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ANALYSIS OF HAND AND FACE IMAGES FOR THE PURPOSE OF ENGINEERING SUPPORT FOR PARKINSON'S DISEASE DIAGNOSIS

Kamila BIAŁEK[1], **Anna POTULSKA-CHROMIK**[2], **Jacek JAKUBOWSKI** [1],
Monika NOJSZEWSKA[2] and **Anna KOSTERA-PRUSZCZYK**[2]

[1] Faculty of Electronics, Military University of Technology, 00-908 Warsaw, Poland, jacek.jakubowski@wat.edu.pl
[2] Department of Neurology, Medical University of Warsaw, 02-097 Warsaw, Poland, apotulska@wum.edu.pl

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Abstract – Engineering support in the field of recognizing Parkinson's disease against the background of other diseases, its progression and monitoring the effectiveness of drugs is currently widely implemented as part of work devoted to the use of recording and analysis devices equipped with sensors of movement parameters attached to the patient's body, e.g. accelerometers and gyroscopes. This material touches on an alternative approach, in which the concept of using techniques for processing selected image data obtained during a clinical examination evaluating a patient using the unified UPDRS number scale is proposed. The research was conducted on a material that corresponded to selected components of the scale and included images of faces recorded in the visible light range and images of the outer surfaces of the hand recorded with a thermal imaging camera. This was aimed at assessing the possibility of differentiating persons in terms of detecting Parkinson's disease on the basis of registered modalities. Thus, tasks aimed at developing characteristics important in the binary classification process were carried out. The assessment of features was made in a modality-dependent manner based on available tools in the field of statistics and machine learning.

Key words – image processing, medical diagnosis, Parkinson's disease.

INTRODUCTION

The paper presents the preliminary results of the project, the aim of which is to explore the possibilities of innovative use of data mining techniques in the process of early identification of patients with Parkinson's disease [1]. Patients from the pilot group were invited to the study. These were people with con-firmed Parkinson's disease and healthy people – a total of 16 persons. These individuals were subjected to selected tests during a standard clinical interview. As a result, material was collected including images of faces and hands recorded and archived during a medical examination using a set of devices supervised by a computer. Data retrieval, i.e. recording, took place in a completely non-invasive way using cameras operating in the visible light and far infrared range. The aim of the data analysis was to assess the possibility of differentiating people in terms of detecting Parkinson's disease. Thus, tasks aimed at developing characteristics important in the binary classification pro-cess were carried out. The assessment of features was made in a manner depending on the type of data based on available tools in the field of statistics and machine learning. It was a preliminary process, the development of which will appear in subsequent stages as a result of the registration of a larger population of patients and healthy people.[1]

I. CHARACTERISTICS OF THE PILOT REGISTRATIONS

Data for pilot studies were obtained as part of registration sessions conducted at the Clinic and Department of Neurology of the Medical University of Warsaw, in accordance with the cooperation agreement. The sessions included patients classified by medical staff using the unified UPDRS [2] scale as sick patients and people without known disease symptoms. This scale corresponds to the test standard validated in the process of diagnosis and assessment of the progression of Parkinson's disease. The scope of the tests per-formed, corresponding to the UPDRS scale, is shown in Figure 1. Each of the patients, during a standard medical visit to the Clinic, was informed about the scope and purpose of scientific research and confirmed the voluntary and informed consent to the registration and processing of obtained biometric data with a handwritten signature.

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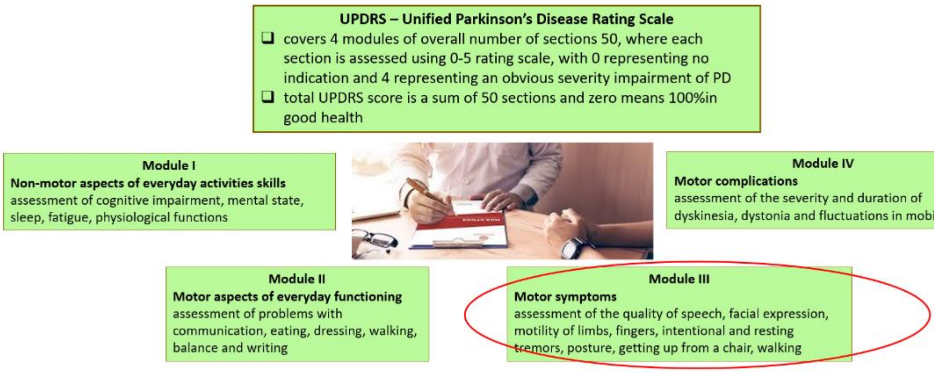

Fig. 1. Scope of the proposed studies in the context of the UPDRS clinical test

Before the start of the registration sessions, the consent of the Bioethics Committee to conduct the research was also obtained. The study selected 8 patients diagnosed with Parkinson's Disease (PD), among whom there were an equal number of women and men aged 48 to 81 years.

Table 1. Medical characteristics of patients with diagnosed Parkinson's disease

No	sex	age	character of the PD	body side	UPDRS scale part III	years of illness
1	F	62	classic	right	26	2
2	F	56	classic	right	22	3
3	M	79	classic	both	34	10
4	F	52	classic slowdown	left	24	8
5	F	48	classic	both	20	6
6	M	73	classic	both	34	10
7	M	81	classic	both	42	12
8	M	73	classic slowdown	both	33	8

All were treated with L-dopa preparations and the duration of the disease covered a period of 2 to 12 years. The severity of the disease, assessed according to the UPDRS scale, ranged from 22 to 42. For details on patients, see table 1. As a rule, these patients participated in registrations in the phase of action of drugs that reduce the symptoms of the disease. This places much greater demands on data processing methods, but at the same time gives hope for the development of methods that will allow for effective diagnosis in the early stages of the disease. The HC (Healthy Control) control group used as a reference consisted of 8 people, among whom there were also an equal number of men and women with an average age of 40. They were people who did not have family relations with sick people.

II. Data Acquisition

A multimodal system developed as part of the previous work presented in [3] was used for the recording. The subset of devices responsible for the acquisition of analysed data is depicted in Figure 2.

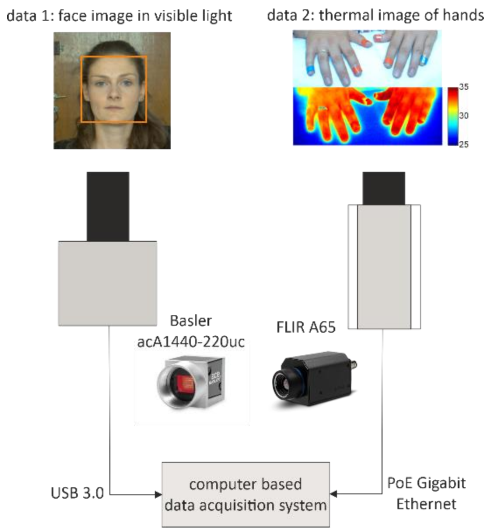

Fig. 2. The set of devices used to acquire data for the analysis: face images in visible light and images of hands in the infrared range

The basic motivation for building the set is the specificity of clinical tests recommended by the International Society for Parkinson's Disease and Movement Disorders [4]. The investigator should assess with the use of the UPDRS scale "what is seen". Therefore, the developed laboratory set includes devices to expand the ability of human perception.

In order to record a thermal image in the wavelength range from 7.5 to 13 µm, a Flir A65 thermal imaging camera with a focal length of 25 mm was used. The camera provided a field of view of $25^0 \times 20^0$ and was equipped with a matrix with a resolution of 640 × 512. The maximum speed of the camera is 30 Hz and its temperature sensitivity does not exceed 0.050C. The accuracy of temperature measurement is ±5% of the indication. The Flir A65 was chosen because of its relatively small size and the ability to operate it from a computer via a Gigabit Ethernet interface, which is also used to power the camera through the use of PoE (Power over Ethernet) technology.

Image acquisition in the visible range was carried out using the Basler acA1440-220uc camera equipped with the Basler C125-0818-5M lens providing a field of view with dimensions of 35^0 x 26^0. The matrix of the Basler acA1440-220uc camera is made in CMOS technology and allows recording color images with a resolution of 1440 x 1080 pixels at a maximum speed of 227 frames per second. The device is equipped with a USB 3.0 interface for power supply and data transmission between the camera and the computer.

The developed concept of collecting multimodal data assumed the same conditions for the use of recording equipment for all examined persons. The patient who came to the separate office for the examination occupied a sitting position on a chair, whose distance to the cameras, because of the constant focal value of their lenses, was unchanged and determined by means of markers placed on the floor.

The controller of the devices described above was the MSI GF63 8RD laptop, equipped with a 6-core Intel Core i7-8750H processor, 16 GB of RAM and a fast SSD with a capacity of 1 TB. The controller performed its functioning thanks to dedicated software developed in the Matlab programming and computing environment with the use of the *Image Acquisition Toolbox* library functions enabling support for image recording devices and *Parallel Computing Toolbox* functions, which allowed for parallel running of several processes in separate threads

III. ANALYSIS OF THERMAL IMAGERY OF HANDS

The inspiration for remote hand temperature testing of patients with Parkinson's disease are medical observations indicating skin dysfunctions caused by the degradation of nerve fibres. The possible source of such degradation is the accumulation of a pathological substance in it, called alpha-synuclein [5][6]. Due to the observed asymmetrical range of the disease's impact on the human body in many cases (right-sided, left-sided or both-sided – see Table 1 of the medical assessment of patients), temperature distributions on the outer surface of both hands were recorded and analysed. The corresponding grayscale images in which temperatures, sent by the camera as digital values of 14-bit resolution were encoded, are shown in Figures 3 and 4 (images of the hands of women and men with Parkinson's disease).

Thermal images presented in Figures 2 and 3 were obtained on the basis of the recorded temperature distribution by mapping the temperature range from 20 to 30 degrees Celsius into the intensity range from 0 to 255 of a monochrome image with standard 8-bit resolution.

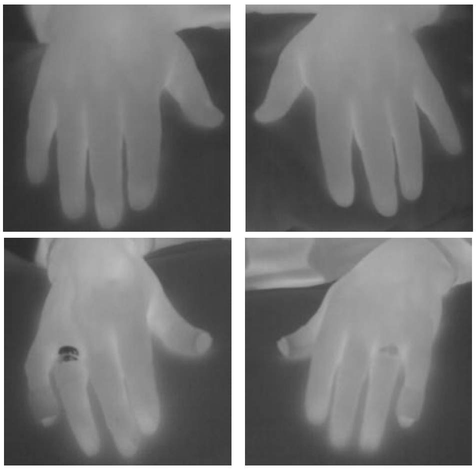

Fig. 3. Thermal imagery of hands in the PD group of 2 women (column 1 – right hand, column 2 – left hand)

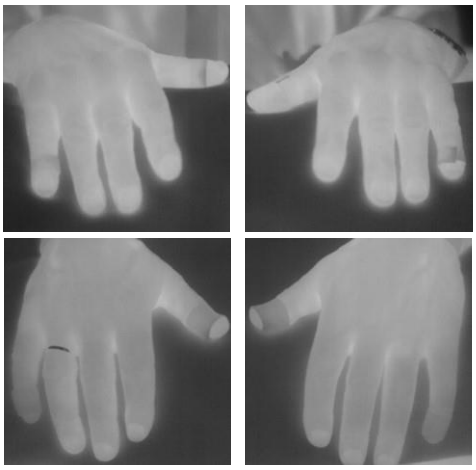

Fig. 4. Thermal imagery of hands in the PD group of 2 men (column 1 – right hand, column 2 – left hand)

Segmentation, aimed at separating the area of the hand from the background, was made on the basis of expected temperature values of the human body, as shown in Figure 5. From the separated areas of both hands, the first 100 largest values were analysed to examine if the temperatures of hands differ. A statistical assessment of the equality of hand temperature can be made using the Student's statistical test for difference of average values. This test verifies the statistical hypothesis of the equality of the mean values of the two normal populations X and Y on the basis of samples with numbers described by N_1 and N_2, respectively. Assuming the truth of the hypothesis, the statistics t determined on the basis of the sample:

$$t = \frac{\overline{X} - \overline{Y}}{\sqrt{\frac{N_1 s_1 + N_2 s_2}{N_1 + N_2 - 2}\left(\frac{1}{N_1} + \frac{1}{N_2}\right)}} \quad (1)$$

where: s_1, s_2 are variances from trials, is subject to the Student's distribution with the number of degrees of freedom $\nu = N_1 + N_2 - 2$.

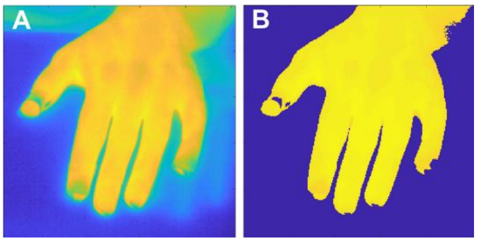

Fig. 5. Selection of the area corresponding to the temperature distribution on the surface of the hand (B) from the result of temperature measurement (A)

Verification of the hypothesis is carried out by comparing the module t calculated from the sample with the quantile of the Student's distribution for the level of significance α determined by $t_{1-0.5\alpha}$. The following relationship:

$$|t| \geq t_{1-0.5\alpha} \quad (2)$$

means that the probability of the statistic (1) accepting the value obtained from the sample is less than or equal to the assumed level of significance. Thus, the hypothesis of equal temperatures of both hands should be rejected. In the conducted research, an alternative approach was used, which consisted in determining the *p*-value, i.e. the probability of obtaining the *t* statistics module in the experiment. Again – the low *p-value* supports the rejection of the hypothesis of equal temperatures of both hands. Tables 2 to 5 present the results of temperature assessment in the PD and HC group, taking into account the division into women and men. In most cases, a statistically significant difference was observed between the temperatures of both hands in both groups.

Table 2. Temperature of hand surface in the PD group of women

women	R [^{0}C]	L [^{0}C]	body side in PD	*p-val.*	temp. equality
Patient 1	33.18	32.44	R	0	NO
Patient 2	31.31	31.27	R	0.002	NO
Patient 4	31.98	30.46	L	0	NO
Patient 5	35.38	35.61	L+R	0	NO

Table 3. Temperature of hand surface in the PD group of men

men	R [^{0}C]	L [^{0}C]	body side in PD	*p-val.*	temp. equality
Patient 3	31.79	32.16	L+R	0	NO
Patient 6	33.03	33.00	L+R	0.08	YES
Patient 7	30.66	30.75	L+R	0	NO
Patient 8	33.77	33.90	L+R	0	NO

Table 4. Temperature of hand surface in the HC group of women

women	R [^{0}C]	L [^{0}C]	*p-val.*	temp. equality
Patient 9	35.45	35.44	0.32	YES
Patient 10	33.41	33.77	0	NO
Patient 11	30.21	30.05	0	NO
Patient 12	32.32	31.53	0	NO

At the same time, no statistically significant difference was observed between the averages in the two populations: It was 32.54 ^{0}C for PD and 32.83 ^{0}C for HC with a *p-value* of 0.61. There were also no regularities in the values of differences between hand temperatures in both groups – table 6. The table compares the values of the differences and their modules between the temperature of the left hand and the right hand in both populations.

Table 5. Temperature of hand surface in the HC group of men

men	R [^{0}C]	L [^{0}C]	*p-val.*	temp. equality
Patient 13	33,02	32,77	0	NO
Patient 14	31,86	32,10	0	NO
Patient 15	32,30	32,63	0	NO
Patient 16	34,46	33,99	0	NO

The presented data allow us to conclude that the absolute values of the differences between the hand temperatures of patients from the control group HC are not statistically significantly different from the absolute values of differences between hand temperatures in the population of PD people. In the Student's difference test, a *p-value* of 74 % was achieved, which is not sufficient to reject the null hypothesis.

IV. Analysis of image data representing facial masking

Facial masking, the so-called hypomimia, is manifested by difficulties in expressing emotions on the face due to the deterioration of speed and coordination of the action of the

Table 6. Differences between hand temperatures in PD and HC groups.

Sex	PD			HC		
	Patient No.	$T_R - T_L$ [^oC]	$\mid T_R - T_L \mid$ [^oC]	Patient No.	$T_R - T_L$ [^oC]	$\mid T_R - T_L \mid$ [^oC]
women	1	0.74	1.39	9	0.01	0.01
	2	0.04	0.28	10	-0.36	0.36
	4	1.52	1.72	11	0.16	0.16
	5	-0.23	1.73	12	0.79	0.79
men	3	-0.37	1.32	13	0.25	0.25
	6	0.03	0.29	14	-0.24	0.24
	7	-0.09	1.61	15	-0.33	0.33
	8	-0.13	1.71	16	0.47	0.47
	average		**0.394**	average		**0.326**
	p-value = 0.74					

relevant muscles [7]. Patients living with hypomimia experience significant difficulties in adjusting facial muscles to emotional expression [8]. As a result, they give the impression of people who are not interested in the surrounding environment. During daily communication, this even leads to a loss of emotional contact between PD patients and healthy people [9][10]. The slow nature of the progression of hypomimia is a common reason for delayed prevention and treatment. The general idea of studying facial masks using imaging techniques is to determine the characteristic points on the faces of Patients during a neutral expression (facial expression A) and then to quantify the changes in the position of these points during the simulated expression of emotions. However, because of the specificity of the object and the conditions of the research performed, this is not a trivial task. First of all, due to the possible movements of the patient's head in front of the camera, suitable tools for this purpose should be sought among the processing methods that are independent of the displacement and rotation of the object. The methodology itself is also important, which should minimize the strong impact of individual characteristics on the recorded material. Hence, in this work, it is proposed to use the detection of characteristic points, between which, regardless of rotation or displacement, there will be unchanging relations with a fixed facial expression. With a changing facial expression, these relationships should be disturbed, according to the type of emotion and the patient's ability to express them. Potential such points are therefore the tip of the nose, the corners of the eyes, the points on the arches of the eyebrows and eyes, the points of the outline of the mouth, etc.

Modern techniques for searching for facial characteristic points are based on supervised machine learning methods, in which, on the basis of a large learning set with manually marked points, models used to detect test image points are created [11][12]. This paper uses an algorithm based on deep learning techniques (neural convolutional network), in the development of which 10,000 learning patterns were used [13]. The motivation for its use was the fact that the training data included images of faces with strongly differentiated poses, with partial occlusions and images representing variable facial expressions. The algorithm detects 68 points, but requires prior indication of the area of interest in the form of a border of the face image, which can be relatively easily obtained using for example the classic Viola-Jones algorithm [14]. Figure 6 and 7 show the results of combining the two above approaches in the processing of the image recorded during the pilot studies together with the numbering of characteristic points adopted in this work, for the neutral face expression and for expression of happiness, respectively.

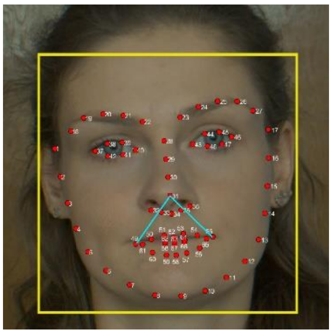

Fig. 6. Face detection in an image using the Viola-Jones algorithm and the set of characteristic points detected during neutral facial expression (distances between exemplary points marked with cyan)

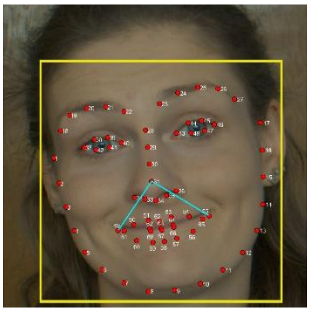

Fig. 7. Face detection in an image using the Viola-Jones algorithm and the set of characteristic points detected during expression of happiness (distances between exemplary points marked with cyan)

Due to the observed largest changes in the appearance of the face caused by the expression of happiness (facial expression B), the pilot studies presented in this study were limited to quantitative research related to changes under the influence of this emotion. Figure 8 shows examples of distributions of characteristic points corresponding to the patients from the HC control group and the PD study group.

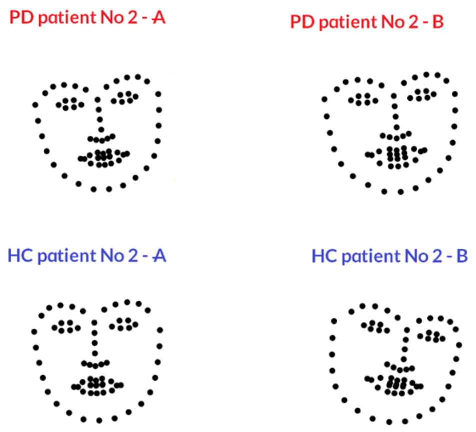

Fig. 8. Distributions of characteristic points on the faces of patients from the PD and HC group: A – neutral facial expression, B – happiness (joy)

In order to quantify changes in facial expression, the differences between Euclidean distances found between the corresponding characteristic points in neutral image A and image with emotion B were calculated.

The value of the resulting difference was related in percentage to the distance in image A (neutral face expression), according to equation (3):

$$p(i,j) = \frac{D_B(i,j) - D_A(i,j)}{D_A(i,j)} \cdot 100\% \qquad (3)$$

where $D_X(i,j)$ is the distance between points numbered by indices i and j (see Figures 3 and 4) and the X index takes letter values depending on the face expression, i.e. A or B. Thanks to that, the parameters expressed by (3) can be treated as differentiating features in classification for medical purposes. It is essential to identify characteristic points relevant to the generation of such features. Some of them, e.g., points describing the inner corners of the eye or the top of the nose, can theoretically be treated as points independent on emotions and use as reference points for those that lie in close distance to the muscles responsible for facial expressions.

Table 7. The meanings of the relevant features - distances between selected points

No.	points in Fig. 6 *i*	points in Fig. 6 *j*	distance between:
1	31	20	the top of the nose and the middle of the right eyebrow
2	31	25	the top of the nose and the middle of the left eyebrow
3	31	49	the top of the nose and the right corner of lips (see Fig. 6 and 7)
4	31	55	the top of the nose and the left corner of lips (see Fig. 6 and 7)
5	38	42	right eyelid and lower line of the right eye
6	44	48	left eyelid and lower line of the left eye
7	49	55	left and right corners of the mouth
8	54	59	upper and lowers lines of the mouth
9	24	48	the middle of the left eyebrow and lower line of the left eye
10	21	41	the middle of the right eyebrow and lower line of the right eye

For definitions of the 10 examples of characteristics designated for all persons participating in pilot studies, see Table 7. The assessment of these potential features was made again using the Student's difference test. The values of the 10 examples of determined for all persons participating in the pilot studies, together with the results of the *p-value*, are given in Table 8.

Table 8. Comparison of numerical values of 10 features and corresponding p-values in differentiating people by facial expressions

no.	HC patients 1	2	3	4	5	6	7	8	PD patients 1	2	3	4	5	6	7	8	p-value
1	1.5	7.0	2.3	1.1	0.3	1.9	1.4	2.0	0.9	0.9	2.6	4.7	0.7	8.9	1.4	4.0	0.517
2	5.4	2.7	8.3	0.9	1.8	0.2	3.8	4.0	3.5	2.4	1.9	0.7	3.1	2.3	4.6	5.0	0.669
3	9.2	2.4	11.3	13.0	3.3	10.8	11.8	8.6	5.3	3.9	22.6	7.9	11.9	4.9	11.2	2.4	0.993
4	8.7	1.6	8.6	13.1	3.3	10.4	11.7	8.4	4.7	4.8	20.6	9.0	12.7	4.2	12.0	3.0	0.802
5	11.7	17.8	20.6	10.1	11.5	14.0	15.5	9.7	7.3	9.6	34.7	7.7	17.3	16.9	2.6	9.7	0.863
6	11.9	17.0	20.5	10.0	9.6	12.3	15.0	9.0	7.1	8.7	34.1	8.4	16.0	15.5	2.8	8.6	0.890
7	26.6	22.4	15.2	6.0	7.8	10.5	10.5	8.8	16.5	14.6	33.7	12.1	19.2	20.6	9.1	17.4	0.253
8	29.2	37.9	13.0	11.3	11.2	18.0	12.2	8.6	23.7	22.8	49.1	17.3	20.9	26.0	15.8	18.3	0.232
9	11.8	9.9	15.0	15.5	3.1	14.1	14.2	5.3	6.3	6.0	3.3	1.5	11.7	7.3	2.6	0.3	0.010
10	9.5	12.2	8.8	16.1	4.3	14.9	14.3	5.6	6.2	4.4	2.8	4.0	14.9	10.4	2.3	5.6	0.063
average	7.5	0.2	6.3	6.1	1.5	5.0	5.5	2.3	0.6	1.4	5.7	4.0	4.2	0.6	5.2	0.7	0.237

The presented features refer to the points between which changes in distance were expected due to natural changes in facial expression. As it can be seen, a difference between average values of two of them is statistically significant.

Regardless of this expert approach, exploratory research was also carried out. It consisted in determining all possible distances between points and then searching for those features that for both populations were characterized by the lowest possible *p-value* values showing statistical significance. Examples of the results of such searches are presented in Figures 9 and 10. They correspond to the features determined for both PD patients and healthy cases by equation (3). The presented results together with possible separating hyperplane indicate the possibility of differentiation of both analyzed populations.

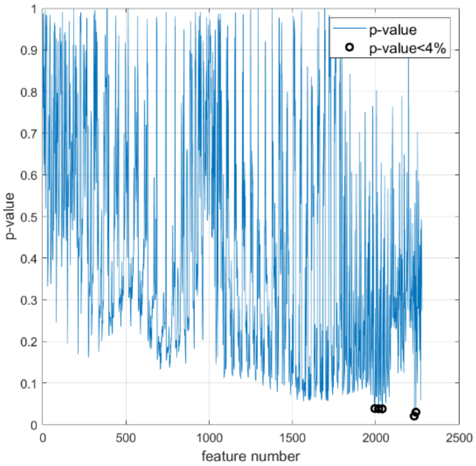

Fig. 9. Summary of p-values for all possible features expressing changes in the distance between facial characteristic points

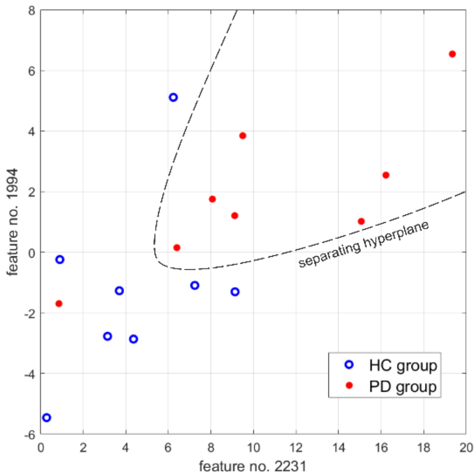

Fig. 9. Scatter plot for two exemplary features with a p-value of less than 4 %

V. Conclusions

The presented material illustrates the preliminary results of processing imaging data from the phase of pilot studies carried out as part of the task of supporting clinical diagnosis of Parkinson's disease. Achieved results allow for the development of recommendations for the implementation of the program of further research using a wider population of patients and healthy people. At this stage, it seems that recordings of temperature distributions on the surface of the skin of the outer parts of patients' hands using a thermal imaging camera do not bring the desired differentiating information. The reason may be the influence of both the environment on the results of measurements (additional heat sources in the office, variable solar radiation) and the patients themselves, whose activity before the examination is difficult to unify. The temperature tests presented in the literature [5] were based on such unification by applying pre-cooling of limbs, whose process of reaching normal temperature was only monitored by means of a thermal imaging camera.

However, the second modality seems to be highly promising. In the examined population, the possibility of using it to differentiate patients was observed. It should be noted that the methods used for the individual assessment of features were preliminary and did not take into account possible synergies between them, as well as synergies between features and the target classifier. Work in this direction will be carried out in the next stage.

ANALIZA OBRAZÓW DŁONI I TWARZY NA POTRZEBY INŻYNIERSKIEGO WSPARCIA DIAGNOSTYKI CHOROBY PARKINSONA

Wsparcie inżynierskie w zakresie rozpoznawania choroby Parkinsona na tle innych chorób, jej progresji oraz monitorowania skuteczności leków jest obecnie szeroko realizowane w ramach prac poświęconych wykorzystaniu urządzeń rejestrujących i analizujących wyposażonych w sensory parametrów ruchu przymocowanych do ciała pacjenta, np. akcelerometry i żyroskopy. W prezentowanej pracy przedstawiono alternatywne podejście, w którym proponuje się koncepcję wykorzystania technik przetwarzania wybranych danych obrazowych uzyskanych podczas badania klinicznego oceniającego pacjenta za pomocą ujednoliconej skali liczbowej UPDRS. Badania przeprowadzono na materiale, który odpowiadał wybranym składowym skali i obejmował obrazy twarzy utrwalone w zakresie światła widzialnego oraz obrazy zewnętrznych powierzchni dłoni rejestrowane kamerą termowizyjną. Wykonane badania miały na celu ocenę możliwości różnicowania osób pod względem wykrywania choroby Parkinsona na podstawie zarejestrowanych metod. W ten sposób zrealizowano zadania mające na celu opracowanie cech istotnych w procesie klasyfikacji binarnej. Ocena cech została dokonana w sposób zależny od modalności w oparciu o dostępne narzędzia z zakresu statystyki i uczenia maszynowego.

Słowa kluczowe: przetwarzanie obrazów, diagnoza medyczna, choroba Parkinsona.

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