Acta of Bioengineering and Biomechanics
Vol. 18, No. 4, 2016

Original paper
DOI: 10.5277/ABB-00428-2015-03

Telerehabilitation approach for patients with hand impairment

ARLETA STASZUK[1], BENITA WIATRAK[2]*, RYSZARD TADEUSIEWICZ[1], EWA KARUGA-KUŹNIEWSKA[3], ZBIGNIEW RYBAK[4]

[1] Faculty of Electrical Engineering, Automatics, Computer Science and Biomedical Engineering, AGH University of Science and Technology, Kraków, Poland.
[2] Department of Basic Medical Sciences, Wrocław Medical University, Poland.
[3] Division of Infectious Diseases of Animals and Veterinary Administration, Department of Epizootiology and Clinic of Bird and Exotic Animals, Wrocław University of Environmental and Life Sciences, Poland.
[4] Department of Experimental Surgery and Biomaterials Research, Wrocław Medical University, Poland.

Purpose: Telerehabilitation is one of the newest branches of telemedicine which has been developed because patients need regular trainings outside the medical institution but still under specialist supervision. It helps maintain regularity of exercises and reduces costs. The professional and advanced systems for telerehabilitation are presented in papers, however, there is still lack of development of minor systems which provide therapeutic values and are more accessible to people. Therefore we focus on a solution for hand telerehabilitation of post-stroke patients, based solely on a personal computer and camera. *Methods:* We focused on the manipulative hand (fingers, metacarpus, wrist) movements trainings for patients with cerebral palsy. The contact between patient and physiotherapist is provided by using web cameras and web service. Additionally, the camera can be used to monitor the effectiveness of performed exercises. Computer vision system keeps track of the patient's hand movement. The digital image processing is used to detect if the patient performs exercises correctly. *Results:* We created web service and software application TeleReh that provides therapeutic values for the hand impaired people. The system created was evaluated by three physiotherapists, one doctor and a cerebral palsy patient. *Conclusions:* Our solution applies to all patients who have undergone basic rehabilitation in hospital and need to continue hand rehabilitation at home. The main advantages are: easy adaptation to the individual needs and abilities, monitoring the progress by using automatically generated reports after each training session. It is worth noticing that discussion between IT specialists, rehabilitants and patients was necessary to achieve good results.

Key words: *stroke, telemedicine, telerehabilitation*

1. Introduction

Telemedicine can be considered as an area of practical activities (both technological and medical) and a new way of providing healthcare services. Development of telemedicine systems can only be possible with the collaboration and support of experts from technical specializations (such as telecommunication, information technology, biomedical engineering, automatic control, robotics) and medical sciences (such as doctors, physiotherapists, laboratory technicians, radiologists, surgeons) [22], [23]. Most of the existing telemedical equipment finds its application in rendering diagnosis [20], [25]. An important goal of telemedicine is permanent and ubiquitous monitoring of the patient's health [2], [9], [16]. Due to the strained financial situation in the healthcare sector, hospitals and other healthcare providers are facing an increasing pressure to improve their efficiency and reduce costs. These trends motivate healthcare organizations to introduce innovative information technology (IT) based supportive processes [13], [25]. It means that telemedicine, as a more economical way of providing

* Corresponding author: Benita Wiatrak, Department of Basic Medical Sciences, Wrocław Medical University, ul. Borowska 211, 50-556 Wrocław, Poland. Tel: 667 398 821, e-mail: benita.wiatrak@gmail.com
Received: July 21st, 2015
Accepted for publication: January 13th, 2016

healthcare services, should be used for therapeutic purposes [18]. Providing medical services at a distance is a challenge for system developers and future users – patients. Patients should also participate in creating telemedical system because only they can specify the system usability requirements. Of course, not every treatment can be carried out by means of telemedical facilities, but in certain cases it is safe, effective and comfortable [14].

This paper covers particular subarea of telemedicine – IT applications in telerehabilitation. The area of telerehabilitation is still "a promised land" for biomedical engineers, IT specialists, medical doctors and the patients. This paper deals exactly with this issue. Telerehabilitation provides rehabilitation services at a distance and applies to all patients who were first rehabilitated in hospital and need to continue their rehabilitation at home [4], [15]. It has a great potential for reducing the costs of healthcare delivery for people who live in villages far from big cities. Most of them are not able to come to a rehabilitation center due to various deformities or disabilities, but can do the exercises at home under specialist's supervision at a distance.

Telerehabilitation merge medical and technical sciences and is developed mainly by biomedical engineers, programmers and rehabilitants. Therefore two types of publications databases were investigated. In the IEEE Xplore Digital Library, which contains scientific and technical content, there are over one hundred articles concerning telerehabilitation. In the PubMed digital library, one can find biomedical literature, of which more than 250 papers are related to telerehabilitaion. Figure 1 shows that over the last 20 years interest in the "telerehabilitation" subject has grown. Selected results of research, which can be found in publications from the two databases, are presented in this article.

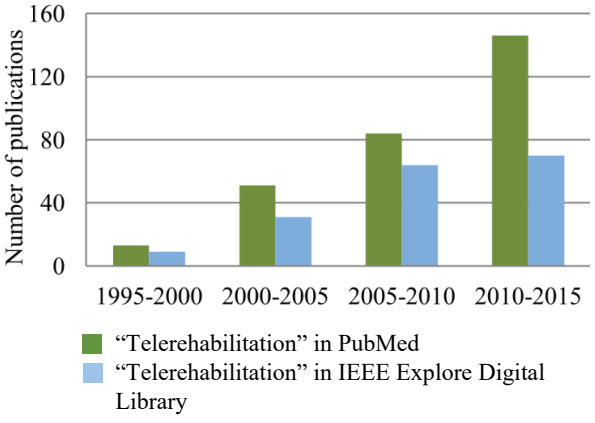

Fig. 1. Number of articles related to "telerehabilitation" keyword in two digital libraries – PubMed and IEEE Xplore Digital Library, 1995–2015

1.1. Existing solutions for hand telerehabilitation

Frequently, the hand rehabilitation is supported by additional devices. Most manipulators support passive movement, but it is noted that it does not provide expected results of strengthened limbs, because the movement is performed by device, not a patient. The devices equipped with electromyography sensors measure the patient's force and support active movement. A specialized telemanipulators for hand telerehabilitation can also be used during the treatment [26]. The rehabilitant uses the master device for controlling the patient's device mounted on the hand [12], [19]. The process of rehabilitation becomes more interesting and motivating when games, Virtual Reality, or Augumented Reality are used [1], [6], [15]. The exercises could be presented as games and such games could include movements from daily activities.

It can be observed that there is still lack of minor applications which still provide therapeutic values but are more accessible to people, without the necessity of purchasing additional specialized devices. In this paper, such a solution is presented.

1.2. Typical disorders which can be treated by means of telerehabilitation

Telerehabilitation can transfer some parts of the therapy from hospital to the patient's home. But not all patients can be treated this way, because epilepsy, spasticity, sensory impairment, cognitive and consciousness disorders can limit the use of equipment and telerehabilitation systems. The possibility of practical application of remote rehabilitation depends on the type and severity of the disease. It is helpful for patients who have life-long rehabilitation needs, like patients after bone fractures, patients with degenerative joint disease and neurological diseases such as stroke, polyneuropathy and spine cord injuries.

Stroke is a type of cardiovascular disease affecting the arteries within the brain or leading to the brain. Ischemia (caused by blockage at about 85% of all strokes) or a hemorrhage damages the brain and therefore a part of the body does not work as it should. Stroke appears suddenly and affects a large group of people. Every year, about 70,000 people in Poland and more than 795,000 people in the United States have a stroke. Stroke causes long-term disabilities and leads to the lack of independence. Additionally, the

impact on the national economy is noticeable. In the United States an estimated total cost of patients after stroke is $36.5 billion each year and includes care services, medications to treat stroke, and missed days of work [8]. Another disease – osteoarthritis (degenerative joint disease) also occurs frequently and affects about 8 million people in Poland. Recent studies have shown that repetitive and continuous training is necessary to help the patients to convalesce or return to independent life [21].

Each type of rehabilitation should be continued under the supervision of a physiotherapist, because patients are motivated to exercise and regularly take the required training. The director of the rehabilitation center estimates that 90% of the exercises realized by unsupervised patients are performed incorrectly and they cause more harm than good.

2. Materials and methods

Proposed in this paper telerehabilitation system requires computers, web cameras, microphone and Internet connectivity. Nowadays more than 40% of the population use Internet and this value increases each year.

The architecture of the proposed system is presented in Fig. 2. The Web service (Fig. 2B) is used for the medical data exchange. At the hospitals, laboratories or rehabilitation center (Fig. 2E) the specialists add the medical test results and patient medical orders and can discuss the medical case with other specialists all over the world. Additionally, as a part of the healthcare the medical images (registered by Magnetic Resonance, Computer Tomography, Ultrasonography) with diagnosis are stored in the database. It is worth mentioning that specialists and users are permitted to access selected data related to their needs. Optionally Smartphones, tablets or smartwatches (Fig. 2D) can be used. The data collected by the devices equipped with sensors can also be stored in the central database, on demand. The central database (Fig. 2A) is designed to gather information about patients from scattered sources and to store history of diseases. The patient who is abroad and has health problem can be better diagnosed because the doctor or rehabilitant can have an access to the patient's medical history, course of the disease, the process of rehabilitation, medications taken and can have a contact with the doctor in patient's country. The database with protected personal data is an important source of knowledge for medical students, because they have the possibility to analyze many medical cases with professional diagnosis. The tablet equipped with the camera and with installed mobile application for telerehabilitation can be used instead of the computer at patient's home or other places convenient for the patient. One of the assumptions of the present solution is reducing the need of placing additional equipment on the body.

Each case of the disease and the level of disability is different, therefore it becomes necessary to adapt the exercises individually to each patient. The possibility of adaptation to the patient without the necessity of changing the system is one of the most important requirements of the application.

The proposed application TeleReh is designed as a part of telerehabilitation system presented in Fig. 2.

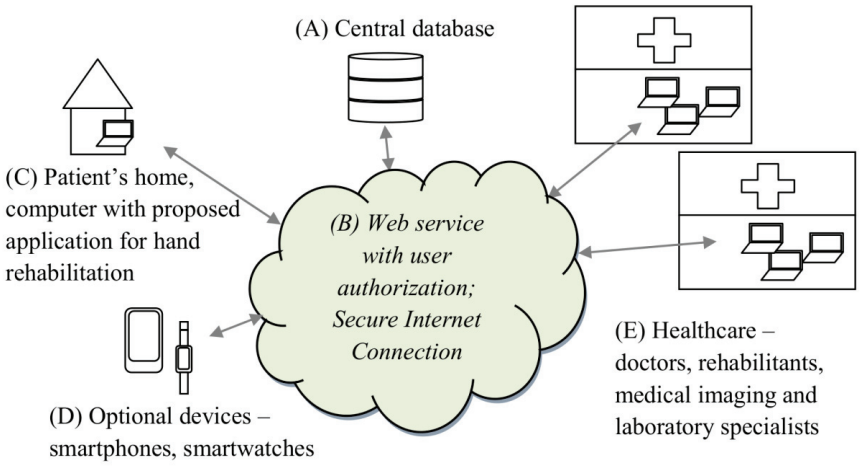

Fig. 2. The components of telerehabilitation system proposed: patient performs exercises at home and uses personal computer (C) or available devices (D) with Internet connection and uses proposed Web service (B). The Web service provides communication with the healthcare sector (E). The central database system (A) stores the data and provides secure access

The software can be installed on the patient's computer at home (Fig. 2B) or on the portable devices like tablets (Fig. 2C).

3. Results

Patients can do specific exercises being guided by photographs prepared by their doctors. The patient is at home, the computer and Internet are available and camera is set over the patient's hand – on the preview the patient should see the fingers and wrist of one hand (or both hands). Figure 3 shows the exercise tab in the TeleReh application. It is recommended to remove all unnecessary objects which are in front of the camera. The proposed method for telerehabilitation constists of two stages. Firstly, the rehabilitant shows the required hand position. The patient tries to set the fingers and wrist in accordance with the order. If rehabilitant confirms that the patient does the task correctly the picture can be taken and uploaded to the service. The photo will act as template for the rehabilitation process. The software installed on patient's

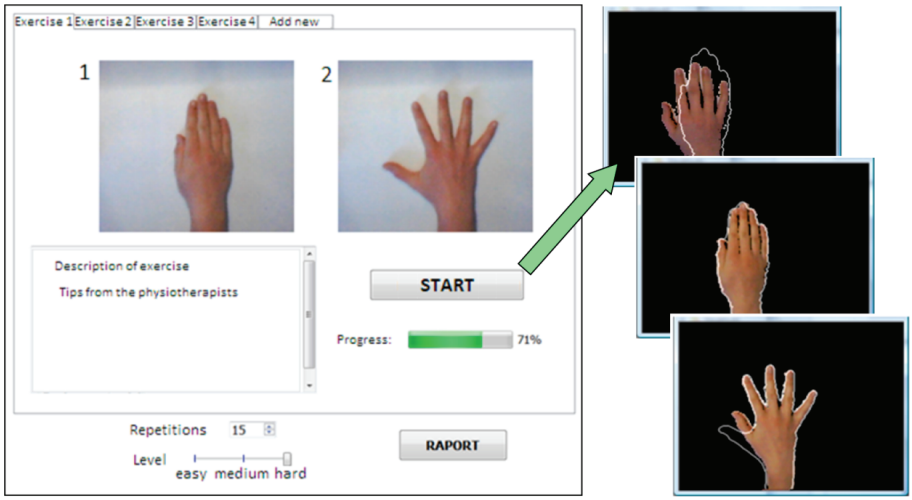

Fig. 3. TeleReh software for telerehabilitation system – exercise tab. One exercise tab contains: images that present the task, description, suggestions from the specialist, progress and difficulty level. Pictures on the right show the stages of exercise

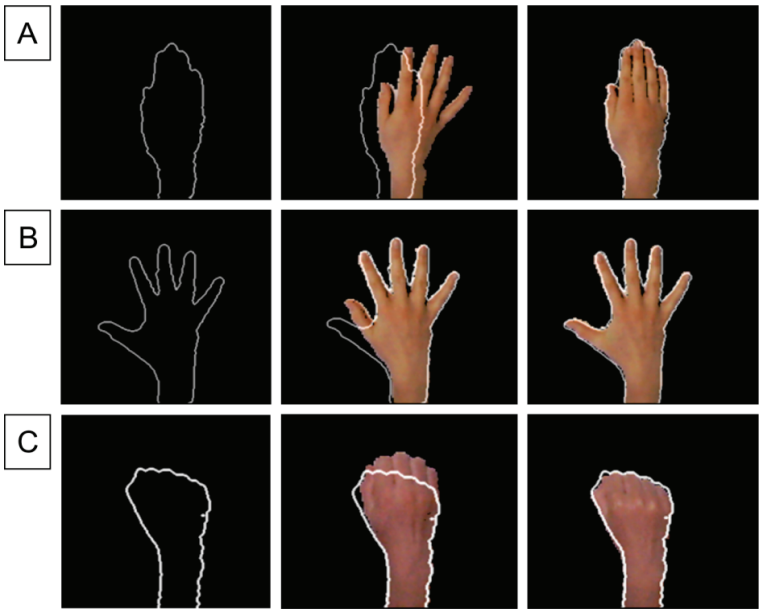

Fig. 4. Sample tasks for hand rehabilitation and correctly performed tasks: (A) all fingers joined, fingers straight, (B) maximum spacing between fingers, (C) closing the fingers into a fist. The patient sees the task (white contour of the correct hand position) and his hand in the real-time movement (extracted from the camera preview)

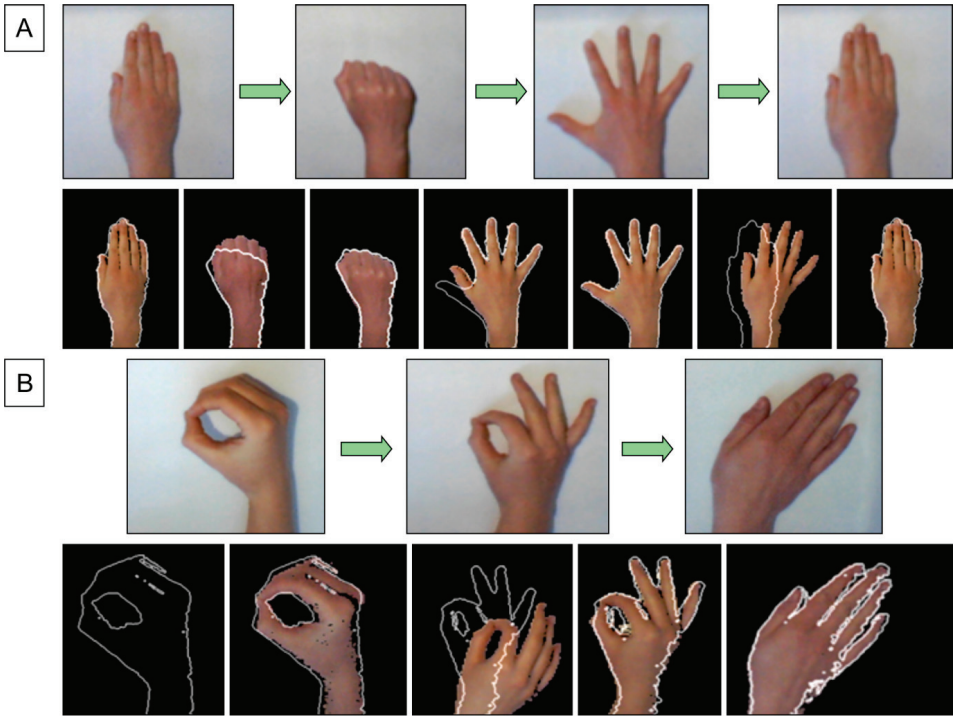

Fig. 5. Sample sequence of tasks for hand rehabilitation: (A) the excercise important for grasping objects like a bag: the fingers straight –> filling into a fist –> spreading fingers, (B) the excercise important for grasping tiny objects: touching the thumb and index finger (pinching gesture) –> moving the wrist

computer automatically downloads the picture and processes the image to extract the contour of the hand. Sample tasks are presented in Fig. 4. The sequential photos captured when executing the movement can also be added, but each step of this movement has to be performed correctly.

Second stage covers proper rehabilitation. During this stage patient performs the same exercise(s) with the program checking and monitoring his/her movements. If the program recognizes correctly the exercise performed, it will notify the patient and change to the next task. In case of any doubt the patient may consult a specialist. If the patient places his/her hand as in the first task in the database, he/she will be informed that the part of the movement is performed correctly and the movement can be continued in accordance with the next image. Figure 5 shows examples of sequential movements task. After each session a report is generated. The report contains information about excercises performed, time spent on excercises, time between steps of movement in sequences, progress and statistics.

3.1. Application architecture

The proposed application contains 6 major modules. Figure 6 shows the dependencies between modules. The division into modules allows for easy extension of the system's functionality. Within the modules the specialized libraries can be easily replaced or added. First module "Images Loader module" (Fig. 6A) is responsible for loading images for the selected task. This module contains also camera handling units which check the availability of the camera connection and collect data from the camera if device is available. Second unit "Image Processing module" (Fig. 6B) contains functions necessary for the preparation of exercise templates and for a real-time hand detection during performing the exercise. The most important units are binarization and filtering units, hand detection unit, hand contour extractor, hand area computation unit and logic functions responsible for decisions if the patient does the exercise correctly. "Visualization module" (Fig. 6C) allows the patient to see the white contour of the task on the black background and preview from the camera with the detected hand pixels. "Task Manager" (Fig. 6D) contains task scheduler which loads from the web service a list of the suggested tasks prepared by the physiotherapist. The module also consists of units responsible for computing the progress of the task and level of coverage of the current state of the exercise with the given task. In this module settings such as the threshold of required percentage of covering (the higher threshold exercise should be performed more precisely that makes exercises harder) are available. Exercise control unit al-

lows for the choice of task, change to next exercises or sessions, decision of terminating the session. The exercises performed or changes are saved in reports. "Reports Generator" (Fig. 6E) automatically creates a summary of the session and performed exercises with additional values such as level of difficulty or time of the movement. It generates the statistics and can support task scheduler by generating suggestions of exercises which were not performed well. "Internet Connection" module checks the availability of the Internet connection, runs the videoconference (on demand), gives information about new exercises and allows generated reports to be uploaded.

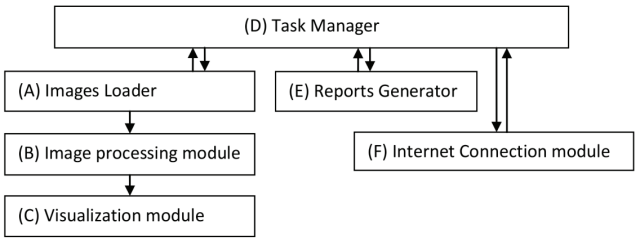

Fig. 6. Dependencies between modules in TeleReh – patient's side: (D) Task Manager is responsible for exercises management, loading number of repetitions, sequence of exercises related to specialist's request; modules (A) –(C) provide images loading and processing during the exercise; the component (E) Reports Generator provides the reports on the Task Manager's demand; (F) Internet connection module checks the ability to establish a connection, gets exercises recommended by specialist from the Web service or loads patient's results to the Web service

3.2. Image processing as a key technology in telerehabilitation

Image processing encompasses a wide and varied field of applications. Prevalence of computers with built-in cameras facilitates introduction of telerehabilitation based on a vision system at the patient's home. The vision system contains cameras and special software. The main issue is the correct interpretation of the observed image and understanding of what the picture shows. Figure 7 presents the main stages of digital image processing. Firstly, the scene is observed by camera and images are collected frame by frame. The next step is preprocessing – filtering, normalization, histogram equalization [24]. The aim of segmentation is to find the areas with similar features. The simplest method is global thresholding for detecting homogeneous areas, but for the skin it does not work properly. Better results were achieved by using local thresholding – the image is divided into smaller parts and thresholding is performed. The thresholding based on pixel's neighbors analysis gave the best results, but was time-consuming. The problem after segmentation was to make a decision which area belongs to the hand. The mathematical description of object's features, shape, color and also object orientation, localization was too complicated, because of many possible hand positions. The hand detection and gesture recognition problems are the subject of numerous research works. A number of image analysis methods are based on a comparison of the new image with the pattern in the database. The hand detection methods can be based also on shape, color and texture features [3], [7], [27]. The hand detection for the purposes of the proposed application to the telerehabilitation process requires the feature independent of the orientation and localization, therefore finding all pixels with high probability to have a skin color seem to be the best choice. The other color space with luminance and chrominance values was tested. Chrominance depends on distribution of skin and background colors. Figure 8 shows the effect of skin detection after thresholding the hand image in HSV (Hue Saturation Value) color space.

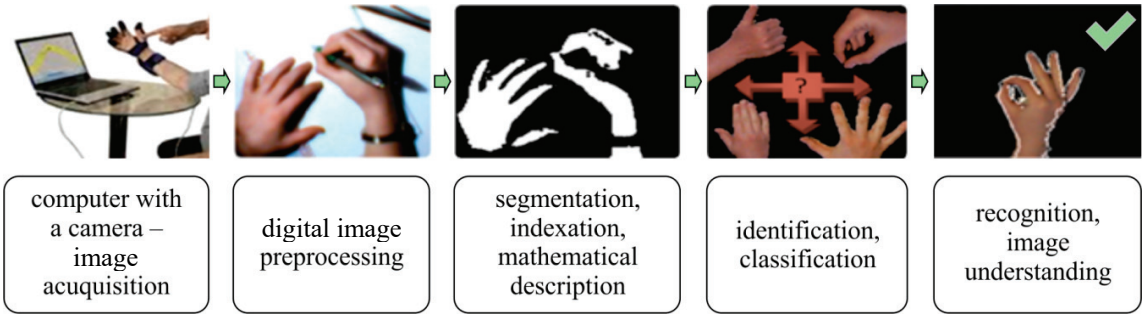

Fig. 7. Main stages of visual analysis: data acquisition, digitization, image processing, segmentation, classification, recognition and understanding image

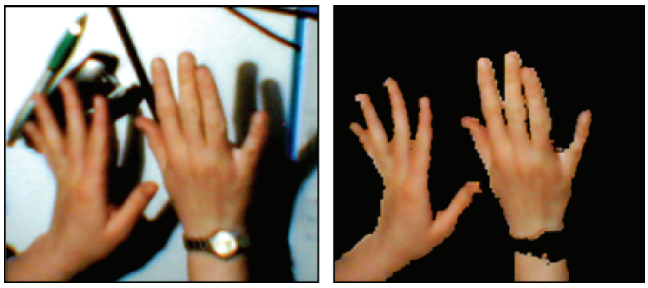

Fig. 8. Result of skin detection in the image – hands are detected, all other objects are correctly removed

4. Discussion

The purpose of telemedicine is the transmission of medical data for prevention, diagnosis, treatment and rehabilitation. Telemedicine is a very promising idea. The overriding goal is to improve and increase the efficiency of healthcare in many areas of medicine. The telemedicine includes mainly such branches as telecardiology, telepsychiatry, telerehabilitation, telesurgery, telepharmacy, teleaudiology. However, the Agency for Health Technology Assessment (ATOM) in Poland gave currently permission only for telerehabilitation [28]. In Poland, through the use of telecardiology tools, there was seen a reduction in the number of hospital patients after heart attack and with cardiovascular diseases. However, due to the problem with access to medical data telecardiology does not have the approval of ATOM [28].

In the area of telerehabilitation, one can mention rehabilitation in neurology, physical disability (e.g., patients after stroke, with cerebral palsy, with spinal cord injury) and rehabilitation of speech and language disorders [10]. Telerehabilitation could bring many benefits especially to people that live far away from clinics and cannot attend standard rehabilitation every day [5], [13], [16]. In the medical and technical databases the number of publications related to telerehabilitation increases in recent years. According to Saran et al., it is estimated that approximately 40% of medical consultations in the United States are carried out via the Internet [17]. This shortens visits by 60% without reducing the patient's satisfaction. TeleReh application also contributes to reduction of the time of medical visits and travels to health care units.

In Poland, it is possible to have access to several types of devices for telerehabilitation, telecare and telediagnosis. Most of the available devices are designed for telecare for the elderly and people with disabilities. The telecare software for smartphones as noted by Saran et al. increases the motivation for rehabilitation [17] as well as TeleReh application.

The device for cardiac telerehabilitation introduced by Piotrowicz et al. allows for rehabilitation at home providing continuous recording of ECG and data transmission during, and after the exercise [17]. The TeleReh application contains modules "Reports Generator" and "Internet Connection" to generate and transmit reports on the performed exercises, which allows continuous professional care.

In Hong Kong there was carried out a pilot study on 21 patients after stroke [11]. The aim of the study was to provide telerehabilitation to patients using videoconferencing. The study showed that telerehabilitation has a high level of acceptance among post-stroke patients. Feasibility and effectiveness of this health care method were also demonstrated. The TeleReh application also allows for videoconferencing as well as independent exercises with software verification (with reports sent to an expert).

Other scientists present the works on advanced systems with additional equipment. Song et al. and Park et al. proposed the robotic system which can be operated remotly [12], [19]. Connelly et al. described the use of pneumatic glove for grasp movements training in Virtual Reality [6]. Alamri et al. presented an augumented reality framework [1]. The patient can train daily movements such as turning the key in the lock. Use of the augumented or virtual reality or manipulators can be more interesting and motivating for the patient than conventional rehabilitation. The weakness of such solutions is the need of the additional equipment placed on the hand.

In this paper, the telerehabilitation system based on personal computer and web camera for patients with hand impairment was proposed. The TeleReh application is easily adapted to the patient because exercises are based on the photos of the patient's hand, so it is guaranted that patient is able to perform exercise. The types of exercises are not limited – the rehabilitant can create the best exercise for the patient. Additionaly after each session the reports with statistics are automatically generated and uploaded to the service, so the rehabilitant has the possiblity to check the progress. The rehabilitant can also supervise the patient's exercising remotely by using videoconference mode. The application and the service is designed to cumulate medical information about the patient and rehabilitation process in one place, which is safe and accessible to authorized users from anywhere in the world.

Nowadays, the pilot study of TeleReh is in progress. The research is carried out in a commune (5000 residents) in the Łódź region. Three physio-

therapists and the doctor working in the Rehabilitation Center are involved in the project, and they submit reports and their suggestions about the TeleReh software. Patients with various movement disorders will be involved in research. TeleReh application is being developed and improved since 2014. It is expected that patients under 12 years of age will enjoy attractive form of exercise while older patients will emphasize the significant convenience of the TeleReh method. In the future the clinical studies will be conducted on statistically significant group of patients with cerebral palsy and after a stroke.

References

[1] ALAMRI A., CHA J., EL SADDIK A., *AR-REHAB: An Augmented Reality Framework for Poststroke-Patient Rehabilitation*, IEEE Trans. Instrum. Meas., 2010, 59(10), 2554–2563.

[2] AUGUSTYNIAK P., *Interpretive software conversion following changes of patient status and diagnostic goals*, Acta Bioeng. Biomech., 2009, 11(2), 3–11.

[3] AZIZ M.A.A., NIU J., ZHAO X., LI J., WANG K., *Using novel shape, color and texture descriptors for human hand detection*, [in:] Proceedings of 2014 11th International Bhurban Conference on Applied Sciences & Technology (IBCAST), IEEE, Islamabad, Pakistan, 2014, 150–157.

[4] BRENNAN D.M., TINDALL L., THEODOROS D. et al., *A Blueprint for Telerehabilitation Guidelines – October 2010*, Telemed e-Health, 2011, 17(8), 662–665.

[5] CHUMBLER N.R., QUIGLEY P., SANFORD J. et al., *Implementing Telerehabilitation Research for Stroke Rehabilitation with Community Dwelling Veterans: Lessons Learned*, Int. J. Telerehabilitation, 2010, 2(1), 15–22.

[6] CONNELLY L., JIA Y., TORO M.L. et al., *A pneumatic glove and immersive virtual reality environment for hand rehabilitative training after stroke*, IEEE Trans. Neural. Syst. Rehabil. Eng., 2010, 18(5), 551–559.

[7] DAWOD A.Y., ABDULLAH J., ALAM M.J., *Adaptive skin color model for hand segmentation*, [in:] 2010 International Conference on Computer Applications and Industrial Electronics, IEEE, Kuala Lumpur, Malaysia, 2010, 486–489.

[8] GO A.S., MOZAFFARIAN D., ROGER V.L. et al., *Heart Disease and Stroke Statistics – 2014 Update: A report From the American Heart Association*, Circulation, 2014, 129(3), e28–e292.

[9] GUZIK A., MICHNIK R., RYCERSKI W., *The estimation of rehabilitation progress in patients with psychomotor diseases of upper limb of upper limb based on modelling and experimental research*, Acta Bioeng. Biomech., 2006, 8(2), 79–87.

[10] KAIRY D., LEHOUX P., VINCENT C., VISINTIN M., *A systematic review of clinical outcomes, clinical process, healthcare utilization and costs associated with telerehabilitation*, Disabil. Rehabil., 2009, 31(6), 427–447.

[11] LAI J.C.K., WOO J., HUI E., CHAN W.M., *Telerehabilitation – a new model for community-based stroke rehabilitation*, J. Telemed. Telecare, 2004, 10(4), 199–205.

[12] PARK H.-S., PENG Q., ZHANG L.-Q., *A portable telerehabilitation system for remote evaluations of impaired elbows in neurological disorders*, IEEE Trans. Neural. Syst. Rehabil. Eng., 2008, 16(3), 245–254.

[13] PARMANTO B., SAPTONO A., *Telerehabilitation: State-of-the-Art from an Informatics Perspective*, Int. J. Telerehabilitation, 2009, 1(1), 73–84.

[14] PRAMUKA M., VAN ROOSMALEN L., *Telerehabilitation Technologies: Accessibility and Usability*, Int. J. Telerehabilitation, 2009, 1(1), 25–36.

[15] REINKENSMEYER D.J., PANG C.T., NESSLER J.A., PAINTER C.C., *Web-based telerehabilitation for the upper extremity after stroke*, IEEE Trans. Neural. Syst. Rehabil. Eng., 2002, 10(2), 102–108.

[16] SAPTONO A., SCHEIN R.M., PARMANTO B., FAIRMAN A., *Methodology for Analyzing and Developing Information Management Infrastructure to Support Telerehabilitation*, Int. J. Telerehabilitation, 2009, 1(1), 39–46.

[17] SARAN T., HOROCH A., *Telemedyczne podtrzymywanie aktywności ruchowej za pomocą smartfonów – system telemonitorujący w Instytucie Medycyny Wsi*, Med. Ogólna i Nauk o Zdrowiu, 2013, 19(4), 500–503.

[18] SCHMELER M.R., SCHEIN R.M., MCCUE M., BETZ K., *Telerehabilitation Clinical and Vocational Applications for Assistive Technology: Research, Opportunities, and Challenges*, Int. J. Telerehabilitation, 2009, 1(1), 59–72.

[19] SONG G., GUO S., *Development of a Novel Tele-rehabilitation System*, [in:] 2006 IEEE International Conference on Robotics and Biomimetics (ROBIO), IEEE, Kunming, China, 2006, 785–789.

[20] STRZELCZYK P., WOCHLIK I., TADEUSIEWICZ R., IZWORSKI A., BUŁKA J., *Telemedical System in Evaluation of Auditory Brainsteam Responses and Support of Diagnosis*, [in:] N.T. Nguyen, M.T. Le, J. Świątek (eds.), *Intelligent Information and Database Systems*, Second International Conference ACIIDS 2010, Part 2, Springer, Berlin, Heidelberg, 2010, 21–28.

[21] SZCZERBIK E., KRAWCZYK M., SYCZEWSKA M., *Ground reaction force analysed with correlation coefficient matrix in group of stroke patients*, Acta Bioeng. Biomech., 2014, 16(2), 3–9.

[22] TADEUSIEWICZ R., *Systemowe podejście do wybranych zagadnień telemedycyny*, [in:] P. Kulczycki, O. Hryniewicz, J. Kacprzyk (eds.), *Techniki informacyjne w badaniach systemowych*, WNT, Warsaw, 2007, 341–360.

[23] TADEUSIEWICZ R., *Telemedycyna – nowe wyzwanie współczesnej nauki*, Nauka, 2004, 3, 57–80.

[24] TADEUSIEWICZ R., KOROHODA P., *Komputerowa analiza i przetwarzanie obrazów*, Wydawnictwo Fundacji Postępu Telekomunikacji, Kraków, 1997.

[25] TOMASZEWSKI W., *Computer-Based Medical Decision Support System based on guidelines, clinical pathways and decision nodes*, Acta Bioeng. Biomech., 2012, 14(1):107–116.

[26] TONG K.Y., HO S.K., PANG P.K. et al., *An intention driven hand functions task training robotic system*, [in:] 32nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Buenos Aires, Argentina, 2010, 3406–3409.

[27] WANG Y.-R., LIN W.-H., YANG L., *A novel real time hand detection based on skin-color*, [in:] 2013 IEEE International Symposium on Consumer Electronics (ISCE), IEEE, 2013, 141–142.

[28] ZGLICZYŃSKI W., PINKAS J., CIANCIARA D. et al., *Telemedycyna w Polsce – bariery rozwoju w opinii lekarzy*, Med. Ogólna i Nauk o Zdrowiu, 2013, 19(4), 496–499.