Lecture Notes in Networks and Systems 409

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Innovations in Biomedical Engineering

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Contents

Experimental Research in Biomedical Engineering

Experimental research has a very wide range of applications in the field of biomedical engineering, as evidenced by the publication topics of this chapter. It is a key part of each research, enabling the verification of theses as well as indicating the possibilities of implementing the proposed practical solutions. The chapter presents works covering the subject of biomechanical measurements and practical verification of the designed devices. muscle response to and given rhythmic sound stimulus, the impact of the pandemic on physical activity, body posture while sitting and the possibility of using virtual reality in rehabilitation of the ability to maintain balance are examples of works included in the chapter. Additionally some practical solutions, like innovative furniture for the elderly or an electronic stethoscope are also presented.

Furniture for Elderly People

Iwona Benek, Iwona Chuchnowska, and Kamil Joszko

Abstract The article presents a description of the results of interdisciplinary cooperation. It is related to the implementation of research carried out in the form of Project Based Learning as a part of the project 'Silesian University of Technology as the Centre for Modern Education based on research and innovation'. Employees and students of the Faculty of Biomedical Engineering and the Faculty of Architecture of the Silesian University of Technology have attempted to design some furniture for senior integrated with control systems located in the LeonardoLab—2014a room for testing technological solutions for the elderly.

Keywords Elderly dependents · LeonardoLab

1 Introduction

The issue of designing for older people becomes an important question in connection with demographic changes and an increasing number of people who need support in everyday life due to their advanced age and health problems. For a number of years, this topic has been developed at the Faculty of Architecture and at the Faculty of Biomedical Engineering of the Silesian University of Technology in Gliwice. In this work, the issues related is caring for a dependent elderly person were considered. Based on this project, the need to determine optimal design solutions related to

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shaping the internal environment has been identified. Important research issues have also emerged and what is more, they should be focused on shaping elements supporting the care of dependent people in order to be used by them in everyday activities.

1.1 Purpose of the Work

The main purpose of this work is to determine the optimal—functional, spatial and formal features of furniture in the room for an elderly dependent person. Items of furniture ought to support the treatment process. They should create proper conditions, which supports the functional competences of older patients. The research part focuses on the stay zone of a dependent elderly person and analyzes some ergonomic requirements and psychological needs resulting from their state of health. The following assumptions were made in this work: – adequate spatial conditions are one of the most important factors supporting older patients in their current functional competences, – individual elements of the environment for an elderly dependent person should increase their activity, mobility and independence, – the basic criterion in designing the space surrounding an elderly person is the reduction of stress resulting from maintaining the proper level of control over the environment. A very important source of data and the basis for formulating conclusions about the comfort felt by an elderly dependent person and working conditions of caregivers is information obtained from users about the ways of using facilities in the Geriatric wards [1].

1.2 Methodology

At the initial stage of work the methods of analysis and criticism of the literature were used, thanks to which the goals of the project were defined. The main trends in equipping rooms related to the stay of a dependent elderly person were indicated. Ergonomic guidelines determined a reference point for the functional and formal conditions in shaping the pieces of furniture in rooms dedicated to the elderly [3]. The work also included pilot studies at the Geriatric Hospital in Katowice, this action helped to characterize the surrounding environment of the geriatric patients and verify the proper design assumptions. Research techniques were applied in the form of: interviews with medical and nursing staff, observation of the functioning of the ward, tracking the patient's path and interviews with selected patients. The research was carried out for separate functional, behavioral and technical categories. Observation of the daily habits of dependent people made it possible to notice the frequent use of bedside cabinets and hospital cabinets. It proved the primary role that proper furniture plays in organizing the control centre of an elderly person. Practical access to everyday objects, and carrying our independent daily activities are the basis for a sense of security and control for dependent people. Hospital patients valued cabinets by their beds and they also reported many disadvantages. The remarks concerned: the size and availability of the countertop (too small a surface, no possibility of height adjustment), drawers (not accessible to a person who is lying down), no possibility of recharging the phone, as well as being able to putting away everyday objects in a safe way (medicines, glasses, etc.). A list of the most frequently used items and devices was prepared during the observations (for instance: a cabinet, a lamp, a contact plug, a telephone, glasses, newspapers, an alarm clock, a wrist watch, a calendar, a comb, a cosmetic bag, photo frames, a mascot, a medicine pack and a cup, etc.). The conclusions from the tests have been verified using the method of study in design-through conceptual work for selected pieces of equipment, it allowed the identification of the most important activities in creating an environment supporting older patients. The result of the research conducted is the formulation of design guidelines in the form of a furniture design (a bedside cabinet) serving a dependent elderly person. The project site was the LeonardoLab-a smart laboratory located at the Faculty of Biomedical Engineering at the Silesian University of Technology in Zabrze. From the technological aspect, the LeonardoLab is operated by the NAZCA building automation system designed by the initiator of the project, the APA Group in Gliwice. The aim of the LeonardoLab is to develop technological solutions that will make it easier for medical staff to care for the elderly and the injured. It is used to test prototypes of products, services and technologies.

2 Analysis of the Problem

In the report entitled The Situation of Caregivers of Elderly Dependents [1], it is written: Seniors—it is a very wide term, depending on the definition, people from 55 to 65 and above are included in this group. (...) Older dependents are also a heterogeneous group. First of all, the causes of dependence are different, and there are also various areas in which dependent seniors need support. Designing an environment for the elderly requires a detailed and insightful approach that includes the ability to adapt it on a regular basis to the changing skills and needs of seniors. It is also necessary to take into account the disabilities commonly encountered like motor, auditory, visual and mental types. Susanne Iwarsson (professor of rehabilitation at the University of Lund, Sweden) in the book Housing Enabler [2], gives a set of the following disabilities that impede independence: – difficulties in interpreting information (dementia, Alzheimer's disease), – partial or total loss of vision, – partial or total loss of hearing, – problems with keeping balance, – lack of physical coordination, – poor physical condition, – difficulties in moving the head, – difficulties in raising the arms, – difficulties in lifting and catching objects, – loss of superior manual activities, – difficulties with bending down and kneeling, – walking on crutches, – using a wheelchair, – being overweight (a rare situation among the very elderly) or being extremely tall. To sum up, the ergonomic requirements of older people are specific due to the various physical dysfunctions. The disabilities are associated with difficulties in moving around and using crutches, walking sticks, walkers or wheelchairs.

2.1 Overview of the Solutions

In order to be able to specify the conceptual assumptions, the components of the equipment and the support for the elderly dependents were reviewed. One of the groups of items were cabinets and bedside tables. The analysis concerned material, colour and functional solutions. These products were characterized by a lack of adaptation to the needs of elderly dependents in terms of ergonomics (no possibility to use the worktop in a lying position, no access to drawers), in forms of personal style preferences terms (for instance inadequate colours) and lack of electronic systems. Another review was focused on a group of electronically controlled items. Examples of such the furniture was inspired by the control systems available in the LeonardoLab. Well-developed telecare services were also analyzed such as the OPOS24 telecare unit, which uses communication via GSM network (the set is equipped with a gas leak sensor, a motion sensor, an open door sensor and an (SOS) band or keychain [4]), and mobile telecare systems (e.g. PillDrill—the device sends notifications to the smartphone, in the form of a message. The device scans the pillbox, then checks whether the appropriate drug has been selected and opens the lid [5]).

3 Project

3.1 Conceptual Work

The next step was to analyze the interior design for dependent elderly people in terms of design, rehabilitation and implementation of modern technologies.Three proposals for furniture were put forward—a bed, a cabinet and an armchair. Each proposed piece of furniture is often used by the elderly or handicapped dependent. A bed has already been placed in the LeonardoLab, which has been attached to the control system in an intelligent room. The NAZCA system controls the built-in actuators in the bed, it also allows you to control the bed using an additional optical interface, in which the camera recognizes the facial expressions of the person lying on the bed and uses a mobile application on the smartphone. The Android system allows you to control modules plugged into NAZCA through voice commands. The advanced bed control features inspired the team to construct more furniture for the LeonardoLab studio. Additionally, further work was focused on the bedside cabinet design because it was universal in terms of functionality. Four variants of the bedside table were proposed, what is more, it was important to think about the available functional solutions that could be implemented by an interdisciplinary team of bioengineers and architects. The first option Fig. 1 was based on designing a movable column at the cabinet, which would raise the drawer and counter to the appropriate height, adapted to the user's hands range.

Fig. 1 The model of the bedside cabinet with a presentation of functional in one of the material solution *Source* Own data

Fig. 2 The first option based on designing a movable column at the cabinet *Source* Own data

In the second variant Fig. 2, mobile cabinets moved horizontally, which allowed the patient to adjust the storage area to their changing needs.

The third version Fig. 3, consisting of a table with a top, offered the possibility of controlling its height. The fourth type of bedside cabinet was also mobile. In this option, the drawers could be hidden in the carrying body of this furniture (Fig. 4). The further parts of the project were focused on the third solution (the cabinet with raised countertop).

Fig. 3 The second variant—mobile cabinets moved horizontally *Source* Own data

Fig. 4 The third version consisting of a table with a raised top *Source* Own data

3.2 The Evolution of the Project

After analysis, it was decided that the designed piece of furniture would combine the features of a bedside table and a cabinet with drawers.This solution is the most secure, thanks to which the product will compete with the latest technologies appearing on the market over a long period of time. It will be clearly more expensive than other proposals, which despite the lowest level of advancement is characterized by the highest mobility. The most important function of the furniture is the possibility to adjust the height of the countertop. The aluminum profile from Bosch Rexroth was chosen as the basis of the construction because of its durability and simplicity. The first version of the project (Fig. 5) took into account the implementation of one electric column, which allows the table to fit enter under hospital bed. This solution was characterized by a very massive column, which took up a lot of usable space. This version was disqualified due to the very limited range of the column extension and its large dimensions. The next stages of project involved using a smaller lift system—the ram. This version of the project assumed the construction of two table tops, one fixed and the other one lifted and rotated. Lifting only one table top resulted in a large difference in height between the work planes. In addition, the seemingly small ram required a proper construction to improve the stability of the structure,

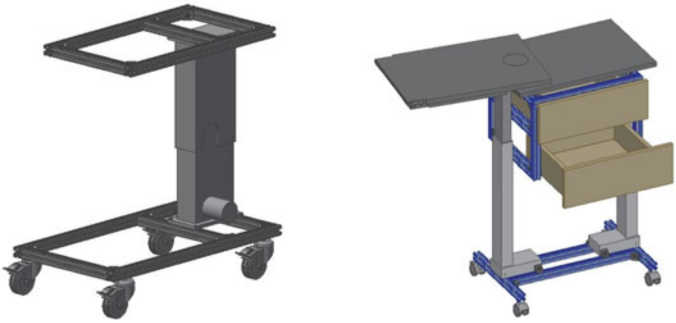

Fig. 5 Functional model of furniture. The first version of the project (on the left). The third version of the project (on the right) *Source* Own data

and thus the size of the table increased significantly. In the third version, two electric columns were used to raise the countertop (Fig. 5). The rotating countertop was connected to the main table thanks to a swivel bearing and made it possible to easily rotate it. The space for the drawers was placed right under the top, thus creating a free space at the bottom of the cabinet. In the final version of the project, the columns have a very large range of motion, furthermore, they are extremely stable, and have a special protection to prevent objects from being destroyed. The rotating countertop is equipped with an additional folding part, thanks to that the worktop is accessible in a lying position (Fig. 6). According to the original assumption, the aluminum profile from Bosch remained the basis of the structure. The drawers are mounted on solid roller guides. The selection of electronically controlled functions that can be implemented in the furniture was proposed, for instance to automatically adjust the cabinet's height using a drive system of Jiecang's desk. The system is based on a dual synchronized electric drive with Hall effect sensors. The system is controlled by a remote control provided by the manufacturer. For the purpose of the project, the control function was provided by the NodeMCU ESP8266 board, which was chosen due to its integrated Wi-Fi wireless communication module, due to which it was possible to communicate with the NAZCA system, responsible for controlling LeonardoLab (Fig. 7). The communication protocol between the NodeMCU board and NAZCA system is Modbus TCP/IP.

Work related to the implementation of the functional model was carried out simultaneously with the development of its design (Fig. 6). The aspect of functionality of the bedside cabinet and the possibilities of modifying the furniture by adjusting it to the individual needs of the user were also important for the team. The final effect is a prototype of furniture for seniors, which can be integrated with the NAZCA systems found in LeonardoLab (Fig. 7). In this way, the task of designing an innovative component of the LeonardoLab equipment was successfully completed in a comprehensive and interdisciplinary way.

Fig. 6 The model of the bedside cabinet with a presentation of functional in one of the material solution *Source* Own data

Fig. 7 The model of the bedside cabinet with a presentation of functional in one of the material solution *Source* Own data

4 Conclusion

As a part of the project, the conducted interdisciplinary research was conducted with the participation of the Faculty of Architecture, the Faculty of Biomedical Engineering, the APA Group—a company that deals with automated technology and systems for intelligent construction, EMC Silesia Ltd.—a Geriatric Hospital with the Research and Development Centre. One of the aims of the project was to give it an overall aspect of interdisciplinarity basis. Undoubted advantages of such cooperation include a comprehensive recognition of the needs of elderly dependents, better results of the preparation of the functional model, while paying attention to formal solutions. The biggest difficult, was to determine the needs and limitations at the stage of design. On the one hand, it generates some problems, but on the other hand it gives the opportunity to learn more about solving them. Eventually, such cooperation gives better results at the design and implementation process—people from various fields are able to assess both the progress of a given project and the final effect, as well as the further possibilities of its development or potential corrections

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Thermal Stabiliser of Knee Joint

Iwona Chuchnowska, Katarzyna Białas, Iwona Benek, Zbigniew Opilski, Jadwiga Małecka, Wojciech Michalec, Patryk Mielniczek, Oliwia Nowicka, Paweł Podsiedlik, and Piotr Szaflik

Abstract Cryotherapy, also known as cold therapy, is a method consisting in the lowering of the temperature of tissues using water, ice, air, ethyl chloride, dinitrogen monoxide or liquid nitrogen. Treatment with low temperature may be applied generally or locally. General cryotherapy consists in the cooling of the whole body, whereas local one refers to the decrease in the temperature of skin and tissues. In this method, the cooling area should not be too big. The research project involved the second type of the above-mentioned cooling methods. The project entitled "Thermal Stabiliser of the Knee Joint" was implemented by a team of students. The objective of this project was to develop and then fabricate a cooling system using the Peltier module, including the attachment of the system to the stabiliser of the knee joint. The developed device will find application in local cryotherapy of the knee joint. This type of therapy is commonly applied in early post-trauma conditions with the damage to soft tissues (spraining and dislocation of joints, contusions of muscles), chronic inflammatory and degenerative diseases as well as overload disorders (degenerative diseases of knee joints, rheumatoid arthritis of joints), conditions of increased muscle tension and limitation of joint mobility, chronic oedema and joint exudates. The first stage of the research encompassed a review of the existing solutions of ortheses and methods of cooling the knee joint. Next, two concepts of the device were developed and their visualization was prepared in the Inventor software programme. The third phase involved the development of the documentation concerning the project

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implementation and the applied technology. This was done using the CAD software programme. The project was also analysed with a view to satisfying the functional requirements. In addition to that, necessary elements were printed using a 3D printer. The last stage involved the manufacturing of a prototype of a functional device taking into consideration electronics and an Android system application.

Keywords Cryotherapy · Local cryotherapy · Orthesis · Knee joint stabiliser · Knee joint

1 Introduction

Cryotherapy involves activities aiming to alleviate pain by means of various types of substances having cooling properties. Such substances include ethyl chloride, dinitrogen monoxide, liquid nitrogen, water or ice. The birth of cryotherapy for the purpose of pain alleviation goes back to the 20th century, when a medium in the form of cold water or ice was laid on the body organ affected by disease. The rule of the operation of cryotherapeutical procedures remains the same, however, the technological progress contributed to the development of new, more effective, methods of cold therapy. With the passing of time, the discovery of further substances with cooling properties led to the distinguishment of two types of cryogenic procedures, namely local and general [1]. Local cryotherapy consists in the placement of a cooling compress directly on the sites of pain occurrence. This method aims to lower the temperature of skin and tissues by laying there, for instance plastic bags filled with specialist cooling gel, water of lowered temperature or ice. It should be noted that a local cryotherapy procedure should not exceed 20 min due to the fact that a longer period of time may cause adverse effects in the form of frostbite. The procedure lasting 20 min is sufficient to cool the tissues down to a temperature of 13 °C. This is an optimum temperature to obtain a desired effect of the loss of sensation and analgesia [2, 3]. Whole body cryotherapy is a method of rehabilitation involving the cooling of the patient's whole body by staying in a special cryogenic chamber which is filled, for instance, with nitrogen. Such treatment lasts no longer than 3 min due to very low temperatures, dropping even to –100 °C. The advantages of this type of treatment include the improvement of psychological condition, relaxation of muscles and disappearance of internal pains in the organism [1–3].

2 Materials and Methods

Tests of power consumption of the device were conducted using an ammeter, a voltmeter and a thermal-imaging camera Flir One Pro, whose measurement range falls between –20–400 °C. The measurements were carried out three times and the obtained results were subjected to the calculation of the arithmetic mean. The performance of measurements in the above-described way aimed to minimize as much as possible the range of error of each device. The design of the casings of two separate devices was developed in the CAD Autodesk Inventor 2020 software programme. It was done taking into consideration optimum dimensions. It is possible to ‘seal’ the casing model with screw joints for the purpose of using hydraulic and electric devices. During the preparation of models for 3D printing, the Z-suite software programme was used, whereas 3D printing was executed with the application of a Zortrax m200 printer. The appearance of the whole object and the way of attachment of all elements on the user’s body were designed in the Photoshop and SketchUp software programmes. The software for controlling the device was developed in the programming environment of the Android Studio, which enables the creation of applications in a compatible way with the majority of mobile phone systems based on the Android system. A three-dimensional model of the designed device and the technical documentation of all the elements which were necessary for its creation were prepared in the Autodesk Inventor 2020 software programme.

3 Results of Investigations

The conducted investigations refer in particular to the obtained temperatures, cooling time and power input necessary to supply power to the whole mechanism. A small bag filled with liquid was placed on the knee joint in such a way as to effectively lower the temperature of the site where the patient may feel pain. The measurement of the temperature of the bag containing liquid was conducted using a thermal-imaging camera (Fig. 1).

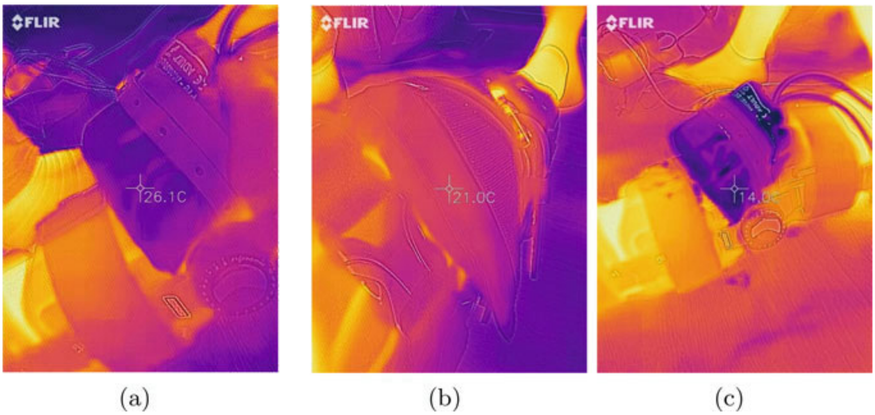

Fig. 1 Temperature of liquid **a** at the beginning of measurements **b** after 15 min of tests **b** after 40 min of tests

Apart from the temperature, the measurements involved also the power consumption of the whole device. The results were averaged in order to minimize the measurement error of devices (Table 1, Fig. 2).

A belt, playing a function of a holder for the casing, was fitted on the hips. The casing houses, among other things, a battery supplying the whole mechanism with power and electronic control elements. The battery is connected to another casing by means of supply cables. The second casing is fitted on the thigh slightly above the knee orthesis and contains elements of heat removal (heatsink) which cool the

Table 1 Results obtained during the measurements of temperature

Time (min)	Electric current (A)	Temp. ($°C$)	Time (min)	Electric current (A)	Temp. ($°C$)
0	5,5	22,5	30	5,5	18,7
2	5,5	22,8	32	5,5	18,2
4	5,5	23,5	34	5,5	18
6	5,5	24,5	36	5,5	15,1
8	5,5	23,9	38	5,5	15,0
10	5,5	22,2	40	5,5	14,5
12	5,5	22,1	42	5,5	13,0
14	5,5	21,8	44	5,5	12,8
16	5,5	20,9	46	5,5	12,1
18	5,5	20,4	48	5,5	11,6
20	5,5	19,9	50	5,5	10,9
22	5,5	19,5	52	5,5	10,5
24	5,5	19,6	54	5,5	10,2
26	5,5	19,2	56	5,5	9,7
28	5,5	18,9	58	0,6	9,0

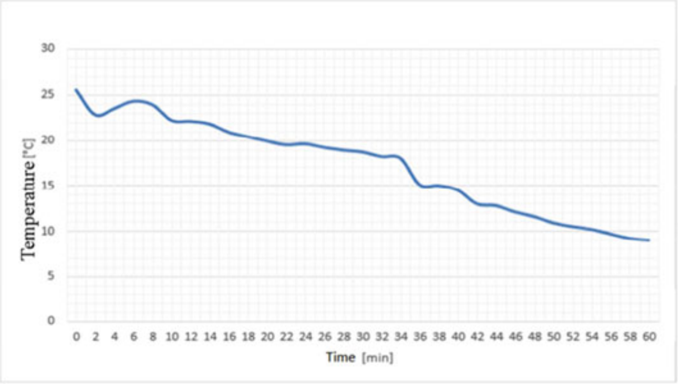

Fig. 2 Diagram of the dependence of the obtained temperature on the duration of the measurements

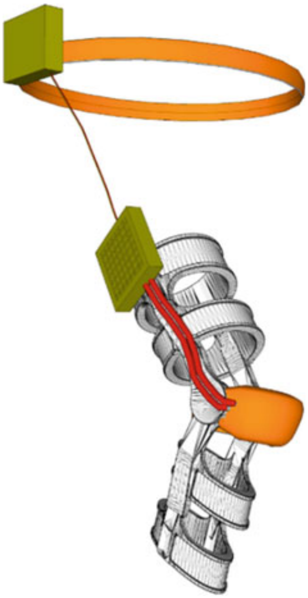

Fig. 3 Visualization of the developed design of the device

substance in the plastic bag. A water pump is responsible for the transport of liquid. The pump forces the substance cooled by the Peltier module into the bag and receives the liquid warmed up by the knee, creating thus a closed cycle. The whole system is stabilised by the knee orthesis, which stiffens the joint and provides protection during the rehabilitation of the knee joint (Fig. 3).

One of the assumptions of the project was to apply a microcontroller of the Arduino family. The selected plate: Arduino Nano 33 BLE is characterized by very small dimensions and extremely low power consumption, amounting to less than 20 mA. Module HC-06 is in charge of the connection of a Bluetooth microcontroller and a mobile phone application with the Android system. The communication is maintained by means of a series connection in the Bluetooth 2.0 standard. The obtained temperature is measured with analogue temperature sensor LM35. The selected sensor has a wide range of temperature readings (from –55 to 150 °C) with accuracy of 0.5 °C. The executive element is a 60 W Peltier module. In order to determine the power needed for the cooling of the system, it was necessary to take into consideration all elements which charge electric energy from the supply system. In this case, the elements were as follows: Peltier module, cooling fan, pump of liquid and electronic control system. It was assumed that power reserve should be also taken into consideration. It was decided that a maximum end power at one Peltier module should equal 65 W. The device is fed by a pack of lithium-ion batteries. The programme, which is implemented into the Arduino microcontroller, is secured against setting too low temperatures. The default lowest temperature is 0 °C. The programme

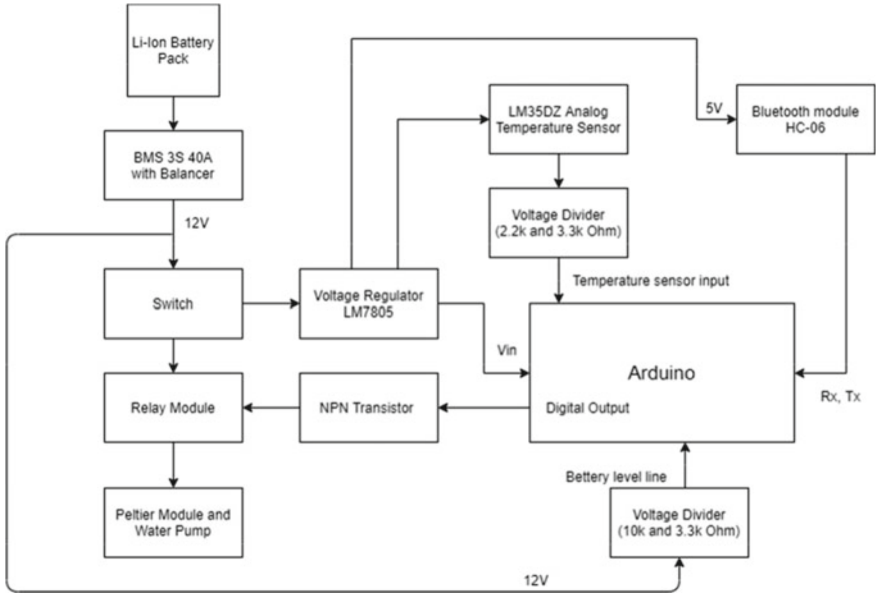

Fig. 4 Diagram of the system

also has a safety function turning off the cooling after a certain time. The default maximum time amounts to 3 h (Fig. 4).

4 Android System Application

One of the assumptions of the design of a thermal orthesis of the knee joint was the development of an application in the Android system, which would serve the purpose of the management and controlling of the device. The application should be wirelessly connected to the device (for instance, through the Bluetooth interface) and make it possible to start the operation of the device, turn it off and change the set temperature. The interface should be readable and easy to use. It should enable the user to check the current state of the battery and temperature readouts. In order to implement the above-mentioned assumptions, the Bluetooth interface was applied. The main reason for the application of this type of a communication system is the availability of modules - each updated mobile phone with the Android system has the Bluetooth module. In order to complete the final version of the application, the official software programme Android Studio, provided by Google, was used. The fabricated interface can be seen below (Fig. 5). In the central part of the application, there is a chief control button START or STOP, serving the purpose of turning on and off the device. Above the control button, there is a slider which enables setting the target

(a) (b)

Fig. 5 Interface of the application **a** in use **b** ready to use

temperature of the device (current and target temperatures are shown in the upper part of the application on the right and left side, respectively). In the lower part of the application, below the chief control button, there is an instruction field informing the user about the operating status and purpose of the application. In addition, the screen of the application enables the readout of the current temperature of the device and the battery status. Following the start-up, the programme makes a series of attempts to connect with the device by means of a wireless BT communication. When the connection is not possible, the user receives a message about an error and is asked to make sure if the device has been turned on. In order to repeat the communication attempt, it is necessary to turn on the application once again. When the device gets connected to the application, the user is informed about that and asked to select temperature and press the START button. The programme sends a 'start' order and a set temperature to the device.

5 Discussion

The conducted tests show the cooling efficiency based on one Peltier's module. Calculations performed by means of analytical methods provided the basis for the estimation of safe capacity of a battery being able to supply power to the whole device. The above-mentioned capacity amounts to 10 Ah. Taking into consideration low cooling efficiency of the Peltier module in relation to significant power input, it would be advisable to improve the device. One of the methods of efficiency improvement is the addition of a subsequent cooling module to the whole system, which would decrease the time of cooling the liquid to a required temperature down to 17 min of the device operation. However, this is connected with the application of a bigger battery of greater capacity. As a result, a heavier device, which is held and attached to the hips (Fig. 6), will cause the loss of comfort by the user. Another way of the

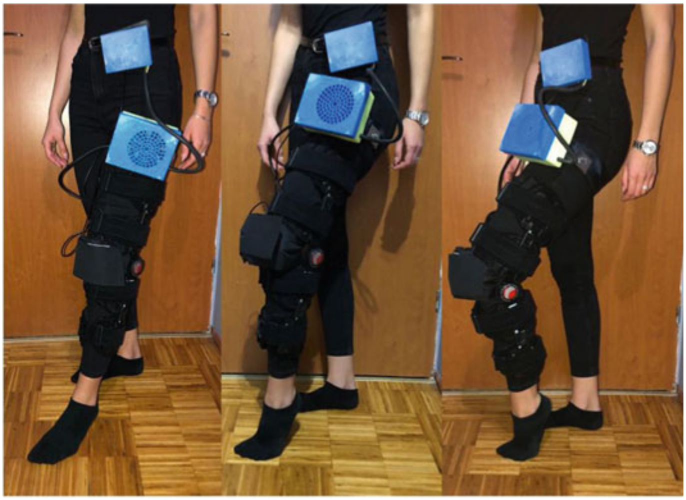

Fig. 6 Fabricated cooling system attached to the knee joint stabiliser

system improvement is the storage of the bag with the cooling substance, prior to its use, in the refrigerator until it achieves a suitable temperature for the analgesic effect. The role of the device mechanism would be then just maintaining the already lowered temperature on the site of pain occurrence. Such a method would contribute to the functionality and comfort of use in patients. The obtained temperature results are burdened with a high tolerance error. This fact results from imperfections of the thermal-imaging camera, whose long calibration time and fluctuations of displayed temperatures are far from real-life results.

6 Summary

The implemented project aiming at the local cryotherapy of the knee joint with the simultaneous use of the stabiliser successfully underwent the investigations. Further development of the above-described cryogenic system is planned in order to improve its efficiency and design as well as increase the comfort of use for the patients. All this will enable the adaptation of the system to the expected results. In spite of numerous problems in different phases of the construction, the creation of the mechanism has enabled better understanding of physiotherapeutical issues and broadened the knowledge of local cryotherapy used in the knee joint rehabilitation.

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MONITORING HELMET—The Use of Thermal Imaging to Monitor the Epidemic Threat Caused by the Corona Virus

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Abstract The objective of an interdisciplinary team of IT specialists, bio-engineers, architects, a specialist in thermovisual measurements and medical personnel was to develop an apparatus enabling a remote measurement of human temperature using a thermal imaging camera coupled with a mobile phone and the Augmented Reality technology. The team designed a portable device which makes it possible to conduct measurements in an automatic way without the use of hands.

Keywords Thermovision · Covid-19 · Monitoring · Thermal imaging

1 Introduction

A coronavirus identified in 2019, SARS-CoV-2, has caused a pandemic of respiratory illness, called COVID-19. COVID-19 is an infectious disease that can be severe and has caused millions of deaths around the world as well as lasting health problems in some who have survived the illness. The coronavirus can be spread from person to person through droplets and virus particles released into the air when an infected person breathes, talks, laughs, sings, coughs, or sneezes. Larger droplets may fall to the ground in a few seconds, but tiny infectious particles can linger in the air and accumulate in indoor places, especially where many people are gathered and there is poor ventilation. The most common symptoms of COVID-19 are fever, cough, muscle pain, and fatigue. Fever is the symptom the easiest to identify. Since the virus

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outbreak, thermal screening using infrared thermometers and thermal imaging has been used at public places to check the body temperature to identify infected among the crowd [5, 6].

This study proposes the design of a simple, cheap, and easy to obtain monitoring helmet that has the capability to detect humans with a fever automatically from the thermal images. The thermal camera technology is combined with AR (Augmented Reality) technology with the use of a standard mobile phone. Additionally, the proposed system is equipped with facial recognition technology. It can automatically measure the temperature of surrounding people and inform if the recorded temperature exceeds the set threshold. This proposed project can be quickly, simply, and cheaply implemented by the health care system and other services that exposed their employees to potentially sick people and could potentially help prevent the wider spread of the coronavirus.

2 Temperature Measurement

Two approaches can be distinguished among temperature measurement methods, namely contact and contactless methods of temperature detection. The above-mentioned techniques make use of various devices enabling the estimation of the body temperature values in invasive or non-invasive ways. The tools which are applied clinically to measure the body temperature can be divided into contact and contactless devices.

Contact devices are devices whose measurement element comes into contact with the tested surface. Such devices are widely used at home and in medical practice. They include liquid and electronic thermometers. **Liquid thermometers** use that the volume of the liquid in a container grows along with an increase in temperature. he disadvantage of this type of device is its vulnerability to mechanical damage, as well as a relatively long time of measurement lasting from 4 to 10 min. Such a thermometer makes it possible to measure temperature in the oral cavity, armpit or anus. **Electronic thermometers** most often use thermistors, i.e. semiconductor resistors, whose resistance is strongly dependent on temperature. This type of thermometer is used to measure temperature in the oral cavity, anus and armpits. A great advantage of this type of device is a very short, in relation to liquid and phase-change thermometers, time of measurement, from 10 to 15 s. Unfortunately, contact electronic thermometers also have some disadvantages, namely they are sensitive to electromagnetic fields and require the use of batteries as their means of supply.

Contactless devices are devices whose measuring element does not come into contact with the tested surface and the measurement of temperature is conducted at some distance from the tested object. An example of a thermometer based on the above-mentioned contactless operation is an electronic radiation thermometer, which is used both at home and in medical practice. **Infrared thermometers** detect infrared radiation emitted by each body having its temperature higher than absolute zero. The devices of this type are built using optical detectors, often thermostats, which enable the detection of radiation. The result is displayed just after a few seconds, which makes this method the fastest of all. Unfortunately, a disadvantage of contactless thermometers consists in its lower accuracy in comparison with contact devices, which in most cases equals ±0,2 °C. In addition, factors related to the measurement site (both forehead and ear canal), such as make-up, sweat, hair and dirt, may all generate read-out errors [6]. What is more, due to the fact of using different algorithms, radiation thermometers may show some discrepancy in the obtained results and thus require repeat calibration after a long period of application.

Infrared thermometers and **thermal imagers** basically have the same function. An infrared thermometer uses short-wavelength infrared light to illuminate the area of interest and measures the average surface temperature of a given "spot". Spots vary in terms of size which depends on the specification of the thermometer and their distance from the target. A thermal imager can provide a more detailed and sophisticated result. It uses mid- or long-wavelength infrared energy and a single image can provide hundreds or thousands of individual temperature readings, one for every pixel view. These images (Fig. 1) can be recorded, and processed for viewing using specialized software. Thermal imaging, which finds application in many areas of life, is a very useful tool for the detection of changes in temperature on the object's surface. Thermography has broad application in different fields of medicine. The development of technology, first of all, the standardisation of thermographic tests contributed to the growth of popularity of thermovision in medical circles. Thermal imaging makes it possible to carry out and support medical diagnostics in a non-invasive way and, what is more, painless for the patient. In addition, according to the subject literature [3], the thermovision enables the assessment of the efficiency of prescribed medicines and assistance in various types of medical procedures, including cardiovascular procedures or physiotherapeutic treatment [1, 4]. Thanks to the detection of infrared radiation, thermal imaging enables the localisation of the changes of temperature on the surface of the patient's body, which makes it possible to discover pathological phenomena occurring in the patient's body. Thermal imaging examination is effective due to the fact that the pathological tissue is characterised by increased blood supply and metabolism, which in turn leads to the higher than average temperature of the skin in an affected area [2]. At present, the above-mentioned technique is used by specialists in various medical fields, from dentistry, ophthalmology, laryngology, rheumatology, etc., to cardiology. The most frequent application of thermal imaging is for the evaluation of the extent of inflammatory condition in joints, e.g. temporomandibular joint, disorders of blood supply, chronic diseases, including neoplasms, most often breast neoplasms. In laryngology, this method enables the diagnosis of the inflammation of nasal sinuses, whereas in endocrinology the diagnosis of thyroid gland diseases. What is important and what should be emphasised is that such an examination should not be the only basis for the diagnosis, but should be treated as an auxiliary test accompanying other examinations, for instance histopathological ones. A thermal imaging camera is a device allowing the recording and visualisation of the temperature distribution on the object's surface.

3 Materials and Research Methodology

The Authors of this work aimed to develop a device which would make it possible to diagnose heightened body temperature in the surroundings in a quick and mobile way. The key factor contributing to the efficiency of this solution is the possibility of use in the way which would physically limit the user to a minimum degree.

The requirements of the device have been defined and are as follows:

- Automatic detection of individuals located in the user's surroundings and the recording of their temperature.
- Display of the results of temperature measurements in such a way that distracts the user's attention to a minimum degree.
- Ergonomics of the device use. Selection of the mounting system and portable elements which physically limit the user to a minimum degree and ensure flexibility of the mounting.
- Affordable price, easy access to the device components.

A meeting with an expert allowed the Authors to determine the best places for thermal imaging in humans. During the analysis it was determined that the measurement tests should be carried out within the face of the subject. The temperature on the face can be equal to or lower than the internal temperature if the skin has not been heated from the outside. Therefore, the end result is the warmest point on the face.

The work was undertaken in order to determine possible methods of taking automatic measurements of temperature. Thermovisual solutions, which are available on the market, were reviewed. The efficiency of the temperature measurements was tested by means of widely available thermal imaging cameras of a small format. It was determined that the requirements for the thermal imaging camera should be as follows: it has to be equipped with the SDK (Software Development Kit) which will enable its efficient operation from the level of a dedicated application. In addition, the temperature measurements must be accurate up to several metres of distance and have a resolution up to the tenth part of the degree. The camera for the project must be compact, mobile and operable by means of a separate device, for instance a mobile phone. For purposes of the project, two thermal imaging cameras, which are available on the market, were compared: Seek Thermal Pro (USB-C) and Flir One Pro LT (USB-C). The following features were analysed:

- size and easiness of designing of inter-connected portable elements,
- available programming interfaces,
- measurement accuracy,
- quality of obtained images and processing efficiency.

The above analysis showed the supremacy of the Flir thermal imaging camera in many aspects important to the project. Due to this fact, further development of the project focused on this particular device. Also, available algorithms of the thermal imaging analysis were analysed. The efficiency of generally accessible algorithms

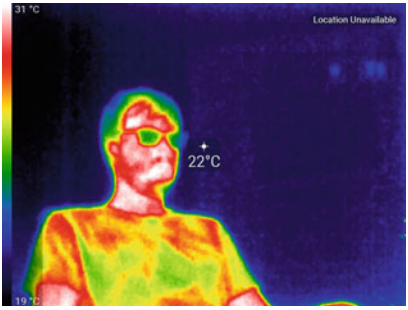

Fig. 1 An example of thermal images. *Source* own data

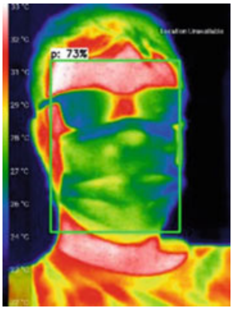

Fig. 2 Detection of a face with the mask in thermal imaging. *Source* own data

of the face detection was tested, also in the case of a partial covering of the face, for instance with a mask (Fig. 2),

Within the framework of the current project, in order to process thermograms, the authors used a neural network which enables the detection of face. The Auto ML Vision Object Detection artificial neural network learned from thermal face images and identified the location of the face. This is an architecture developed by Google that allows for mobile and cloud-based object detection solutions. The MIT licence neural network [7] was trained on the basis of one set containing photos of faces taken in visible light (Cloud AutoML) and two sets including thermovisual images of faces (Tufts Face Database, FLIR ADAS Dataset).

At the input, the model receives 3-channel images from the thermal imaging camera. These images were transformed into tensors of the following dimensions: 192×192. At the output, the following tensors are obtained from the network: coordinates for drawing a rectangle, class labels, certainty result for detected individual faces within a range of <0.0, 1.0>, the number of rectangles. Tensors are sorted according to the recognition certainty result, which means that the first index includes the detected face with the highest certainty result. Thanks to that fact, the verification of the certainty threshold may be limited to the first few results. In our implementation these were the first three results.

The selected model may be implemented into the Android application on a mobile phone. The application processes images obtained through a small-format thermal imaging camera connected to the mobile phone. Prior to the implementation of the selected model into the Android application, the researchers carried out tests in Python in order to check the operation and accuracy of the facial recognition by the neural network. First of all, the network was tested on the basis of random photos of faces and figures (silhouettes) downloaded from the Internet. Next, images taken by a thermal imaging camera were tested. The last phase of the tests in Python was a video recording in thermovision. The model was able to process approximately 12 exposures per second with the settings of 4 themes in the i5-6400 2.7 GHz processor. The obtained results confirmed the utility of the network.

The last stage following the face recognition is the search for the highest temperature within the outlined rectangle. If the temperature goes beyond the set threshold, the information is transmitted to the results presentation module.

Within the framework of the project, it was decided to use three independent forms of measurements presentation enabling the user to choose the method best suited to their needs and limitations:

- AR smart glasses,
- transparent OLED display located on the visor of the portable device,
- standard OLED display, from which the information will be reflected on a reflective foil located on the visor of the portable device.

The requirements were formulated in relation to the equipment which could be used in the final solution:

- AR smart glasses must have an open application programming interface (API) in order to be able to create own application for the operational system used by the AR glasses. In addition, they must have one of the wireless communication technologies to enable the transmission of data from the mobile phone to the glasses.
- Device controlling the OLED display must be of small dimensions and charge a small amount of electric power to enable the power supply by a portable source of energy. In addition, the device must have wireless technology compatible with the technology used in mobile phone applications and an interface enabling the communication with the OLED display.
- OLED display must be of a small size and be able to provide easy communication with its controlling device.

For the needs of the project, two pairs of Augmented Reality smart glasses were compared: Epson Moverio and Vuzix Blade. The following features were analysed: operation of smart glasses, size and weight, image display, operational system, communication, creation of applications, and additional functions. On the grounds of the conducted analysis, the smart glasses Epson Moverio were chosen for purposes of this project.

Within the framework of designing work, the use of two OLED displays was tested. The selected displays were as follows: a standard OLED display and a trans-