Visual Control System Based on Nociception-Analgesia Index for Patients in a Vegetative State/Unresponsive Wakefulness Syndrome and Minimally Conscious State

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Abstract. Considering people who are in a coma, doctors have to rely on physical clues and information provided by monitoring systems. It is commonly used for patients in a vegetative state, as contact with them is difficult. Taking into account the typical workload of the doctor, they require several tools to monitor the coma depth, since it is hard to perform a clinical evaluation hourly. Therefore, visual perception and monitoring of physical state for coma personnel proved to be more convenient for prompt decision-making. In a number of cases, it would be possible to make prognosis for their recovery and monitor effectiveness of treatment courses. Visual control system based on RGB led strips according to the ANI range of values was created. In conclusion, the connecting scheme of ANI monitor with implementation of visual object was presented.

Keywords: ANI-monitoring, Coma, Index of Analgesia/Nociception.

1 Introduction

Caring for health is somehow linked with the automatic systems [1]. Special attention is paid to healthcare industry because monitoring and controlling physical signs like temperature, pressure, humidity, lights are more effective instead of being in stuck into bedside monitor. It should be mentioned monitoring of coma patients is tough job for staff to control each patient's 24 hours, that may lead to difficulties due to human error. Thus, automatic products are the main interest for more convenient and comprehensive medical monitoring.

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The main idea is to develop a non-intrusive visual control system without compromising the patients' privacy which can display any patient data in any part of body and issue a timely warning by visible light.

2 Relevance

Diagnostic methods for assessment of impairment of conscious level are still widely used in the treatment in an Intensive Care Unit. It includes tests of orientation, attention, memory, language and visual-spatial skills. At first, J. Bennett invented Glasgow Coma Scale (GCS) for reliable and objective way of recording the conscious state of a person in 1974. The Mini-Mental State Exam (MMSE) by Folstein M.F. was developed in 1975 as test of cognitive function among the elderly [2]. Nevertheless, traditional neuropsychological tests are not enough as a daily routine screening tool and require continuous supervision by a paramedical assistant. Besides physiological assessment is a critical step for the detection of signs of consciousness.

Recent applied developments opened up new avenues for research and exploration in the all fields including medical and health care industry. They are able to make a better description of what consciousness actually is. Samuli Siltanen from University of Helsinki proposed electrode helmet, using electrical impedance tomography, however, it was found information is not easily extracted from the results since electricity flows throughout the body whereas x-rays travel only in straight lines [3]. The main drawback is application after surgery, before removing stitches and in the presence of head wounds is possible. Akane Oyama, Shuko Takeda proposed completely different method, the eye tracking-based cognitive scores for sensitive detection of cognitive impairment [4]. The ubiquity of haptic technology created new care model advanced medical tools simultaneously. As an example, Far Eastern Federal University VR/AR Center conducts research on the use of VR / AR technologies in rehabilitation program for stroke patients with impaired motor functions.

In Intensive Care Unit special attention is paid to bedside monitors for prompt evaluation after surgery under general anesthesia. They are Analgesia Nociception Index Monitoring, Bispectral index Monitoring, MedStorm. [5]. Even through presented methods are extremely important for coma patients, there has been no complex method for reading physical signs of coma patient and simultaneous displaying on textile visual control system so far. We present approach of reading Analgesia Nociception Index from monitor and further visual interpretation on a visual object. ANI Technology was chosen as available technology in Almazov Research Medical Centre participating as partner. Jacket was offered as the initial visual object.

3 Medical preconditions

The main idea of the proposed method is that the binary image is transformed into a geometric graph where each node corresponds to the pen position at some point during writing and edges model the pen movement between nodes. This way, the initial A coma is a deep state of prolonged unconsciousness as a result of traumatic brain injury,

stroke, brain tumor, diabetes or an infection [6]. But coma usually lasts for less than 2 to 4 weeks in itself, then a person may wake up into a vegetative state/unresponsive wakefulness state (VS/UWS) or minimally conscious state (MCS). Patients in VS/UWS and MCS either do not perceive reality at all or perceive it partly. It requires operative action to preserve life and brain function as well as visual controlling of basic physical cues such as heart rate, pulse, body temperature.

The continuous visual-based monitoring of the VS/UWS and MCS coma patients could be more convenient and comprehensive, cause the usual monitoring process can lead to a tough load for health-care professionals Imaging techniques, including functional magnetic resonance imaging, FDG positron emission tomography is proven to be useful in determining the diagnosis of VS/UWS and MSC. However, diagnosis of the VS/UWS and MSC should be based on a patient's clinical history and on simple visual observations as well. In this context the development of visual control system with established light-emitting diodes allows to facilitate control process, which is commonly used in Intensive Care Unit, Critical Care Unit, and Emergency Rooms of hospital. Thus, in the emergency cases, the doctor is able to monitor patient condition efficiently to reduce time consumption.

4 Analgesia-nociception index for predicting of hemodynamic reaction

Currently, it is possible to make pain assessment by determining the nociception and analgesia index using an ANI monitor. This technology has been proposed for long-term monitoring of nociception. ANI monitoring is a non-invasive technique that can be used in patients of all age groups to avoid effects of over or under-dosing of analgesics during surgeries. ANI technology also monitors the parasympathetic tone, which provides information about the patient's comfort, i.e. the appearance of pain or stress.

The ANI index is expressed on a scale between 0 and 100 %. It expresses the relative amount of pΣ tone present as compared to sum of sympathetic and pΣ activities. When level of anesthesia is more than pain, it is between 50 and 70, patient has a dominant parasympathetic tone and possibly less pain/nociception. When the ANI index is lower than 50, hemodynamic reactivity is very likely. Thus, clinicians make a decision which analgesics are preferable.

Figure 1 shows elements of the ANI monitor.

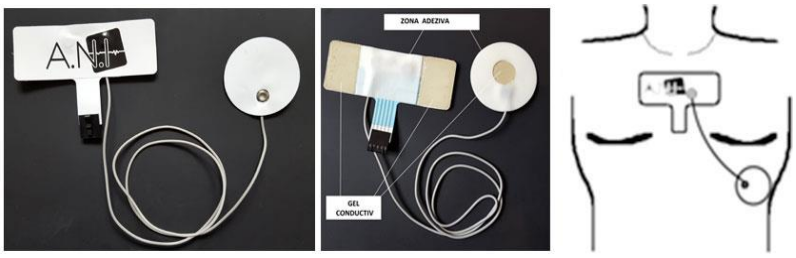

Fig. 1. Elements of ANI monitor

They are a single sensor and a dual sensor. The sensor itself is divided into two areas: adhesive area and the other active region which is covered with a conductive gel. A dual sensor is applied on the patient's chest. Electrodes are connected to the acquisition device using the cable. The last one is connected to the ANI monitor.

5 Methods

5.1 Visualization method

Jacket-based visual system with established light-emitting diodes is a current offer and serves as primary prototype. It consists of 6 strips of 29 light-emitting diodes with pixel addressing. The matrix 6x29 is presented in Figure 2.

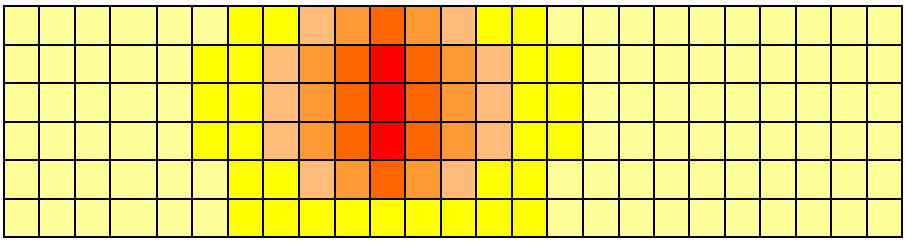

Fig. 2. Light-emitting diodes as color matrix on a visual object

Each element is setting the color code in the HEX format (0; 0; 0) for addressing specific light elements.

5.2 ANI-index interpretation method

The principle of data interpretation in accordance with the range of values from 0 to 100 % is presented. During treatment, the patient monitor is continuously monitoring the coma patient to transmit the important information. It based on the ANI index and the lighting effects on a jacket. ANI range from 0 to 100% was divided into 3 ranges or lighting effects for the jacket: lower than 50%, 50-69%, 70-100%. Jacket is light up depending on which range the ANI index falls. The latest simplifies the observation of physiological sign and increases the monitoring effectiveness. Moreover, using the ANI index interpretation method during anesthesia it is possible to predict the risk of a hemodynamic reaction in response to nociceptive stimulation.

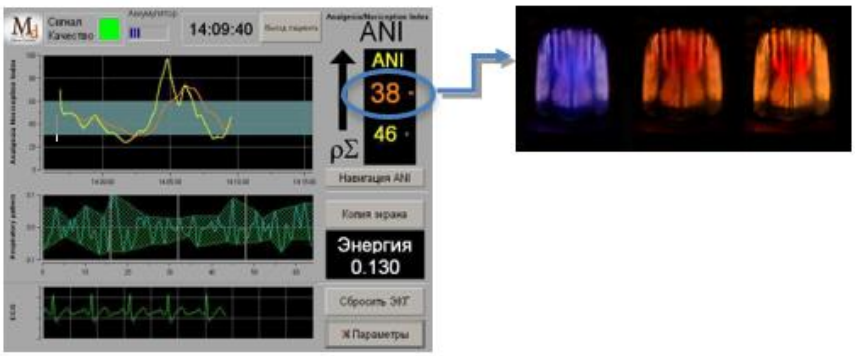

Fig. 3. Data transmission to visual object

5.3 Monitoring system for patients in a coma by pain assessment

A diversity of pain for patients with prolonged disorders of consciousness (PDOC) - VS/UWS and MSC is defined by the International Association for the Study of Pain (IASP) as unpleasant sensory and emotional experience related to real or potential tissue damage…». It raises the question of whether sensory or emotional experience is possible for such illnesses. It is obvious that the conscious perception of pain in this category of patients is non-existent. Simultaneously, some processes which are afferent signals of pain are constantly presented in a patient with congestive heart failure. They are spasticity, contractures, calcifications and polyneuromyopathy [2-3].

One more issue is the influence of nociceptive afferentation without pain experience on the possibility of consciousness recovery. Traditionally, pain therapy is aimed at stopping pain experience. Assuming that patients with heart failure feel no pain, the stabilization of autonomic parameters may be insufficient. The main task to solve this issue is studying the functional features of the central nervous system. The group of patients highlighted in recent years with the phenomenon of "covert consciousness" is of particular interest. During the studies of the response to pain stimulus (PS), the informative significance of the scale for assessing pain in patients in a coma and device for the study of cardiac interval using the ANI monitor were studied (analgesia-nociception index). ANI monitor was used for 29 patients with congestive heart failure (9 patients in a VS/UWS and 20 patients in MCS). The age of the patients ranged from 22 to 56 years (the average age is 34.75 ±11.54). Measurements are presented in the Figure 4.

The average value of the ANI index for patients in a VS/UWS is - 67.44 ± 10.73 before PS, 49.55 ± 14.49 during PS, and 73.66 ± 10.48 30 minutes after. The average values of the ANI index in patients in MCS: 66.25 ± 14.11 before, 45 ± 16.12 during PS and 66.55 ± 18.1 after. A comparison of the average values of the ANI index between two groups of patients before, during PS and 30 minutes after PS did not reveal statistically significant differences ($p > 0.05$).

Thus, the same dynamics of changes in the ANI index was noted both in the initial and in response to PS. The initial value of ANI index was higher than 66.25, indicating the absence of pronounced vegetative reactions in the dormancy paradigm.

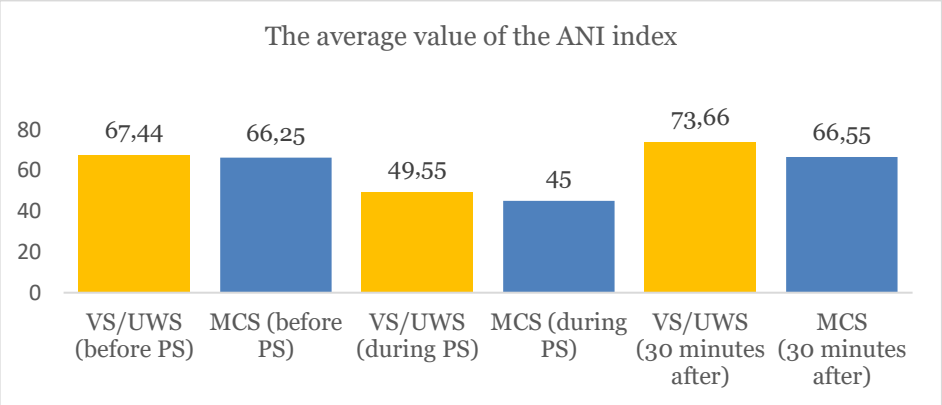

Fig. 4. The average value of the ANI index

6 Designing of visual control system

Further, it describes a framework with simplex communication.

The jacket consists of three layers: fabric, diffusing and the main with established light-emitting diodes strips. Currently, it is operating from a 220 VAC and has 3 lighting effects. The jacket scheme is shown in Figure 5.

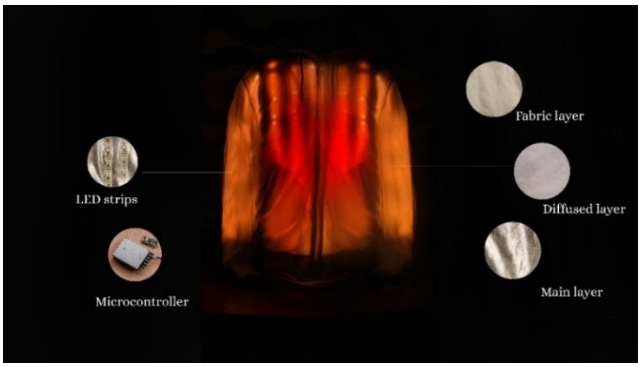

Fig. 5. Elements of visual object (jacket)

The electrocardiogram signal from the electrode on the chest is processing by the acquisition sensor. The digitized ECG signal is transmitted to the ANI monitor using the RS232 protocol. The jacket is connected to the monitor using a specially designed

cable. It lights up depending on the ANI index (nociception and anesthesia index) and range it falls.

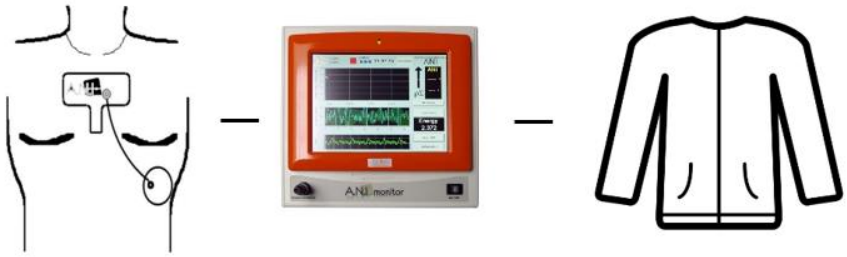

Fig. 6. Construction scheme of visual control system

7 Results

The visual control system, integrated in the ANI-monitoring scheme, was developed. The jacket-based visual control system was tested in the Intensive Care Unit in Polenov Neurosurgical Institute. The average values of ANI index for patients in a VS/UWS and MCS were measured. It was found previously that the ANI index is 10 minutes ahead of the change in hemodynamic response parameters within nociceptive stimulation during general anesthesia. So, in conclusion, the visual control system allows to make the process of informing about timely medical intervention faster. However clinical judgment should always be used when interpreting the ANI index in conjunction with other available clinical signs.

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