Telemedicine: Its Sub-Systems & The Corresponding Actants

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Abstract. In order to identify factors influencing adoption of information technology in healthcare, various IS theories, frameworks, and approaches have been applied. This research uses actor-oriented approach to explain telemedicine sub-systems and their actants. Telemedicine has been viewed from system engineering's perspective. In systems engineering, the dynamics and interactions amongst various components and modules lead to the desired outcomes of the system. This research aims to: i)delineates the linkages and relationships that exist between various sub-systems within a telemedicine system ii)traces affiliations and roles of key elements within each of the sub-systems. The outcome of this research is expected to enable professionals like system analysts, system designers, developers, technologists in understanding the aspects needed to be considered while eliciting user requirements.

1. Introduction

In their study of the normative literature, researchers have stated that while understanding the factors influencing adoption, much emphasis has been laid on organizational, human, and social dimensions (1). But the technical factors that influence adoption still remain to be researched. Factors identified so far primarily correspond to economic, organizational, and behavioral knowledge categories (2)(3). Furthermore, understanding how technological barriers impede the adoption of telemedicine is even more important because technological barriers were largely responsible for failure of the first wave of telemedicine projects in the 1970s and 1980s (4) (5).

Besides other qualitative and quantitative research tools, IS research tools used so far include factor-oriented approach (6), actor-oriented approach (7)(8), and the diffusion of innovations theory (9). We have adopted actor-oriented approach from the group of researchers who identified non-technical actors involved in adoption of innovations in healthcare organizations (1).

Researchers have defined an actor as an encapsulation of actions performed by a module (or a component) to produce an effect (or an influence) or output data (10). Actors strongly affect the adoption process (11) of the technical system to which they belong. Actors collaborate with each other to produce the desired deliverable, and this collaboration gives birth to the creation of the actor-network. A heterogeneous network of actors can be viewed as a single actor "from a distance." By working out logical relationships and linkages, a complex system like telemedicine system can be broken into a form or nested sub-systems which are composed at each level to form a network of interrelated components. Hierarchy could be worked out with the help of abstraction that hides the detail of a subsystem from the rest of the system. Researchers and practitioners have applied the actor-oriented approach in diverse environments (12) (13) (14) (15). Researchers have used the term "actor" in multiple contexts. It has been used for people and objects (including equipment, computer software, hardware or technical standards, etc.) (16).

2. Methodlogy

Telemedicine has been classified as a complex innovation bundle that is a technical as well as an organizational and social innovation (17) (18) (19). Hence, telemedicine is a heterogeneous, composed of a set of heterogeneous agents which interact with each other for a desired outcome (20).

Telemedicine as a System - Key sub-systems that enable development of a telemedicine system include: software, hardware, and the communications link (21). To identify a broader range of key technical actors, it may be meaningful to have a disintegrated view of telemedicine systems. This can be achieved only if telemedicine systems are looked at from a system designer's point of view. Since telemedicine is a heterogeneous as well as an extremely complex technology, numerous actors collectively form a complete telemedicine system, and most of these actors are system specific. This research thus aims to identify those technical actors which are generic with respect to the telemedicine systems being currently implemented.

System architectures of fifteen mutually exclusive and disparate telemedicine systems were studied and minutely analyzed. The telemedicine systems studied in this research were meticulously picked from leading peer-reviewed journals and patent organizations and have been between 1996 and 2007, i.e. during the second wave of telemedicine (22). The key consideration kept in mind while selecting telemedicine systems has been the application. Such a selection criterion was maintained as it: i) enabled a deeper understanding of variety of architectures used ii) facilitated even greater validity and generalization through replication of the results using multiple cases.

All the telemedicine systems analyzed in this study have been indigenously developed in diverse settings. These have been successfully implemented, and some of these have been commercialized. Both the extremes of technologies, from the simplest (like telephone and emails) to the complex technologies (like telepresence and robotic) being used in telemedicine have been included in this list. Besides in-depth studies of the systems architecture of a diverse range of telemedicine systems, a cross-sectional qualitative study was also conducted with external observations and unstructured interviews. The interviews were conducted at two telemedicine developmental laboratories, and more than thirty developers and technologists were interviewed. Their approach towards: i) gathering users' requirements, ii) software engineering, iii) project management, and iv) Training were understood. Internal documents were also examined. More than 50 users', such as clinicians and paramedical personnel, were interviewed at five different settings in Mauritius, India, and South Africa. Specific remarks include information on i) technology's qualitative features (level of sophistication, ease of use, familiarity, and confidence in using the technology, etc.) ii) relevance of the Technology, iii) completeness of the technology were gathered. Observations pertaining to the users' evolved through a series of stages, commencing with observing users' enthusiasm and style of using the telemedicine technology.

3. Telemedicine Adoption: the Technical Actors

Two of the major technical factors that hinder telemedicine adoption are i) whether the technological capabilities of equipment are sufficient to meet clinical requirements, and ii) whether features related to using the technology inhibit the users from using the technology (4) (5). These factors have also been echoed by the Technology Acceptance Model (TAM) - one of the most promising IS models. As per TAM (23), perceived usefulness and perceived ease of use are two of the factors that influence the user's acceptance of information technology. The issue of identifying factors pertaining to telemedicine adoption has so far been explored from the user's perspective only, but the present research takes it a step further by analyzing the architecture of telemedicine systems, hence the novelty.

Telemedicine System: Critical sub-systems- Following a detailed analysis of each of the telemedicine systems (hardware, software, and communications link), key actors identified within the three sub-systems are as follows:

Hardware Sub-System: prime actors within this sub-system include personal computers, laptops, personal digital assistants, telemedicine servera, and the power supply (24) (25) (26)

Software Sub-System: The key actors include system software, telemedicine application software and databases, etc. (26) (27) (28).

Communications Link Sub-System: In this case key actors include: satellite communications, wired and wireless communications such as GSM, WAP, CDMA, POTS, ISDN, and the Internet, etc. (25) (28) (29). Choice of communications modality has been cited to be a very critical factor in telemedicine system's design (30).

Being inherent in each telemedicine system, these sub-systems can be classified as critical sub-systems. Thus, a typical telemedicine system is expected to comprise of all the three actor-networks found within the critical sub-system. As per actor-orientation, the critical sub-system is comprised of three actor-networks namely: Hardware, Software and Communications Link.

A detailed look at the system developer's documentation and interviews with the system designers indicated that selection of technical actors (like computers and display units in the case of hardware, system software and telemedicine application software in the case of software and various communications modalities) within each of these actor-networks, influenced the design of the sub-systems in a telemedicine system. The following reasons influenced selection of actors within an actor-network:

Suitability of the actor with respect to the need of the system, e.g. GSM is one of the most suited actors (communications modality) if the telemedicine system is based on Wireless Application Protocol (WAP).

The actor must be user-friendly so that the user is encouraged to use it.

Compatibility of the actor with other actors to form an actor-network, i.e. unless the two actors are compatible with each other, they will not form an actor-network.

Hence, the choice of modules / actors-networks and the actors influences the architecture of the system. This in turn influences the users of the technology because adoption of an IT application/innovation is dependant on the characteristics of the technology (31) (32) (33). The three actors-networks, namely hardware, software, and communications exist within the critical sub-system and each of the actors within these three critical actor-networks can be classified as critical actors. In telemedicine genre these critical actor-networks, namely hardware, software, and communications can be classified as telemedicine platform, telemedicine user-interface, and telemedicine connectivity. The three critical actor-networks and their actors are:

Hardware (genre-Telemedicine platform): personal computer, laptop, personal digital assistant, cell phone, power supply back-up.

Software (genre- Telemedicine User-interface & repository): system software, application software, Internet browser, database

Communications (genre-Telemedicine connectivity): wired or wireless modalities (e.g. satellite communications, GSM, CDMA, Internet services, POTS, ISDN etc)

Telemedicine System: Peripheral actor-network

peripherals form an integral part of every computer-based system and enhance the capabilities of their host system. Peripherals are connected to the host system with the help of an interface and are usually commanded through the software (34).

Peripherals have a very significant role to play in a telemedicine system. In some cases peripherals prove to be a barrier to telemedicine (21). There are two types of peripherals being used in healthcare services. These include medical peripherals and non-medical peripherals. Medical peripherals perform one of the following three functions: imaging, data collection, and auscultation and therapy. In regards to the non-medical peripherals, these are the devices and instruments used in conjunction with video conferencing to assist in communication of information and ideas (35). These devices are not specifically designed for healthcare. Non-medical peripherals include cameras, video tape recorders, etc. Many of these peripherals are used as an essential part of a telemedicine network (35).

In-depth analysis of the system designs of various telemedicine systems further enabled identification of key peripherals that facilitate the process of telemedicine by adding an additional functionality to the critical sub-system. In order to provide a clearer description about the peripherals, they have been classified into the following genres: 1. Medical Instrumentation 2. Computers 3. Communications 4. Software. Periperals at nos. 2, 3 and 4 belong to the category of non-medical peripherals. The outcome of this part of the research

indicates that all telemedicine systems have peripherals, and these peripherals are closely linked to almost all the three critical actor-networks, i.e. telemedicine platform, telemedicine user-interface, and telemedicine connectivity. Another observation about telemedicine systems and its peripherals has been that each telemedicine system has a medical peripheral connected to it. Based on the on-site interviews and observations, by default the patient-end has these medical peripherals and these are required for acquiring medical information from the patient. On the specialist-end, the specialist analyzes the medical information and sends back his opinion. Hence, the telemedicine system on the patient-end is technology intense, as it has both medical and non-medical peripherals interfaced to it (26).

Key peripherals (actors) used in various telemedicine systems listed below are:

McKee, Evans et al. (36) – 12 Lead ECG

Scanlon, Evans, et al. (37) (Teleradiology) - Electrocardiogradph (ECG), Electro-encephalograph (EEG), & Active vaginal probe. Additional communication links(GSM, POTS, ISDN, WLAN).

Istepanian & Woodward (38) (Telemonitoring) - Electrocardiograph, Sphygmomanomete

Simmons, Pohl, et al. (39) (Teleophthalmology; Telecardiology; Tele-ENT) - Electrocardiograph (ECG), Pulse Oximeter, Stethoscope, Ophthalmoscope, Fundus Camera & Rhino-Laryngoscope. CCD Camera & Video Display.

Macedonia & Littlefield (40) (Tele-ultrasonograpy / Telepresence) - Portable ultrasound scanner. Video Camera, LCD Panel, CRT TV Monitor, Touchpad, Graphics Software

Popescu, Burdea et al. (24) (Telerehabilitation) - Compressor, Haptic Devices (Knee, Elbow & Hand) Microphone Array.

Woodword, Istepanian et al. *(25)* (Telecardiology) – Electrocardiography, Laptop, IrDA Interface

Lau, Churchill, et al. [41] (Telehomecare) - Pulse Oximeter, Stethoscope, Video Conf. Systems.

Hung & Zhang 2003 (Telemonitoring) – Electrocardiography

Lin, Wilder et al. 2003 (Robotic Telepathology) – Microscope, Colour Video Camera

*Loch, Barnett et al. (43) (*Telecardiology) – Electrocardiography

Sood & Bhatia (26) (Teleradiology, Telepathology & Telecardiology) - Medical Film Scanner, Electrocardiography, VideoMicroscope, Stethoscope. Video Conferencing System Image Enhancer

Lin, Lin et al. (44) (Wireless Realtime Telemonitoring) - Mobile Physiological Examination Device, Network Management Centre

Shuicai, Haomin, et al. (28) (Telemonitoring) - Physiological Signal Recorders, Video Chat

Lee, Chen et al. (27) (Mobile Telemedicine) Bluetooth Hemadynamometer

In the past, clinicians have expressed their concerns over using medical peripherals (21). Interviews with five specialists (three radiologists and two pediatricians) at a hospital in India reaffirmed this finding. The specialists highlighted that encouragement for them to participate in a telemedicine session to make interpretations was influenced by the correctness and the quality of the medical information received from the patient end. Researchers have highlighted concerns pertaining to the quality of video images transmitted as being sufficient to meet the clinical needs of the healthcare professionals (4) (5). Hence, peripherals form a vital part of the telemedicine system a peripheral in a telemedicine system can thus be seen as an actor because it influences the use of telemedicine technology. The peripheral actors associated with computers, like touch pad, CCD Cameras, communications systems like video chats, overhead cameras, document scanners, and a few other additional interfaces for communications, etc.; and software (graphics software, image enhancer applications, etc.) all add another dimension to the telemedicine system. It is worth reaffirmation that peripheral actors in the peripheral actor-networks cannot be generalized, as their selection depends on the application of telemedicine being designed. Based on the information from users, the determinants of user acceptance of peripheral actors is the same as for the critical actors.

4. Conclusions

Adoption of innovations and specifically the adoption of IT innovations in healthcare has been a

challenging topic. Telemedicine being a heterogeneous, multidisciplinary, and a complex technology, the professionals who have been associated in design, testing, training, evaluation, and management of the telemedicine systems only can be more comfortable in analyzing the technical side of telemedicine. Very critically telemedicine systems were picked out of normative literature. Selected telemedicine systems covered all the key applications of telemedicine, the selections also covered a wide range of communications modalities in diverse environments, such as underwater, wireless, and wired media. The telemedicine solutions analyzed here also represent design approaches followed by system designers world-over.

Researchers have used actor-oriented approaches to identify miscellaneous factors influencing Enterprise Application Integration in healthcare. Use of the actor-oriented approach in this research i) allows better realization of telemedicine adoption process from the technical perspective ii) enables system designers, system testers and evaluators, technology managers, and researchers in understanding the range of technical actors that need to be considered during the study of telemedicine adoption iii) the taxonomy proposed in this research may also kick off efforts for a separate research stream to finalize terminology specifically for telemedicine systems, and iv) might lead to enhanced telemedicine adoption.

Finer details like modalities of communications, nature of peripherals in the case of software and hardware, etc. have not been explored at depth but these aspects are being research which is underway. This may help researchers to identify more actors, and may enhance clarity about telemedicine systems, and may eventually aid widespread adoption of telemedicine.

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6. References

[1] Mantzana, V. and Themistocleous, M. (2006). A Method for the Identification of Actors Involved in Adoption of Innovations in Healthcare Organisations. Proceedings of 39th Hawaii International Conference on System Sciences (HICSS), USA.

[2] Tanriverdi, T. and Iacono, C.S. (1999). Diffusion of Telemedicine: A Knowledge Barrier Perspective. Telemedicine Journal, 5(3), 223-244.

[3] Croteau, A.M. and Vieru, D. (2002). Telemedicine Adoption by Different Groups of Physicians. Proceedings of the 35th Hawaii International Conference on System Sciences (HICSS).

[4] Institute of Medicine (IOM), (1996). Telemedicine: A Guide to Assessing Telecommunications in Healthcare, Washington DC: National Academy Press.

[5] Perednia, D,A. and Allen, A. (1995). Telemedicine Technology and Clinical Applications. Journal of American Medical Association, 273(6), 483-488.

[6] Khoumbati, K., Themistocleous M. and Irani, Z. (2006). Evaluating the Adoption of Enterprise Application Integration in Health-Care Organizations. MIS , 22(4), 69-108.

[7] Mantzana, V., Themistocleus, M., Irani, Z. and Khoumbati, K. (2008). Information Systems and Healthcare XXV: Factors and Actors Affecting the EAI Adoption in Healthcare Sector. Communications of the Assoc. of Information Systems, 22(6), 103-116.

[8] Mantzana V. and Themistocleous M. (2004). Indentifying and Classifying Benefits of Integrated Healthcare Systems Using an Actor-Oriented Approach. Journal of Computing and Information Technology, 4, 265-278.

[9] Menachemi, N., Burke, D.E. and Ayers, D.J. (2004). Factors Affecting the Adoption of Telemedicine – A multiple Adopter Perspective. Journal of Medical Systems, 28(6), 617-632

[10] Fitzerald, L., Ferlie, E., Wood, M. and Hawkins, C. (2002). Interlocking Interactions, the diffusion of innovations in healthcare, Human Relations, 55(12), 1429-1449.

[11] Bodendorf, F. and Grebner, R. (1999). Actor-Oriented Management of Cooperative Work. Proceedings of the International Conference on Groupware, Phoenix, USA.

[12] Lee, E. and Neuendorffer, S. (2004). Classes and Sub-classes in Actor-Oriented Approach. Proceedings of Second ACM and IEEE Conference on Formal Methods, San Diego, USA.

[13] Liu, J., Eker, J., Janneck, J.W., Liu, X. and Lee, E.A. (2004). Actor-Oriented Control System Design: A Responsible Framework Perspective. IEEE Transactions on Control Systems Technology, 12(2), 250-262.

[14] Ochirusen, E., Indrusiak, L.S. and Glesner, M. (2008). An Actor-Oriented Group Mobility Model for Wireless Ad Hoc Sensor Networks. Proceedings of the 28th International Conference on Distributed Computing Systems

[15] workshop, Beijing, China.

Aanestad, M. (2003). The Camera as an Actor: Design-in-Use of Telemedicine Infrastructure surgery. Computer Supported Cooperative Work, 12, 1-20.

[16] Bashshur, R.L., Reardon, T.G. and Shannon, G.W. (2000). Telemedicine: A New Healthcare Delivery System. Ann Rev Pub. Health, 21, 613–637.

[17] Hu, P.J., Chau, P.Y.K. and Sheng, O.L. (2000). Investigation of Factors Affecting Healthcare Organisation's Adoption of Telemedicine Technology. Proceedings of 33rd Hawaii International Conference on System Sciences

[18] (HICSS), 1-10.

Sood, S.P., Mbarika, V.W.A. and Prakash, N. (2006). Telemedicine as an Innovation system in Developing Countries (abstract). Proc. of XI Int'l Conf. of Int'l Society for Telemedicine & eHealth, 26-29 November 2006,

[19] Cape Town.

Sood, S.P., Mbarika, V., Jugoo, S., Dookhy, R. Doarn, C.R., Prakash, N. and Merrell, R.C. (2007). What Is Telemedicine? A Collection of 104 Peer-Reviewed Perspectives and Theoretical Underpinnings. Telemedicine and

[20] e-Health, 13(5), 573-590.

Paul, D.L., Pearlson, K.E. and McDaniel, R.R. (1999). Assessing Technological Barriers to

Whitten, P. and Sypher, B.D. (2006). Evolution of Telemedicine From an Applied Communication Perspective in

[21] the United States. Telemed e-Health, 12, 590–600.

[22] Davis, F.D. (1989). Perceived Usefulness, Perceived ease of use, & user acceptance of IT. MIS Quarterly, 13(3) 319-340.

[23] Popescu, V.G., Burdea, G.C., Bouzit, M. and Hentz, V.R. (2000). A Virtual-Reality Based telerehabilitation System with Force Feedback. IEEE Transactions on Information Technology in Biomedicine, 4(1), 45-51.

[24] Woodward B., Istepanian R. and Richards, C.I. (2001). Design of a Telemedicine System Using a Mobile Telephone. IEEE Trans. on Information Tech. in Biomedicine, 5(1), 13-15.

[25] Sood, S.P. and Bhatia J.S. (2005). Development of Telemedicine Technology in India: "Sanjeevani"-An Integrated Telemedicine Application. Journal of Postgrad Medicine, 51, 308-311.

[26] Lee, R-G., Chen, K-C., Hsiao, C-C. and Tseng, C-L. (2007). A Mobile Care System With Alert Mechanism. IEEE Transactions on Information Technology in Biomedicine, 11(5), 507-517.

[27] Shuicai, W., Haomin, L., Fanfang, D., Yanping, B. and Song Z. (2007) An Internet-Based Telemonitoring System of Multiphysiological Parameters. Telemed. & eHealth, 13(4), 451-459.

[28] Hung, K. and Zhang, Y.T. (2003). Implementation of a WAP-Based Telemedicine System for Patient Monitoring. IEEE Trans. on IT in Biomedicine, 7(2), 1001-107.

[29] Chau, P.Y.K. and Hu, P.J-H. (2004). Technology Implementation for Telemedicine Programs. Communications of the ACM, 47(2), 87-92.

[30] Markus, M.L. and Keil, M. (1994). If we Built, They Will Come: Designing Information Systems that People Want to Use. Sloan Management Review, 35(4), 11-25.

[31] Saga, V.L. and Zmud, R.W. (1994). The Nature and Determinants of IT Acceptance, Routinzation, and Infusion. IFIP transaction A: Computer Science and Technology, A-45, 67-86.

[32] Davis, F.D., Bagozzi, R.P. and Warshaw, P.R. (1989). User Acceptance of Computer Technology: a Comparison of two Theoretical Models. Management Science, 35(8), 982-1003.

[33] Bradley, A.C. (1990). Peripherals for Computer Systems, (University of Michigan), Macmillan.

[34] Argy, O. and Caputo, M. (2000). Medical Applications and benefit. In Information Technology for Practicing Physician, (Ed.), Kiel, J.A., Springer-Verlag, New York.

[35] Mckee, J.J., Evans, N.E. and Owens, F.J. (1996). Digital Transmission of 12-lead ECG and Duplex Speech in the Telephone Bandwidth. Journal of Telemed Telecare 2, 42-49.

[36] Scanlon, W.G., Evans, N.E., Crumley G.C. and McCreesh, Z.M. (1996). Low –Power Radio Telemetry: The Potential for Remote Patient Monitoring. Journal of Telemedicine and Telecare, 2, 185-191.

[37] Istepanian, R.S.H. and Woodward, B. (1997). Micro-Controller Based Underwater Acoustic ECG Telemetry System. IEEE Transactions on Information technology in Biomedicine, 1, 150-154.

[38] Simmons, S.C., Pohl, J.R., Guess, T.M., Rushing, D.A., Caputo, M.P. and Billica, R.D. (1997). Telemedicine Instrumentation Pack. United States Patent, Number 5, 701, 904.

[39] Macedonia, C.R., Littlefield, R.J., Coleman, J., Satava, R.M., Cramer, T., Mogel, G. and Eglinton, G. (1998). Three-dimensional Ultrasonographic Telepresence. Journal of Telemedicine and Telecare, 4, 224-230.

[40] Lau, C., Churchill, R.S., Kim, J., Matsem, F.A. and Kim, Y. (2002). Asynchronous Web-Based Patient-Centered Home Telemedicine System. IEEE Trans on Biomedical Engg, 49(12), 1452-1462.

[41] Lin, W., Wilder, J., Grossman, S. and Foran, D.J. (2003). A Network-Reactive Model for Distributed Telemicroscopy. Journal of Telemedicine and Telecare, 9, 78-83.

[42] Loch, A., Barnett, K.N., Satchwell, B.R. and Fitzgerald, J.E. (2004). Telemedicine System. US Patent Number: 6,820, 057.

[43] Lin, B.S., Lin, B.S., Chou, N.K., Chong, C.F. and Chen, S.J. (2006). RTWPMS: A Real-Time Wireless Physiological Monitoring System. IEEE Trans. on IT in Biomedicine, 10(4), 647-656.