrams (BUML) [25].

Even if these methodologies are quite classical software engineering techniques, in the telemedicine field they are quite new and not so commonly used, because these new application field potentials are not still completely understood both by customers and developers. On the one hand customers do not know which benefits they can have because they do not know anything about the technology but want, beside innovation, the easiness of usage. On the other hand developers do not know which problems the health world can have and do not have the right sensibility for health matters. A bridging fast process is therefore very important.

The whole process making use of CRC-Cards and BUML involves different steps. Through the execution of different interviews customers and developers come to a common understanding of their problems: from the technical point of view, developers have some limitations (technological or know-how) and, from the application point of view, customers have some specific needs that they often do not know how to formalize in a clear and understandable way.

Commonly these points of view differ due to the different people's backgrounds: CRC and BUML would help bridging these worlds. CRC-Cards have been used to understand high-level technical details and problems behind the system's target with an informal and agile process. BUML has been used as a proof-desk to visualize and understand the business processes and easily share, understand and discuss models with the customers. Both these instruments are flexible enough to be used during the limited time of the customers' interviews.

We can say that a continuous loop refines results, producing better and agreed models of what the system shall do and a clear idea of how to do it.

Figure 4 depicts the whole process, thanks to an UML collaboration diagram and of an activity diagram, where each phase has been numbered: 1) developer writes CRC-Cards trying to snap some technical details directly inspired by the interviews; 2, 3) these Cards are also used to write BUML diagrams shown and discussed with the Customers; 4, 5) the whole process is made during the interviews in real time; 6) the CRC-Cards and BUML are therefore mutually influenced by the interview and its modelling. This method proved itself to be agile and flexible enough to catch all needed details during the interviews. From the business processes analysis we derived the models used to create the system.

One early result of the modelling process has been to clearly define what a SO is for physicians. Figure 5, making use of BUML [21], shows how our tool relates with the habit of asking SOs with non informatics tools, for

example through direct speaking with other colleagues and also introduces three types of users:

- "registered user" who only has read access to SOs submitted to the whole community (e.g. medicine students);
- "registered physician" who does not have a CAROLIN station but can receive/send SOs (e.g. echo-cardiographers outside the CARDNET network with a normal Digital Echo-Lab device);
- "CAROLIN user" who has the same functionalities of a "registered physician" but has special technological requirements (e.g. CARDNET users), such as a specific data format.

A complete UML-based view of the system is the main result of this modelling process. These models helped developers and physicians to understand one each other and more rapidly converge to a working system, avoiding frustration and incomprehension, this definitely also helps migrating from echocardiography to tele-echocardiography.

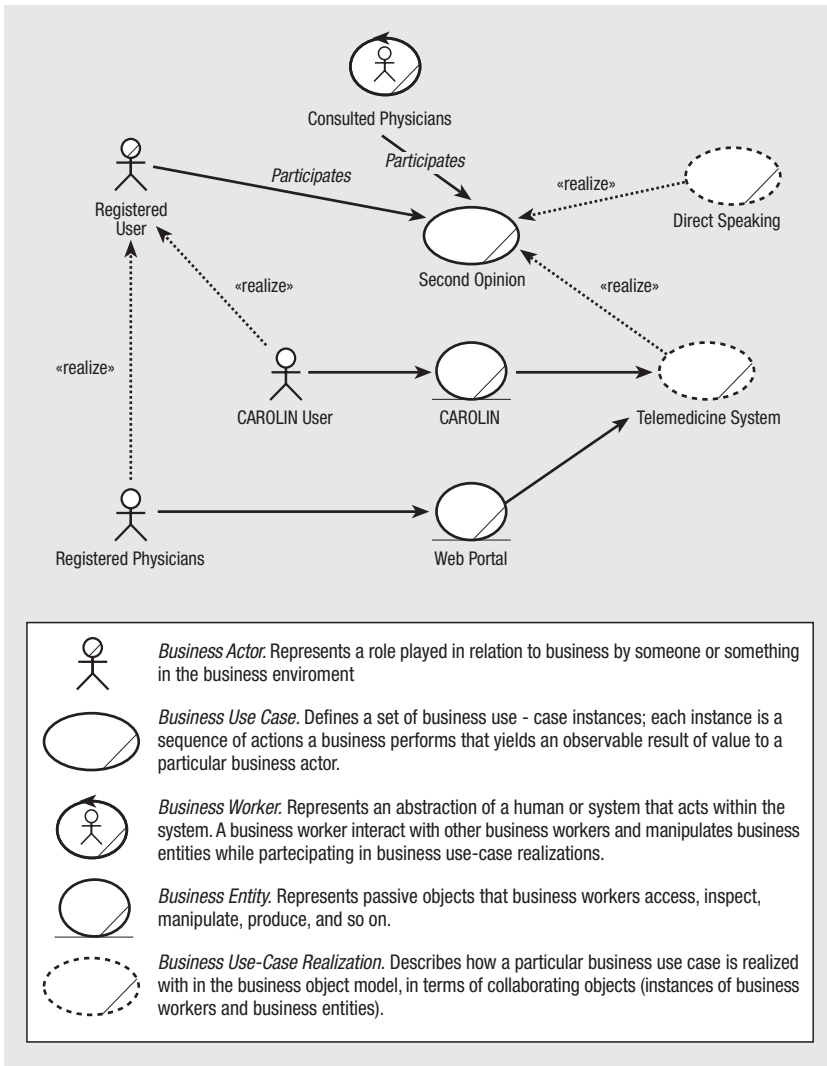
## THE ASSESSMENT OF TELEMEDICINE APPLICATIONS

Tele-echocardiography, similarly to other telemedicine applications, can be primarily seen as a process rather than simply a technology, due to the interaction of the equipment and the information transmitted with the activities of healthcare professionals and patients. Nowadays, pressures for the adoption of telemedicine increased the demand to assess these applications.

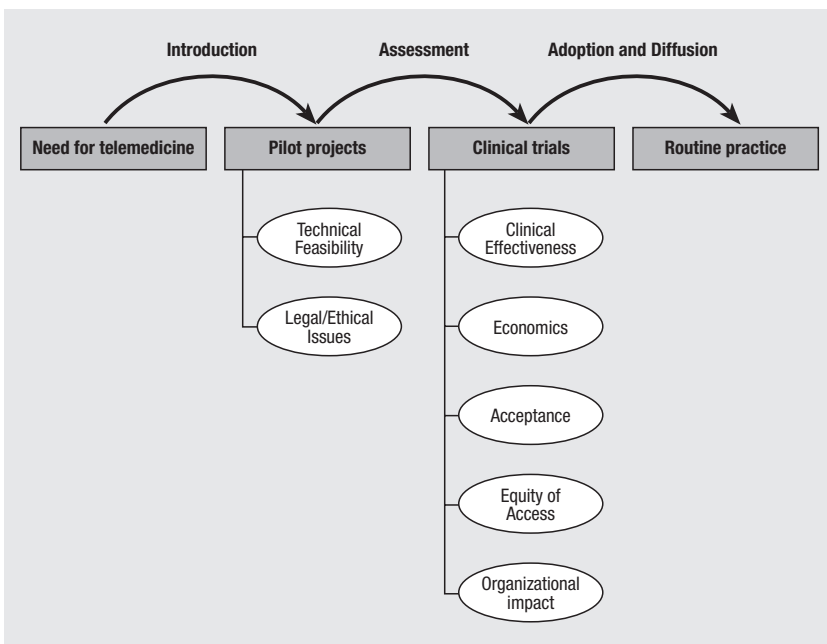
Scientific literature is characterized by some relevant theoretical studies [26-33] which deepen the assessment dimensions in telemedicine or suggest guidelines about the implementation process. In particular, Masella and Zanaboni [34] provide an assessment framework which supports decision makers (authorities and providers) to understand the value of telemedicine applications in terms of real benefits and to support future decisions. The main assessment dimensions identified in the framework include technical feasibility, legal and ethical issues, clinical effectiveness, economics, acceptance, equity of access and organizational impact. Additionally, the framework identifies the linkages between the assessment dimensions and the assessment process of telemedicine applications which starts with the introduction of the service, conducted through early studies testing the basic feasibility and considering legal and ethical implications. The second phase consists in the subsequent assessment of the service, conducted through clinical trials aimed to further demonstrate the value of the intervention. Finally, adoption and diffusion implies the transfer of the service into routine clinical practice. The Figure 6 depicts the phases of the overall process of the assessment of the telemedicine.

### T-E assessment studies

Studies on T-E applications mainly focused on technical feasibility dimension, underlying the early stage of this kind of service. Relating to the technical feasibility a recent paper [11] shows a multicenter



**Fig. 5 |** The adopted second opinion BUML model and a legend of BUML symbols used.



**Fig. 6 |** The phases of the overall process of the assessment of the telemedicine.

study evaluating echocardiographic video high-grade compression with the new Moving Pictures Expert Groups MPEG-4 algorithms. They demonstrated that very high compression grades are achievable without significant degradation of image quality or loss of diagnostic content. Mehta *et al.* [6] tested three types of T-E connections. They measured the time intervals between performing a study and returning the results and found significant differences primarily determined by the mode of transmission. Additionally, physician satisfaction was assessed through a survey, showing that the service improved the management of patients. Widmer *et al.* [35] study aimed at confirming the feasibility and usefulness of telemedical communication for echocardiographic evaluation of paediatric cardiovascular disease. In particular, in 191 children (98%) the remote echocardiographic diagnosis was correct as confirmed by follow-up face to face consultations. Additionally, legal aspects of the telemedicine application have been considered. Woodson *et al.* [36] tried to solve the problem of the permanent storage of telemedicine files based on accurate images but without a significant increase in storage requirements. In this way, they evaluated the accuracy of Moving Pictures Expert Group (MPEG) digitization of incoming video streams and the storage requirements for a T-E program. The study, including 51 patients, showed that all major cardiac diagnoses were correctly diagnosed by review of MPEG images. Additionally, it included time and storage needs. On the contrary, Lewin *et al.* [37] found that the accuracy echocardiographic transmission via telemedicine using video-recordings may be less accurate than via real-time telemedicine. Other studies aimed at demonstrating the utility and accuracy of T-E diagnosis, identifying patients who need emergent transfer [38], optimizing utilization and improving the cost-effectiveness of remotely obtained echocardiography [39] and testing a portable satellite transmission system in the assessment of cardiac emergencies [40]. Finally, Finley *et al.* [41], additionally to the diagnosis accuracy, studied the cost of the application (equipment and telecommunications) and the economic benefits in term of unnecessary patient transfer.

## DISCUSSION

Scientific literature is characterized by few and recent studies focused on T-E applications. Therefore, remote transmission of echocardiographic images

does not seem yet to be widely diffused and it could require additional studies. Starting from the assessment dimensions of the framework, technical feasibility represents the most observed issue. Many scholars, in fact, agree in claiming the accuracy of tele-echocardiography. Additionally, Giansanti *et al.* [42] provide a thorough protocol for the assessment of the diagnostic accuracy of the transmitted images, which considers not only the most common quantitative parameters in medical imaging, but also the use of a dynamic phantom and subjective/partially subjective evaluations. On the contrary, only a study partially considered legal implications. Even if some pilot studies tested the diagnosis accuracy with comfortable results, the evidence of clinical effectiveness has yet to be demonstrated. Analyzing the other assessment dimensions, acceptance has been measured by one study through a survey and economics dimension has been measured by two studies in term of costs and savings or generally in term of general utilization implications. Finally, organizational impact and equity of access have never been considered.

The novelty of this application is the reason for several unexpressed needs of most physicians, the great success of relatively classic software engineering techniques is an important proof. These models helped developers and physicians to understand one each other and more rapidly converge to a working system, avoiding frustration and incomprehension, this definitely also helps migrating from echocardiography to (T-E).

## CONCLUSIONS

In conclusion, T-E applications currently have potential benefits in respect to the traditional echocardiography. Although technical feasibility and diagnosis accuracy have already been demonstrated by many scholars, additional clinical trials (not necessarily randomized controlled trials) could be conducted in order to provide a complete and comprehensive assessment (considering more assessment dimensions together) of the application. Consequently, if the value of the intervention is positive and the evidence of benefits is clear, decision makers will be able to decide to transfer the service into routine clinical practice.

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