**POLITEHNICA UNIVERSITY**
**OF BUCHAREST**

**Doctoral School of Electronics, Telecommunications**
**and Information Technology**

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# Ph.D. THESIS SUMMARY

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METODE NEINVAZIVE DE EVALUARE ȘI MONITORIZARE A STĂRII DE SĂNĂTATE DESTINATE PERSOANELOR CU PROFESII SOLICITANTE SAU VÂRSTNICE

NON-INVASIVE METHODS OF HEALTH ASSESSMENT AND MONITORING FOR PEOPLE WITH DEMANDING PROFESSIONS OR ELDERS

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**THESIS COMMITTEE**

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**BUCHAREST 2022**

# Content

# Chapter 1

# Introduction

The research presented in the doctoral thesis composes an interdisciplinary perspective that interconnects complementary fields of space sciences, performance sports and human health and safety. The author presents a series of exploratory research in the field of space sciences in which he participated within interdisciplinary groups.

## 1.1 Presentation of the field of the doctoral thesis

Being exposed to extreme living conditions, the human body manifests severe problems in the process of adapting to spatial conditions [1] and suffers complex adaptations both physiologically and psychologically [2], [3]. Physiological and psychological deficiencies are both a danger to human health and therefore may represent an increased risk of failure for space missions with human crew [4].

Hence, the term countermeasure for human health and safety is used by the space community to describe procedures, medical treatments, devices and / or other strategies built to keep astronauts healthy and productive both during space missions and in the rehabilitation and readoption phase to Earth conditions. Prior to space flight, potential countermeasures are tested and refined using the existent ground-based facilities.

## 1.2 Scope of the doctoral thesis

The main objective of the doctoral thesis is to design and develop methods, algorithms and devices necessary to assess from the physiological and psychological point of view the people involved in demanding occupations and/or the vulnerable persons by an interdisciplinary manner covering three areas of research, namely human space exploration, performance sports and human health and safety, respectively. During the doctoral thesis the results obtained are presented as follows:

I. Development of methods, algorithms and devices necessary to assess the psychophysiological condition by:
   a. analyzing facial expressions in the visible spectrum image,
   b. analyzing psychophysiological features in the infrared spectrum image,
   c. analyzing speech and language disorders.

II. Development of methods, algorithms and devices necessary for the myotonometric evaluation of striated muscles:

a. evaluation of muscle properties using myotonometry devices,
b. study of muscle behavior under simulated microgravity conditions,
c. evaluation of the myotonometric devices.

III. Development of methods, algorithms and devices for the evaluation of physiological and/or mental health through telemedicine solutions in the benefit of:

a. persons in emergency located in isolated and/or inaccessible areas,
b. elders to reach an independent living climate.

## 1.3 Content of the doctoral thesis

The doctoral thesis focuses on the definition and development of devices and algorithms necessary to assess the health of the individual with regard to psychophysiological, muscular and cognitive characteristics, intended for people in professional categories with high risk (e.g., astronauts, performance athletes, etc.) as well as elderly and vulnerable persons or in emergency situations.

**Chapter 2** presents the author's approaches to the development of algorithms and methods for automatic non-contact, non-invasive and non-intrusive assessment of the psychophysiological condition of the individual.

**Chapter 3** presents existent myotonometric devices and their utilization during a 21-day dry immersion experiment at the Institute of Biomedical Problems of the Russian Academy of Sciences.

**Chapter 4** presents the integration of a telemedicine prototype that allows portability in hard-to-reach areas, and also the development steps taken in order to achieve an eHealth solution for elders to facilitate them an independent life adressing chronologically the definition of a system of interest according to systems engineering methodology, co-design and co-creation phases, hardware and software integration using biometric commercial platforms, testing and validations.

# Chapter 2

# Methods of automatic analysis of psychophysiological behavior

Emotions play an important role in the process of adaptation to the environment, a process that ensures the survival of the individual. In the environment there may be external agents (physical, chemical, biological) that act as stressors that aggress the body, adaptively inducing morphofunctional changes, most often endocrine. The degree of stress depends on the intensity and aggressiveness of the stressor, but especially on the individual reactivity, being involved biological factors but also psychological, cultural and educational. In many professions, employees are voluntarily and informedly exposed to environmental stressors, but through the knowledge they gain and their professionalism, they counteract and reduce the risks of an unstable emotional state.

## 2.1 Automatic analysis of psychophysiological behavior

Facial expression analysis and emotion assessment are remarkable research topics due to their natural and convincing characteristics in describing nonverbal communication through a variety of applications in medicine, security, science and also with an important applicability in assessing the behavioral health of trained astronauts in prolonged spaceflight missions.

### 2.1.1 Automatic visible spectrum image analysis

Starting from the observation that “emotion at one level of analysis is neuromuscular activity of the face” [5]: 188, in recent decades, research on the detection of facial expressions has gained recognition in the areas of personal safety as well as for areas involving clinical diagnosis and therapies, effective education, marketing, etc. The field is strongly influenced by certain theories and concepts, as illustrated in the literature by Ekman and Friesen.

The Facial Action Coding System (FACS) handbook is by far one of the most widely used facial expression encodings that indexes the manifestation of facial muscle movements and one of the most common research tools that is the basis for the emotional analysis software on the market, providing a safe measure to assess facial behavior.

Action Units (AU) are universal elementary expressions that compose the entire facial expression of an expression being fundamental facial actions determined by the relaxation or contraction of a muscle or a group of muscles. Facial Characteristic Points (FCP) are key points with a well-defined position that can be automatically detected in the facial image and are easily recognizable by humans.

Paul Ekman defines seven universal emotions [6]: happiness, surprise, sadness, disgust, fear, contempt, and anger as the emotions recognized by people from most cultures of the world and with various levels of education. As an alternative to universal emotions, Barret [7] introduces the concept of emotional valence and intensity.

Facial expression databases are composed of images evaluated by experts both for selecting images and for annotating them with information such as facial characteristic points, action units, emotions, etc. One of the most popular databases developed for automatic emotion assessment is Cohn Kanade (CK) [8].

OpenFace is an open-source software that integrates state of the art algorithms designed to detect emotions by classifying and/or regressing certain action units, localizing facial characteristic points, determine geometric position of the head, and/or estimating gaze direction, etc. On the other hand, FaceReader is a commercial software developed by Noldus company able to identify human emotions and many others emotion-related clues. Assessment of emotional state is based on the evaluation of a facial landmarks network using large sets of images in order to train and test an emotion detection model.

### 2.1.2 Automatic thermal image analysis

The literature reveals several methods for measuring biometric features of the person (i.e., arterial pulse, respiration rate, patterns of perspirations, etc.) by assessing temperature patterns or changes in certain regions of interest (ROI) [9].
Visible spectrum image analysis is able to provide real-time solutions for ROI detection as well as person recognition and hence, hybrid systems consisting of several imaging sensors (e.g., visible and infrared spectrum) may be a solution for measuring biometric features of the person.

### 2.1.3 Automatic speech and language analysis

Even if the act of speaking includes significant physiological aspects, both speech and language refer to human psychophysiological states and, moreover, speech could be the result of emotional and intellectual abilities, while language deeply reflects the way reality is perceived. As essential tools of behavioral psychology, the automatic determination of interpersonal or intrapersonal psychological problems that may occur in astronauts during prolonged space missions is a topic of interest.

According to the study expressed in [2], the potential disorders of speech and language that could occur in astronauts during a long-term space mission could be presented non-exhaustively as follows:

A. ***Rhythm and fluency disorders***:

- *stuttering* – manifested by repetition of sounds and/or syllables, fragmentation or temporary obstruction of speech could be associated with a provocative emotional context given by personal insecurity, increased anxiety, etc.;
- *tachylalia* – manifested by a disorder characterized by an increased speech rate associated with irritability, instability, hyperexcitability, etc.;
- *bradylalia* – manifested by a decreased speech rate that may be given by slow brain activity and/or the effects of asthenia from a pathological point of view.

B. ***Sound articulation disorders***:

- *dyslalia* – characterized by distorted, omitted, substituted or added sounds that may be caused by limited joint capacity due to equipment, muscle atrophy and morphological changes, vicious posture, etc.
- *rhinolalia* – caused by the blockage of the air flow through the nasal passage.

C. ***Disorders of structuring the internal language*** produce negative effects in understanding communication by structuring and articulating personal ideas with aspects that reside in phonology, morphology, syntax, semantics and are caused mainly by microgravity and environmental stressors, vertigo, multiculturalism, etc.

D. ***Voice disorders***, may be caused by the physical environment (e.g., chemical composition of air, radiation, etc.) as well as by psychogenic factors that may cause pharyngolaryngeal spasms to the detriment of natural phonation:

- *dysphonia* – manifested by alteration and/or partial loss of voice, decrease or abnormal increase in the intensity of the voice;
- *aphonia* – caused by psychological factors and manifested by blocking the mobility or elasticity of the vocal cords for short periods of time.

Moreover, in order to analyze speech semantically, Natural Language Processing (NLP) is a subfield of Artificial Intelligence that aims to use the resources of a computing unit in order to understand and process human natural language. In this context, the descriptor of a word is a mapping of it in the form of a vector of real numbers. The descriptor models the meaning of a word from a morphological, contextual and statistical point of view, related to the whole corpus of text [10].

## 2.2 Methods for automatic analysis of facial expressions using the visible spectrum image

In the field of facial expression analysis, the author participated in the development of methods for determining emotional state, contributing through the software implementation of systems for localization of facial landmarks according to anthropometric principles, resulting in new basic emotion and emotional valence detectors tested and validated. Parallel computing architectures for emotion detection systems and models with reduced number of landmarks were studied in the context of limited hardware and energy resources characteristic of space habitats.

Analyzing the existing facial masks, there is a confusion caused by the very large number of landmarks and especially caused by their symmetrical positioning. Most of these algorithms identify key points that are easier to locate than the landmarks according to anthropometric principles. Based on these needs, another type of facial mask (as shown in Figure 2.3) was built based on the functional morphology of the face, which allows a more sensitive and faster assessment of facial expressions.

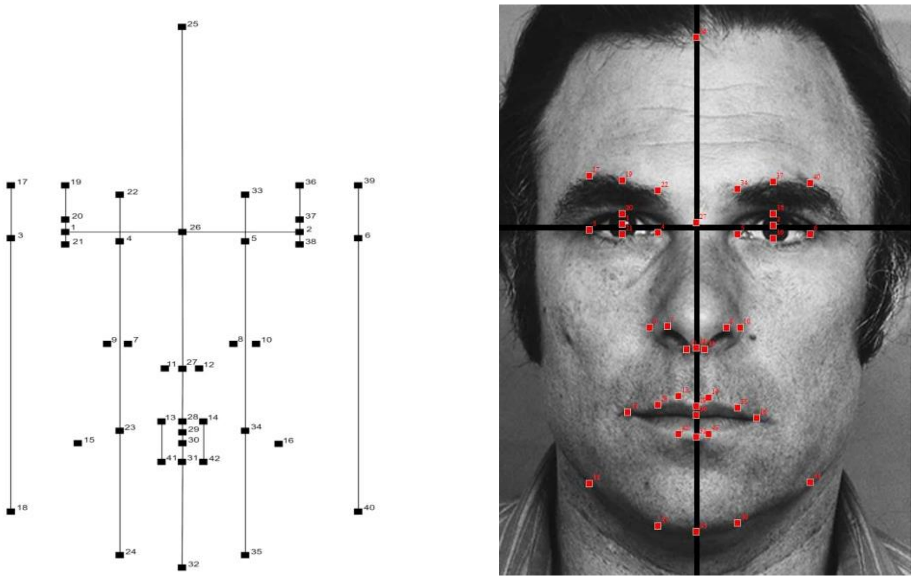

***Figure 2.3*** *Facial mask according to anthropometric principles*

A novel method for facial landmarks localization has also been implemented to detect several facial landmarks in order to estimate the potential benefit of the proposed anthropometric facial mask. In the training-testing-validation process presented in Figure 2.4 and Figure 2.5, respectively, collections of annotated images with information about emotional status will be used as input for the relevant neural network architectures.

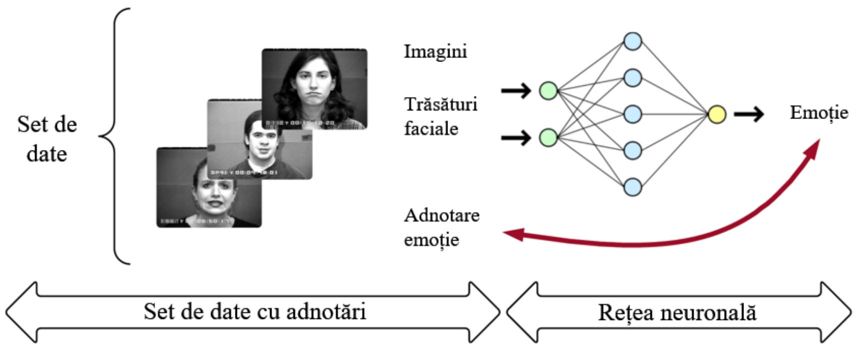


***Figure 2.4*** *Neural network training / testing procedure*

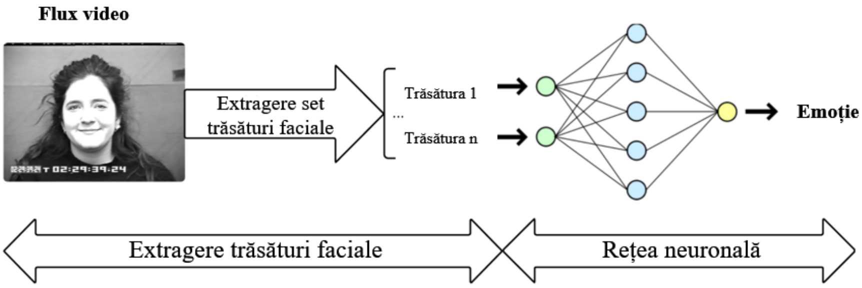


***Figure 2.5*** *The final application (©Jeffrey Cohn)*

Images that capture the maximum intensity of each emotion were extracted from the CK + database. According to the facial mask described in Figure 2.3, 35 facial points were extracted and the distance matrix was calculated, normed at interpupillary distance. The feature space was 595 dimensional. To improve the performance of SVM_AFL, a single-layer neural network (NN_AFL) was developed using MATLAB development environment in order to detect the emotional valence for the beginning. Another neural network input layer was designed for a 741-dimensional descriptor that contains all the distances between the 39 anthropometric facial landmarks. Thus, the performance of NN_AFL compared to previous models is presented in Table 2.3, where: SVM_AFL – classifier based on the Support Vector Machine method using the mask of Anthropological Facial Landmarks (AFL); SVM_AU_valence – classifier based on Support Vector Machine method using Action Units (AU), for comparative purposes being based on state-of-the art methods; NN_AFL_valence – neural network for the detection of emotional valence using the mask of AFL; NN_AFL_emotion – neural network for detecting emotional valence using the mask of AFL.

***Table 2.3*** *Model performance using the CK + dataset.*

| **SVM_AFL** | SVM_AU_valence | **NN_AFL_valence** | **NN_AFL_emotion** |
|---|---|---|---|
| **87%** | 93% | **98.1%** | **89.4%** |

Given that most systems currently use the identification of AU occurrence and intensities in combination with artificial intelligence models on large databases of images or video sequences labeled with information such as emotion, AU, facial features, etc., system for evaluating emotions in a “pipeline” of processing components is presented, as shown in Figure 2.9. Processing is performed in four consecutive stages grouped into several levels of processing. In the first level, images are acquired using video sources, and then in the second level face detection and optionally face recognition from acquired digital images is performed. At this stage, each image is segmented so that sections of the image can be further on used, each containing a single face. At the next level, AU extraction is performed based on these facial images so that at the final processing level, a component of the neural network processes the AU values corresponding to each image in order to determine the emotion. Visualization and statistical analysis components are optional and can be added to present real-time information. The processing steps consist of one or more identical components that communicate over network connections so that the images are transferred over the Network File Storage (NFS) protocol. This architecture allows each step to run on a different processing system, facilitating maximum computational efficiency. The evaluation of the system was performed on a computer system with x86 processor (i.e., laptop computer with quad-core Intel i5-2410M processor and 8 GB RAM) and compared with the new system composed of the Jetson TK1 development kit, equipped with a Tegra K1 SoC processor, consisting of a 4-core ARM processor coupled to an Nvidia GPU. The developed neural network consists of an input layer of 18 inputs, corresponding to the 18 Action Units identified by OpenFace, 36 hidden units and a layer of 7 outputs, representing the 7 universal emotions labeled: anger, disgust, fear, happy, sadness, surprise, contempt. The activation function used in the current setting is a symmetric sigmoid.

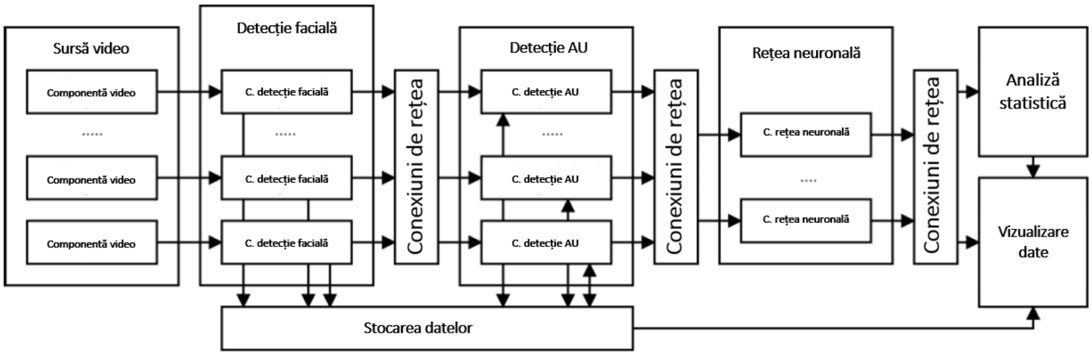


***Figure 2.9*** *Block diagram of the pipeline processing system*

# 2.3 Methods for psychophysiological analysis using combined visible and infrared spectrum imaging

The proposed analysis methodology envisages the construction of a psychophysiological assessment application in terms of respiration rate, heart rate, skin temperature determination, perspiration patterns and / or subcutaneous information. An experimental scenario was designed to collect video data. The experimental setup used in order to validate the methodology and the system is shown in Figure 2.12 and requires the subject to be seated in a chair at a distance of approximately 1-2 meters from the camera.


***Figure 2.12*** *Experimental setup*

The processed signal and the detected maximum values are illustrated in Figure 2.14. The maximum and minimum values correspond to the expiration and inspiration in the breathing processes, given that usually, the elimination of inhaled air from the lungs has a significantly higher temperature than that the ambient air inhaled. The area of interest (ROI) may also include the upper nasal area which behaves similarly by influencing the value in direct proportion to the temperature of the air inhaled and eliminated from the lungs.

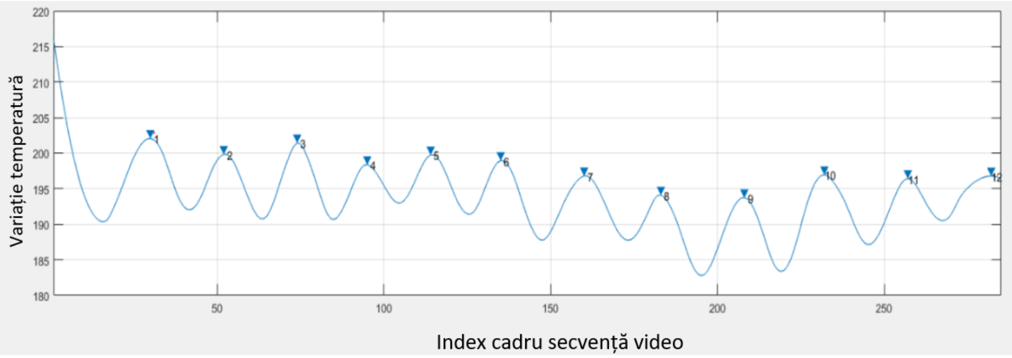


***Figure 2.14*** *Respiration rate detector*

## 2.4 Methods for analyzing speech and language disorders in the voice signal

In order to determine a way to measure speech coherence automatically, the following assumption was made: the more a sentence contains words that are semantically closer to the meaning of the sentence, the more coherent is the speech. Thus, having a vector representation of the words, a vector representation of the phrase is necessary in order to be able to apply the similarity of the cosine and to detect how correlated the two are. To obtain the sentence descriptor, the average of the vectors of the words that make up the sentence was calculated. For this purpose, pre-trained word2vec techniques were used. Missing words in the model's vocabulary were ignored. Thus, the resulting mean vector was further considered as a representation in the vector space of the sentence context. Then, the semantic similarity between the mean vector and the descriptor of each word in the sentence with cosine similarity was calculated.

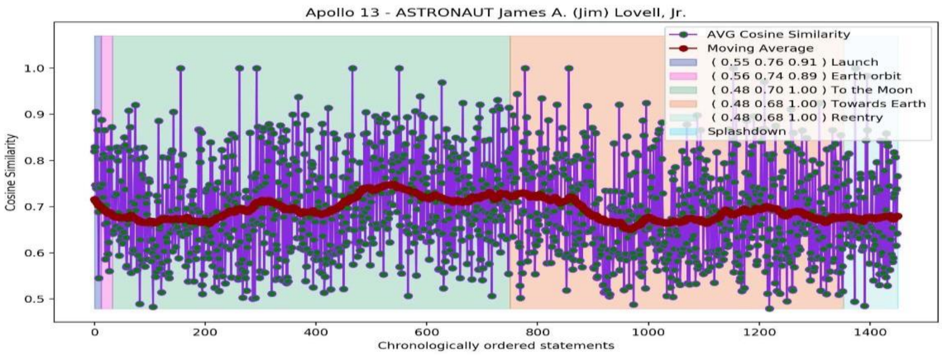


***Figura 2.17*** *Evolution of the average similarities in relation to the average vector of the astronaut's sentences*

Figure 2.17 shows the average similarity graph for each sentence of astronaut James A. (Jim) Lovell, Jr. during the Apollo 13 mission. The sliding average is also displayed for better observation of the trend. The size of the window used in the calculation of the sliding average is variable depending on the number of sentences of the people analyzed: the more sentences, the larger the window.

Determining the predominant feelings and their evolution in the psychological behavior of individuals during human spaceflight missions takes into account two main categories of feelings: pleasant and unpleasant and by customizing each main class into 8 other subclasses. Based on the representative word lists, the mean vector corresponding to each feeling was determined. Subsequently, the mean vector of each sentence was compared to the mean vector of each sentence using the similarity of the cosine. The sliding average of the results obtained is shown and also the maximum, minimum and average values for each of the mission intervals are calculated. Figure 2.20 describes a longitudinal method of interpreting the results: the analysis of a single individual, over time, in terms of the feelings expressed (i.e., the evolution of the similarity between the astronaut's sentences and depression).

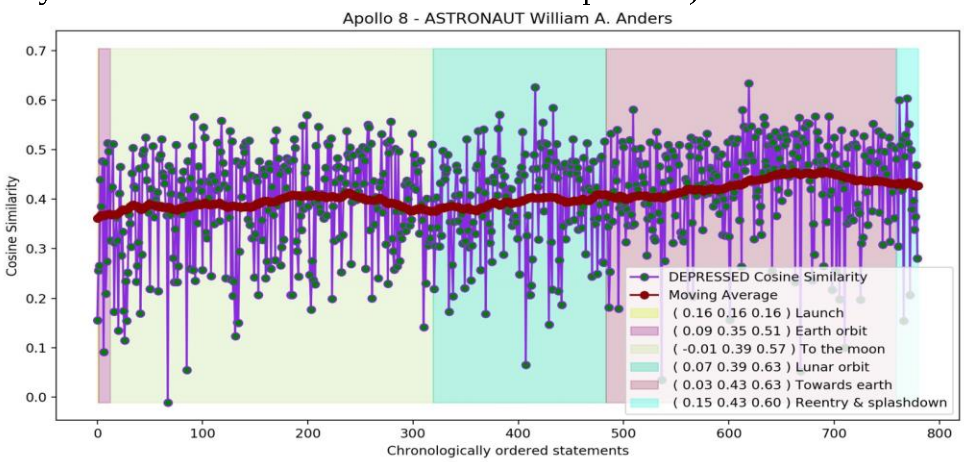


***Figure 2.20*** *The similarity of the astronaut's sentences with depression*

## 2.5 Terrestrial facilities for simulating the psychological conditions specific to the ICE environment

Concordia Station [11] is a research facility built in Antarctica as one of the most isolated locations characterized by extreme living conditions for mankind. Therefore, Concordia station is used nowadays especially for research in the field of space medicine.

The NEK facility [12] is located in Moscow, and represent a multi-module station designed to study the living conditions and activity of the crew in the context of simulated space missions within SIRIUS project.

# Chapter 3

# Myotonometric evaluation

The literature reveals an increased need for the development of methods for characterization and objective evaluation of muscle tissue. There are currently several equipment that can measure muscle characteristics using certain techniques and measurement procedures such as the dynamometer – capable of measuring the maximum force maintained in an isometric contraction for a predetermined time, the myograph – capable of assessing neuromuscular disorders by electromyography procedures, elastography – performed by magnetic resonance imaging (MRI), as well as muscle tissue biopsy, which is the most invasive method listed.

## 3.1 Myotonometric assessment methods and devices

Among the existing myotonometric devices MyotonPro has been noticed as the most used myotonometric device built for non-invasive assessment of soft tissue properties. The device is unitary and uses a thin piston with a cross-sectional diameter of 3 mm. The piston must be pressed with a predetermined force (i.e., 0.18 N), perpendicular to the contact surface of the muscle to be evaluated. After reaching the preset force, the piston provides 5 mechanical pulses with a force of 0.4 N at an interval of 1 second. The data obtained are then mediated in order to obtain a unique result. The viscoelastic properties of the muscles, namely: muscle tone, stiffness, and elasticity are evaluated analyzing the resistance of the tissues to the action of the piston.

## 3.2 Description of the MusTone myotonometric evaluation device

MusTone is a device developed at the Institute of Space Science and as it can be seen in Figure 3.2, it consists of a data acquisition unit, a piston with percussion and palpation function, accelerometers with adherent skin application and accessories (i.e., DC power supply, AC-DC power supply, etc.). Technological advances and developments of the MusTone device have been reported in the literature including preliminary approaches, case studies and reproducibility tests.

The parameters analyzed using the data collected by the MusTone device exclusively at the point of impact could also identified in the literature as follows:

● Oscillation frequency, an indicator of the intrinsic tension of a muscle in a passive state, without voluntary contraction.

● Logarithmic decrement, a parameter that indicates muscle elasticity and dissipation of mechanical energy after deformation.

● Relaxation time after mechanical impulse required for muscle tissue to return to shape before deformation.

● Ratio – the ratio of muscle deformation time to relaxation time.


***Figure 3.3.*** *MusTone device*

For data analysis, a MATLAB application allows data preprocessing, providing possibilities to select analysis accelerometers, mediate signals of consecutive repetitions, signal smoothing and extract a set of parameters of interest (i.e., F – frequency, R – time of relaxation, C – ratio, D – logarithmic decrement).

# 3.3 Terrestrial facilities for simulating the physiological conditions specific to the microgravity

Dry immersion (DI) facilities use a procedure to simulate physiologically the microgravity conditions by immersing the human body in water, as long it is covered with a waterproof cloth in  order to keep the skin dry [13]. This type of experiment is useful in designing physiological countermeasures to the adverse effects of microgravity on the human body. DI facilities are located within the Institute of Biomedical Problems of the Russian Academy of Sciences (IMBP-RAS), the Institute of Space Medicine and Physiology (MEDES), France, etc.

# 3.4 Analysis of myotonometric data collected in a 21 days Dry Immersion experiment

Using the MusTone device in a 21-day dry immersion study on 6 subjects, the evolution of muscle properties was assessed to study the changes in parameters of interest (i.e., muscle tone, relaxation time, logarithmic decrement, ration) and to identify a general behavior of the analyzed muscle exposed to microgravity conditions. Further on, using the data recorded with two myotonomtric devices (e.g., MyotonPro and MusTone), one of the main parameters of the viscoelastic properties of the myofascial complex, muscle tone – also referred as transverse stiffness , was evaluated [14], [15].

The characteristics of the muscle tone of the back and leg muscles are investigated during the 21-day DI study on 6 subjects. The Longissimus (m. Longissimus dorsi) was evaluated in the projection of the spine at the level of T12-L1. Statistical analysis was performed in the GraphPad Prism software. The difference between the sessions was verified using the analysis of the variance of a single factor and the Fisher criterion. Significance level was set $<0.05$. Data are presented as mean ± SD - standard deviation.

- The transverse stiffness of the ***Rectus femoris*** was 14.7 ± 1.5 Hz using MyotonPro, and 22.2 ± 5.1 Hz using MusTone. During the DI there was a decrease in the transverse stiffness of the same muscle, reaching an absolute minimum on the 21st day of immersion, namely 13.4 ± 0.6 Hz (-8.5%; $p = 0.01$) using MyotonPro and on the 13th day (-15%) using MusTone.
- The transverse stiffness of the ***gastrocnemius muscle (m. Gastrocnemius med.)*** was 14.6 ± 1.1 Hz using MyotonPro and 20.9 ± 2.9 Hz using MusTone. During the immersion, using MyotonPro, a significant increase of this indicator was found compared to the value in the recovery period, especially on day 5 of DI. When measuring the transverse stiffness with MusTone on the 10th day of immersion the highest value was recorded.
- The transverse stiffness of the ***anterior tibialis muscle (m. Tibialis ant.)*** was the largest of all the muscles examined. Its initial values were 21.0 ± 2.2 Hz using MyotonPro and 24.1 ± 2.2 Hz using MusTone. Using MyotonPro, there was a significant decrease in transverse stiffness throughout the immersion period, reaching a minimum on day 21 DI (-19.3%; $p <0.001$) and using the MusTone device, a decreasing trend was observed, but no significant differences were found.
- The transverse stiffness of the ***longissimus muscle*** was 16.9 ± 2.0 Hz and 22.2 ± 2.3 Hz when recording using MyotonPro and MusTone, respectively. There were no obvious differences from the initial values using the MyotonPro. It should be noted that during DI, one part of the group decreased and the other increased muscle stiffness. Using the MusTone, there was a gradual increase in transverse stiffness, reaching its maximum level on the 17th day of immersion.

The study concluded that the analysis of the properties of transverse stiffness is very sensitive to the measurement method and can be characterized by low stability. Different results can also be obtained in stiffness recordings using devices based on the same principles. In the muscles where there were obvious changes in transverse stiffness until the 21st day of DI, there was a gradual decrease in this indicator without reaching a plateau. During the study, there was a significant decrease in the transverse stiffness of the gastrocnemius muscle (m. Rectus femoris), and of the anterior tibialis muscle (m. Tibialis ant.).

# Chapter 4

# Telemedicine and elderly assistance

Telemedicine is a field that addresses, among others, solutions for critical situations in remote, isolated and inaccessible areas. In Romania, within the Institute of Space Science, several versions of portable telemedicine workstations have been independently developed [16], one of them being financed by the European Space Agency's (ESA) through ESA-PECS program. On the other hand, given the 20% increase in the number of people over the age of 60 by 2030, a new telemedicine domain has emerged to support older people to live independently using Internet of Things (IoT) and eHealth technologies that have proven to be increasingly promising for making elders' everyday activities easier.

## 4.1 Description of telemedicine and care for the elderly

Special attention in the global healthcare perspectives is focused on chronic diseases, also known as Noncommunicable Diseases (NCD), caused by a multitude of risk factors, especially in terms of low income, environmental and metabolic stressors, physical inactivity and negative behavior patterns, which account for 71% of all deaths globally, while over 85% of these deaths are considered to be premature and occur in low- and middle-income of underdeveloped countries. Globally, the increasing of life expectancy is leading to a growth in the proportion of older adults [17] who require some degree of health care due to health deficiencies. Statistics show that the number of people over the age of 60 will increase by 20% by 2030 and clearly demonstrates the need to develop telemedicine and eHealth systems. In order to keep older adults independent for a longer period of time, one of the most important components of an e-Health system is monitoring health through mental and physiological parameters.

## 4.2 Telemedicine prototype integration

A telemedicine prototype designed for difficult to access conditions, accomplished under the name of PTW - Portable Telemedicine Workstation (as shown in Figure 4.6) was developed according to Systems Engineering (SE) methodology for telemedicine and space sector [18]. In this context, the requirements of the PTW system were established as a result of a complex SE-based process in which the issues and needs of stakeholders were comprehensively determined and end-user requirements were developed for further specification of the system.

In order to facilitate the technology transfer, a fully functional prototype is described in the doctoral thesis, including mechanical, electronic and software solutions, reported in [19], [20]. The prototype is fully functional and was developed in cooperation with the European Space Agency in an attempt that supports the development of space technology applications as a terrestrial spin-off for industry and implicitly for the benefit of society.

***Figure 4.6*** *PTW prototype*

# 4.3 Assistive technologies for elders

The author participated in the activities of defining and developing an eHealth prototype following a co-design and co-creation process carried out together with groups of elders from Romania, Italy and Hungary. The steps were taken within the Active and Assisted Living Program (AAL) which supports the development of smart solutions for aging well.

Identifying and classifying end users were important aspects in the interaction for shaping the technological concept of eHealth. Thus, during the co-design phase, three target groups of end users were identified and selected:

- primary target group - end-users (i.e., elderly people suffering from chronic age-related illnesses and / or mild cognitive impairments);
- secondary target group - caregivers (family and volunteers);
- tertiary target group - public and private sector managers of care units for the elders.

Preliminary requirements for the eHealth service at the end of the co-design session have been determined. Thus, in accordance with the preliminary requirements of the end user obtained during the co-design session in Romania, the eHealth concept was conceived, based on three main components, namely: physical eHealth system, Cloud application, smart device able to run a web browser. Given the AAL interoperability criteria, the proposed eHealth system is designed based on Commercial off-the Shelf (COTS) devices, implicitly on open-source hardware (OSHD) and development platforms for eHealth applications.

The main objectives considered for the development of an eHealth prototype according to the preliminary requirements identified during the co-design session [21] are described as follows:

1) Defining, implementing and integrating an eHealth architecture based on a system of interest (SOI) defined with respect to the Systems Engineering methodology and based on integrated commercial platforms (i.e., MySignals, Arduino) for monitoring biometric information taken from the elderly with NCD and /or MCI to facilitate independent living.
2) Defining and designing the eHealth mechanical prototype in accordance with the needs identified in the co-design sessions.
3) Defining and implementing from scratch a cognitive assessment device in terms of choice reaction time evaluation.
4) Optimization of relevant data of COTS biometric sensors.
5) Analyzing and optimizing the energy consumption of the eHealth prototype.
6) Optimizing the latency of short and long-distance communication for the transmission of biometric data locally and remotely.

The eHealth prototype presented below is based on the low-cost eHealth platform MySignals Hardware produced by Libelium. The development platform allows the integration of IoT-type medical solutions using Arduino boards and biometric sensors that can be connected wired or wireless. Libelium sells MySignals Software (SW) in parallel [22], ready to use, but in connection with Libelium Cloud service. The eHealth prototype was defined using a system architecture according to the Object-Process Methodology (OPM), where the structural, functional and behavioral elements of the system are modeled in a coherent unitary architecture. The structural elements of the eHealth prototype can be observed in Figure 4.13.

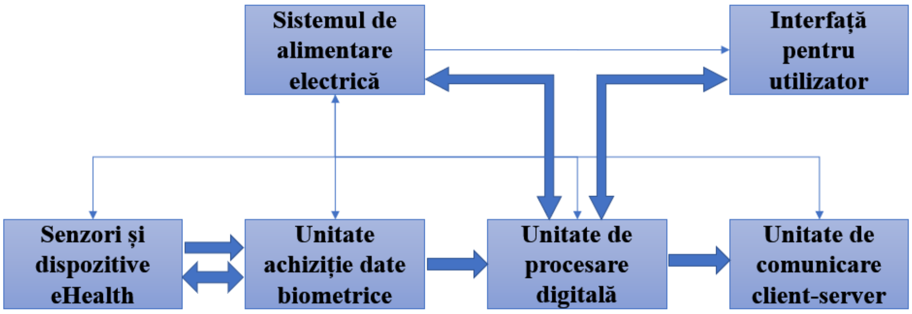


***Figure 4.13.*** *The structural elements of the eHealth device*

Based on the premise presented by the literature on the increasing age of reaction time to visual stimuli, especially in terms of discrimination of chromatic stimuli, the Choice Reaction Time (CRT) methodology is based on several visual stimuli and answer buttons. The methodological principle in this study is similar to that in [23], where a target was designed to be answered by pressing a button, while distracting letters are answered by pressing the second button. Thus, an original methodology described in the Figure 2.22 is connected with a CRT device based on chromatic stimuli emitted by a LED as described in Figure 4.21.

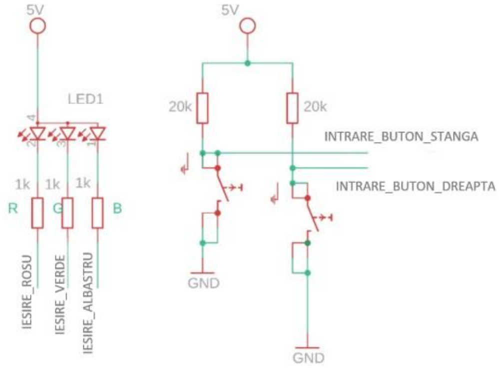


***Figure 4.21.*** *CRT device wiring diagram*.

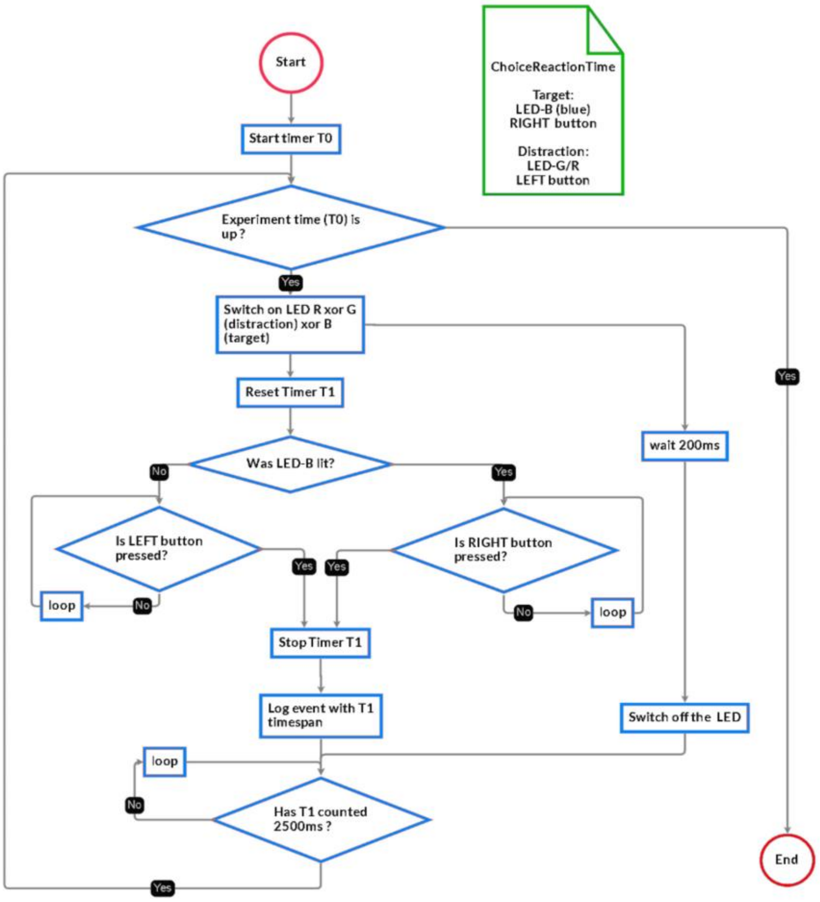


***Figure 4.22***. *CRT methodology.*

# Chapter 5

# Conclusions

The doctoral thesis presents the steps performed by the author in the field of automatic analysis of psychophysiological behavior, muscle properties evaluation, telemedicine and elderly assistance. The author addresses automatic methods of analysis able to extract facial expressions in the visible spectrum image, psychophysiological features in the infrared image and speech and language disorders from a semantical and acoustic point of view. Moreover, in terms of muscle properties evaluation, functional, hardware and software integration and future developments of the MusTone device are presented. Also, data collected from a 21-day Dry Immersion experiment involving two myotonometric devices: MusTone and MyotonPro, is presented emphasizing the changes in skeletal muscle properties. Telemedicine and assistance solutions in which the author took part are presented, along with the functional implementation of a telemedicine prototype as well as the definition and development of an eHealth prototype for the benefit of the elders.

## 5.1 Obtained results

Chapter 2 presents the results obtained by software modules developed to assess the emotional state of the space crew using a limited number of facial landmarks defined later on as an anthropometric system of facial landmarks. Real-time tracking requires optimized and simplified algorithms in the field of manned space applications to facilitate the reduction of computational effort. Thus, the preliminary version of a simplified algorithm for facial expression analysis is a proposed new approach to determine the valence and emotional intensity using a small number of facial features described throughout the chapter. A methodology for evaluating psychophysiological behavior is validated based on visible and infrared image analysis techniques. The analysis of speech and language disorders by analyzing speech and voice signals starts with a case study that analyzes variations in certain speech and language characteristics and then continues by analyzing public transcripts of NASA missions to analyze issues such as speech coherence and feelings analysis using natural language processing.

Chapter 3 describes the functional and software development of the MusTone device developed at the Institute of Space Science and the possibilities of extending muscle quality assessments by analyzing the propagation characteristics of the wave along the muscle fiber. The results extracted by MusTone device in the 21-day DI experiment that took place in Moscow are presented. The study showed that the determination of the properties of transverse stiffness depends on the measurement technique and can be characterized by low stability.

Regarding the telemedicine and assistance solutions discussed during Chapter 4, the results regarding the implementation of a functional telemedicine prototype as well as the definition and development of an eHealth prototype for the benefit of elders as an extensible integrated system connectable on the Internet are presented. eHealth prototype allows the measurement of three biometric parameters: pulse, oxygen saturation and temperature, through several wired and / or wireless sensors addressed to people suffering from non-communicable diseases (NCD) and cognitive assessment by analyzing choice reaction time (CRT).

## 5.2 Original contributions

1. Defined a detector of emotional valence and intensity using a limited number of facial points required by the space field for prolonged human space missions [4];
2. Participate in the definition and development of an automatic system for localizing facial landmarks according to anthropometric principles. Evaluation of the proposed facial landmarks localization system performing tasks of automatic detection of emotional valence and basic emotions achieved by machine learning methods (e.g., support vector machine, neural networks) and existing methods presented by the literature [9, 14];
3. Participate in defining the architecture of the parallel computing system for the evaluation of emotions according to the specifications in the field of space sciences [6];
4. Defined an original methodology consisting of the combined analysis of thermal and visible spectrum imaging for the psychophysiological evaluation of astronauts, conducting an experiment to verify the functionality of the system by determining the respiration rate [7];
5. Carried out a case study of the acoustic analysis of the voice signal extracted from an astronaut's interviews at two key moments, namely before and after the space mission, in order to identify potential speech and language disorders and design automatic methods for assessing them [8];
6. Participated in the design and testing of a system capable of detecting speech coherence and / or emotional characteristics during space missions using natural language processing techniques on public transcripts from NASA missions [12];
7. Description of the MusTone device in terms of mechanical, electronic and software solutions [2];
8. Statistical evaluation of soleus muscle by analyzing the data collected using the MusTone device on 6 subjects in the 21-day dry immersion study of IMBP-RAS, Moscow [11];
9. Assessment of muscle effects to simulated microgravity in the 21-day dry immersion study of IMBP-RAS, Moscow. Extraction of MusTone myotonometric data and statistical analysis of muscle tone [3];
10. Integration of simulated microgravity methods (e.g., 3D clinostat) for the study of the bone and / or muscle system and the development of curative methods [17];

11. Participation in the mechanical and electronic implementation of the fully functional PTW prototype developed by the team the author was part of [5];

12. Participation in the process of designing and implementing the eHealth device, through co-design and co-creation phases established together with groups of elders in Romania in order to facilitate an independent living environment [13];

13. Participate in the design and implementation of the eHealth device as a biometric health monitoring system using IoT to facilitate independent living for elders [1];

14. Performed a literature review on choice reaction time as a complementary method for early identification of idiopathic orofacial pain and the evaluation of noninvasive transcranial magnetic stimulation as a therapeutic potential in the treatment and / or amelioration of oral pain [15, 16]

15. Carried out a case study to assess remanence in computer-assisted neuro-muscular control training [10].

## 5.3 List of original publications

**ISI Journals**

[1] Vizitiu C, Bîră C, **Dinculescu A**, Nistorescu A, Marin M.(2021) Exhaustive Description of the System Architecture and Prototype Implementation of an IoT-Based eHealth Biometric Monitoring System for Elders in Independent Living. Sensors (Basel). 2021 Mar 6;21(5):1837.

**Non-ISI Journals**

[2] Nistorescu A., **Dinculescu A.**, de Hillerin P. (2018). MusTone muscle analysis device. Applicability and data, 2018 Journal of Physical Education and Sport ® (JPES), 18 Supplement issue 5, Art 312, pp. 2084 - 2087, 2018 online ISSN: 2247 - 806X.

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**ISI-indexed conferences**

[4] **Dinculescu, A.**, Vizitiu, C., Nistorescu, A., Marin, M., Vizitiu, A. (2015). Novel approach to face expression analysis in determining emotional valence and intensity with benefit for human space flight studies. 2015 E-Health and Bioengineering Conference (EHB), 1-4.

[5] Văleanu, V., Vasiliu, V., Vizitiu, C., Marin, M., Nistorescu, A., **Dinculescu, A.**, Vizitiu, A., Ion, T. (2015). Portable telemedicine workstation full prototype for technological transfer in critical interventions services. 2015 E-Health and Bioengineering Conference (EHB), 1-4.

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assessment. Verification for respiration rate determination. 2017 E-Health and Bioengineering Conference (EHB), 73-76.
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[9] **Dinculescu, A.**, Baltoiu, A., Strungaru, C., Petrescu, L., Vizitiu, C., Mandu, A., Talpeş, N., Văleanu, V. (2019). Automatic Identification of Anthropological Face Landmarks for Emotion Detection. 2019 9th International Conference on Recent Advances in Space Technologies (RAST), 585-590.
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[15] **Dinculescu, A.**, Dugan, C., Vizitiu, C., Parlatescu, I. Study on Choice Reaction Time as a Complementary Method in Idiopathic Orofacial Pain. Accepted for publication in IEEE E-Health and Bioengineering Conference - EHB 2021, 9-th edition, Iași, Romania, November 18-19, 2021.
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**BDI Conferences**

[17] Chiritoiu, G., Iosub, S., Vizitiu, C., Sima, F., Petrescu, S., Nistorescu, A., **Dinculescu, A.**, Jipa, F. (2018). Differentiation of mesenchymal stem cells into osteoblasts under simulated microgravity, 39th Annual International Gravitational Physiology Meeting and The Life Sciences Meeting 2018-ESA, 18-22 June 2018, Noordwijk, the Netherlands.

**Research reports from the doctoral program**

[18] Localization of facial landmarks using cascading systems of hourglass modules.

[19] Psycho-physiological evaluation using automatic imaging methods for people in isolation environments
[20] Microgravity experiment simulated in dry immersion facilities
[21] Comprehensive description of an e-Health system

## 5.4 Perspectives for further developments

The author intends to continue the development of algorithms and devices presented during this doctoral thesis, especially in order to develop countermeasures to space effects induced by stressors specific to human prolonged space missions. Regarding myotoniometric evaluation methods, the author intends to continue the research using the MusTone device in order to analyze more parameters of wave propagation along the muscle fiber (e.g., time and speed of wave propagation, damping factor, etc.) using information extracted from all sensors in the device during Dry Immersion experiments. Regarding the field of telemedicine and care for the elders, the author is motivated to use the acquired knowledge to develop new systems for the benefit of the field of health and safety of the person.

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