

Autonomous Patient Training and Monitoring System for Stroke Patients

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Abstract. Subsequently, in the last decade a number of innovative treatments of stroke patients have significantly improved patients odds to survive and continue with their productive lives. Virtual Therapist project was defined and instituted as collaboration between a public healthcare institute and a medical school, with a clear distinction of its primary intended use on brain stroke patients and elderly patients with neurological disorders and mental degradation. Virtual Therapist is envisioned as a Kinect based system connecting remote patients and therapists and performing a task of monitoring patients 'exercises at home that would be otherwise possible only in special healthcare institutions.

Keywords. Virtual Therapist, Kinect, stroke patients

1 Introduction

Brain stroke is one of the diseases that were intensely studied in the recent years, resulting in a better understanding of its causes, etiology and prognosis. Subsequently, in the last decade a number of innovative treatments of stroke patients have significantly improved patients odds to survive and continue with their productive lives. While most of these improvements were related to brain stroke treatments, quite a few were focused on patients' rehabilitation and their return to normal lives. The

World Health Organization defines stroke as "clinical syndrome" related to a rapid loss of cerebral functions due to the disturbance of a blood flow to the brain. Two prevalent cases that fit the paradigm are ischemic or hemorrhagic brain strokes, both exhibiting symptoms that if not treated and depending on stroke severity can often result in death. In terms of stroke world statistics, it is enough said that every six seconds, regardless of gender, age or ethnicity, someone has a stroke, and that every minute one person is dying from the stroke consequences. These figures are even scarier when their dynamics is plotted over the last fifty years in the developed. Despite all the technology and improved life standards the number of stroke patients is increasing. As it stands today, about one third of stroke patients gradually recover, another third will experience mild to severe disability and still one third will die. Our primary interest lies with those patients that are disabled in some form and forced to undergo a long and tedious rehabilitation treatment. One way to speed up their recovery is by applying new technologies that can help patients in physical therapy consisting mainly on exercises that can be monitored remotely or by an autonomous system. In this case, a Microsoft Kinect technology has been chosen as a platform for such a system. Immediately following its release, this technology that was originally intended to replace game controllers for an Xbox 360 console, became a platform technology to many scientific projects, especially in medicine and health care applications. In less than a year a dozen of products were introduced, whose purpose is mainly geared

towards the needs of patients with repetitive exercises in the rehabilitation process, or related to speech impediments in children and adults. Recent launch of a Kinect for Windows SDK, a development environment intended for Windows PC applications spearheaded further development of medical applications and it is fair to say that the applications of this technology in healthcare and industry surpassed its intended use.

2 Economic facts about brain stroke

“Stroke does not affect just one person, but rather the immediate environment“, says dr. Michael Hill, a spokesman for *Heart and Stroke Foundation*. “It represents a major challenge for the family of the patient, healthcare providers and entire healthcare system“.

Brain stroke is one of the leading causes of death and permanent disabilities in the world, and respectively so it carries a huge economic toll to the society as a whole.

1. USA

In USA alone, brain stroke is listed as a cause of 150 thousands deaths (6%) out of 2.5 million deaths every year, a third overall cause of death after heart diseases and cancers. Simply said, someone in the U.S. dies every 3.3 minutes from stroke. Stroke affects more than 700,000 individuals annually or approximately one person every 45 seconds. About 500,000 of these are first attacks, and 200,000 are recurrent attacks. Stroke is the leading cause of disability among adults in the U.S. More than 4 million people in the United States have survived a stroke or brain attack and are living with the after-effects. Four out of five families will be somehow affected by stroke over the course of a lifetime. Out of those survivor patients, 25% is with lesser damages to the brain, 40% experiences mild to heavy dysfunctions requiring special care, 10% become long term patients in a specialized disability care units and 15% die within few days after the insult. In addition, 14% of survivors will get another stroke within a year and 25% within 5 years. Total brain stroke related healthcare cost is estimated and \$43B a year. Out of this figure, direct costs are about \$28B and indirect costs, due to the loss of productivity are estimated at \$15B per year. Average cost of treatment and rehabilitation of stroke patients within first 90 days is around \$15000. For about 10% of stroke patients this cost is closer to \$35000. The cost breakup overview:

primary hospitalization 43%, rehabilitation 16%, medical cost 14%, re-hospitalization 14% and other costs 13%.⁴

2. Canada

Total healthcare costs for the care of brain stroke patients in the first 6 months are estimated at \$2.5B. BURST study (Canadian Stroke Network’s Burden of Ischemic Stroke) quotes that indirect cost for stroke survivors is at \$50000 per patient in this period. Roughly, 50000 brain strokes are recorded in Canada annually. Another report from Health Canada’s Economic Burden of Illness quoted a similar figure, about \$2.4B per year. About 300000 people are living with health problems caused by a brain stroke. Dr. Mike Sharma, a BURST study leader, and dr. Nicole Mittmann from Sunnybrook Health Sciences Centre published that all these estimates are unrealistic and that real figures are many times higher, at least double the quoted figures. Hospitalization, drugs, medical services, diagnostics, home care and rehab are already included in the estimated costs, but indirect costs, such as permanent disability, loss of job, cost medical devices and aids, additional help for assisted living, home adaptations etc. are all adding to the overall cost. At least 80% of all costs within first 6 months are incurred by the healthcare system, while the remaining costs are recognized as burdens of patients’ family, including the loss of income. However, with more severe disabilities these costs can become extremely difficult for the family. In brief, for 25% of patients with less severe symptoms these costs are estimated at only \$2000 within first 6 months, but for the most severe cases these figures can go up to the \$200000 for the same period of time. “After the age of 55, the risk of having a stroke doubles every 10 years“, says dr. Hill. “This alone will create a major burden to our healthcare system, as within next 20 years a number of Canadians reaching the age of 65 and higher will go from 4.3M today to about 8M. Their percentage will increase to over 20%, a 7% net increase over two decades”.⁵

3. European Union

In EU brain stroke affects around 8.2 million people per year. Total healthcare costs related to brain stroke, based on 2010 data, are estimated at €64B per year. Out of this €42B are direct healthcare costs and €22B are indirect costs. Healthcare costs per patient are €7775, €5141 for treatment and rehabilitation (direct cost) and €2634 for indirect cost.⁶

4. Republic of Croatia

Mortality figures in Croatia are even higher, in 2006, 16.03% of all deaths were attributed to brain stroke, a second place behind coronary diseases. More than

20000 people are affected by a brain stroke annually in Croatia, with one third patients dying from this illness, precisely 8075 people out of 24467 that were hospitalized with such diagnosis. In 2011 a Cost effectiveness analysis of healthcare costs related to brain stroke showed that the overall cost of stroke treatments amounted to 421,016,881.18 kn annually. Per patient this figure is estimated at 17,207.54 kn, out of which, hospital costs are 5,271.39 kn, intensive care 2,907.90 kn, stationary rehabilitation 2,953.65 kn (21 days) and dissability leave compensation (2 months) at 6,074.60 kn.⁷

3 Theoretical background

Brain stroke prevention, professional rehabilitation, proactive patients' engagement in the healing process, life time care systems, professional educational programs, decreasing brain stroke mortality, maximizing quality of stroke survivors' lives are noble goals that all healthcare systems and organizations agree on. Presently, the average length of post stroke rehab is a task that fills all the hours of the day, performed by many members of the interdisciplinary team in an interconnected way and in a logical sequence. Recent discoveries about brain's capacity to heal and reorganize upon stimulation introduced many methodologies and techniques that should benefit patients. "The brain is more plastic and flexible than it was thought before. Even in elderly people, brain can reorganize and redeploy hidden resource in order to heal itself. Healthy tissue can rearrange itself even within sick tissue", says dr. Michael Moseley. However, even during the institutionalized rehabilitation post stroke patients can't have all the hours of the day dedicated to their recovery due to the hospital staff availability, primarily physical therapists, stemming from the lack of funding. In brief, post stroke patients are once they leave hospital pretty much on their own or left to the care of immediate family. However, if those patients would be constantly engaged throughout the healing process, thanks to the brain neuroplasticity, by repeating certain exercises and rebuilding skills that are important in an everyday life, they would much faster regain specific brain functions and return to the workforce instead of remaining to be a burden to the society. One way to bridge this gap is to introduce new medical aids, devices that could extend reach of physical therapists and doctors into patients' homes where they would be able to perform same exercises that were used during their rehabilitation stay in the hospital. In less than 2 years a number of applications based on Microsoft Kinect Technology were introduced and used in US with spectacular results. Even when patients were only playing selected Kinect games, their recovery was much faster and their attitude toward their disability had changed drastically. In our case, we present a Kinect application designed specifically for the stroke

patients, with all the knowledge about the specific needs of such patient built in. Moreover, as Virtual Therapist application has different clients, one for the doctor, one for the therapist and one for the patient, doctors and therapists can configure required exercises to be monitored through this applications specifically for each patient. As this system can work in both a standalone and networked mode, in a latter one, doctors and therapists can have a constant feedback on how their patients are doing and intervene if necessary.

4 Microsoft kinect technology

About two years ago, at one of the largest shows of the electronic equipment and devices, Microsoft announced and exhibited a Kinect technology for Xbox 360 game console, aimed mainly at gamers and enabling them to control game characters by gestures, movements of extremities and voice. However, this technology was immediately recognized by a number of developers as an excellent platform for developing serious healthcare applications, security applications and more generally, industrial applications for monitoring industrial processes. In US alone, within a matter of months a dozen applications emerged in the healthcare market most of them in the area of telemedicine, weight loss and helping recovery of brain stroke patients. Most of them used games without special modifications in order to invigorate young patients to perform tedious exercises, but a number of them were already tailored for specific health problems and diseases. Soon thereafter, in Croatia, a similar application named KIDNect was developed for kids with cerebral paralysis. Following the footsteps of this inspiring project, a Virtual Therapist project was defined and instituted as collaboration between a public healthcare institute and a medical school, with a clear distinction of its primary intended use on brain stroke patients and elderly patients with neurological disorders and mental degradation. Virtual Therapist is envisioned as a Kinect based system connecting remote patients and therapists and performing a task of monitoring patients 'exercises at home that would be otherwise possible only in special healthcare institutions. In addition to a different segment of patient care, Virtual Therapist differs from similar applications by its architecture, a three layer system with a central part responsible for storing the derived as well as streaming media data and advanced processing of images and audio signals that are at this time not supported by Kinect technology. This mainly

relates to the automation and remoting of the speech therapy sessions that will be a part of the Virtual Therapist product.

As mentioned above, a project Virtual Therapist is based on Microsoft Kinect technology and a number of equally impressive technologies embedded in special SDK tools that are all compatible with a Microsoft Visual Studio 2010 development environment. In addition Microsoft technologies a number of open source technologies were used in order to provide fairly sophisticated functions, namely an OpenCV and Open Source Audio SDKs. A Kinect device is equipped with two cameras and a ranging device capable of producing a 3D image (range image) as well as dynamic data of monitored object movements. Like in other Kinect healthcare or fitness applications, a trainer, in this case a therapist, can define a number of connected movements comprising an exercise for every patient, given his physical status and rehabilitation needs. Therapist can also define parameters for repeating and monitoring patient moves that should mimic the predefined moves in an exercise as well as all the measurements that can take place during an exercise. Parameterized reports can be defined at this stage so that therapist can quickly recognize the efficiency of the exercises and adjust them if necessary. In addition a number of statistics reports can be devised from this data as well. Another client application named "Patient Monitor" uses a Kinect device attached to an Xbox console or to a standard Windows 7 / 8 personal computer, notebook or tablet. This application can perform in a standalone mode or in a networked mode, where it is connected to a central system and sending the derived data or even the stream of images and sounds if configured that way. On the central site a number of other functions are implemented that are either too computationally intensive or storage-wise too large to be performed at the client side. When Kinect avatar dynamic data are not sufficient to recognize how well was rehab exercise performed, a system can be configured to send images that are then analyzed in more detail using an OpenCV library, taking more data and producing many reports that can be crucial in determining whether the therapy is progressing well or there will be necessary for a therapist to intervene at the patient's site.

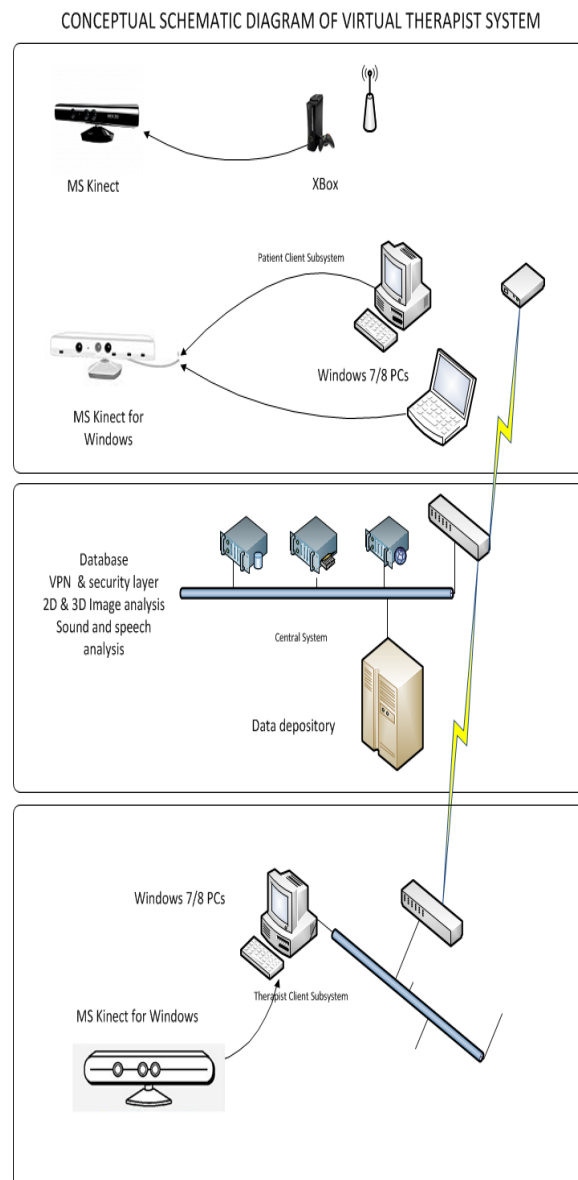


Figure 1. Three key subsystems of a Virtual Therapist system are shown: Therapist Console subsystem as well as Patient Monitor subsystem are based on Kinect technology and therefore require the use of a Kinect device. Console is based on Kinect for Windows while Patient Monitor can use an Xbox instead of a Windows PC as a controller. On the other side, central system serves as a data depository, a VPN layer for connecting patients and therapists, and in addition to functions based on Microsoft DirectX and Kinect SDK technologies employs many other advanced computer vision technologies like Open CV as well as a Speech Server technology for sound and speech recognition and analysis.

Auditive component of a Kinect SDK is mainly based on Microsoft DirectX audio subsystem that per se does not include speech recognition, except for simple

commands. However, by utilizing a powerful Speech Server technology (unfortunately at this time only English language is fully supported), on a remote central server, it is possible to recognize patient's speech for a given speech therapy template and perform a speech analysis for potential deviations and speech patterns. One of the future key goals for the Virtual Therapist project is to develop a number of auditive tools based on Microsoft DirectX SDK and Speech Server technologies that will enable a speech therapist to conduct speech exercises in a similar way as that is today possible for a physical therapy exercise. For English language, this merely represents the application of existing and emerging technologies, while for other languages, and especially for a Croatian language, producing such functionality is still a major challenge.

5 Conclusion

Introduction of new technologies in medical treatments is a necessity for healthcare providers and especially so in cerebrovascular diseases. In a rehabilitation of stroke patients it is important to engage patients in their own healing process. Recent research papers in neuroscience have shown that neuroplasticity of brain assures large capacity for neuronal organization. Despite these positive discoveries about brain's neuroplasticity a full recovery of such patients remain a serious challenge for every therapist. Certain post-stroke symptoms can be diminished by using adaptive approaches. It is clear that the post-stroke brain must be daily trained, either passively (with therapist's help) or actively in order to regain lost brain functions. There are many proven effects of mental exercises performed through applications based on Microsoft Kinect Technology, and among them is patients' positive response to such therapies as well as the obligation to carry on exercises more frequently than in a typical physical therapy treatment. As application can store individualized programs for patients, defined by their therapists, every exercise is performed under system's supervision. System can monitor these exercises, measure deviations and request corrections for as many repetitions as suitable for a specific patient. In addition the system records all the exercise parameters allowing therapist to check on patients and intervene if necessary. System can be used at home and monitored remotely, thus enabling therapists to work with many more patients than what would be possible otherwise. The result is that patients can recover quickly and get

back to their lives sooner than before. Therapists and doctors are supervising the system and have full reporting capabilities on patients' progress or problems with certain exercises. Application of this technology should increase patient's chances to avoid the next occurrence that could be fatal or more disabling. On the healthcare system scale, this approach better utilizes critical resources in patients' treatment and rehabilitation, patients' recoveries are more expedient and the overall cost is significantly reduced.

This interdisciplinary project aimed at developing an autonomous system for brain stroke patients remote physical therapy and monitoring combines experts from diverse fields like medicine, physical therapy, physics, information technology and economy.

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