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The Use of Convolutional Neural Networks to Classify the States of the Maxillary Sinuses in Digital Diaphanoscopy

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***Abstract* — The work presents the results of the use of the convolutional neural network ResNet-50 in digital diaphanoscopy for the diagnosis of maxillary sinus conditions. The analysis of registered diaphanograms of patients with sinusitis, cystic fluid and conditionally healthy volunteers was carried out. It is shown that applying the proposed classification model to diaphanograms recorded at a sensing wavelength of 850 nm and fixation threshold of 80% allows to reduce the false negative result. The results analysis made it possible to establish requirements for the registered diaphanograms. An approach to dividing the developed model into static and dynamic components is proposed.**

Keywords — optical diagnostics, digital diaphanoscopy, otolaryngology, maxillary sinuses, scattering pattern of light, diaphanograms, machine learning, convolutional neural networks

I. Introduction

The prevalence of maxillary sinus pathology is more than 140 cases per 1000 population [1-2]. Standard diagnostic approaches indicate low sensitivity in detecting maxillary sinus pathologies. Nasal endoscopy (sensitivity 0.21-0.69, specificity 0.66-0.80) [3-5] and ultrasound [6-7] (sensitivity 0.32-0.64, specificity 0.53-0.95) are widely used cost-effective methods for diagnosing diseases of the maxillary sinuses. The method of diaphanoscopy allows one to visualize internal organs and tissues using light passing through its. This method is non-invasive and painless, which makes it promising for telemedicine. The use of it can significantly improve access to medical care for residents of remote areas.

The method of digital diaphnoscopy is based on maxillary sinuses transmission by radiation in the visible and near-infrared spectrum (650 nm and 850 nm), registration of diaphanograms and its digital processing [8]. Registration of diaphanograms makes it possible to visualize the presence or absence of pathological changes, such as pus, cystic fluid or tumor [8]. This is due to the fact that pathological formations absorb more probing radiation. Thus, at the wavelength 650 nm, high blood content has a high absorption coefficient, and at the wavelength 850 nm – the presence of exudates [9-11]. The presence of pathological formations in the sinuses, which are normally airy, leads to a decrease in the intensity of the probing radiation and the appearance of dark areas on the diaphanogram [12].

A prototype of the digital diaphanoscopy device (Fig. 1) has been developed, the use of which, together with a classification model based on linear discriminant analysis, allows for the diagnosis of the condition of maxillary sinuses with a probability of a false negative result of less than 0.1 [8, 12]. The development of a classification model for raw diaphanograms using convolutional neural networks (CNN) [13-16] would potentially improve the convenience of classification when developing a medical decision support system.

II. Material and Methods

In this study, digital diaphanoscopy was used to diagnose maxillary sinus pathologies using a previously developed prototype digital diaphanoscopy device. 49 conditionally healthy volunteers and 42 patients of the ENT department of the Clinical Center for Maxillofacial, Reconstructive and Plastic Surgery of the University Clinic of the A.I. Yevdokimov Moscow State University of Medicine and Dentistry were studied. The patients and volunteers signed an

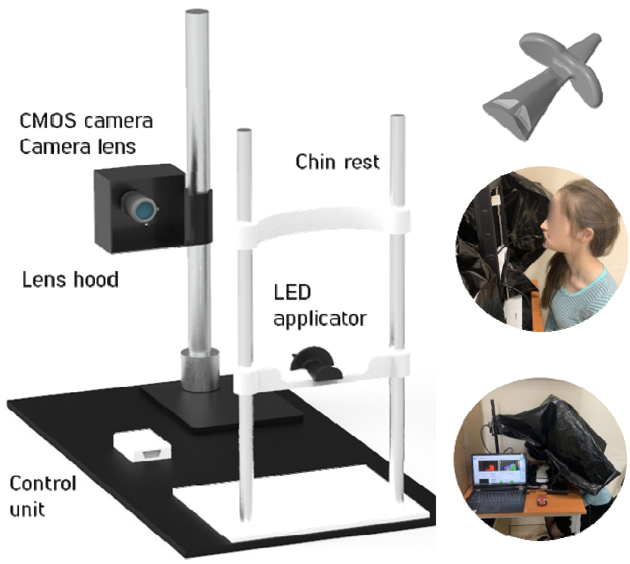

Fig. 1. General view of the experimental setup, fixing patient's head in the chin rest with an LED applicator in the oral cavity under a protective screen

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informed consent indicating their voluntary willingness to participate in the study. The study was approved by the Ethics Committee of the Orel State University (record of meeting No. 15 of February 21, 2019) and carried out in accordance with the 2013 Declaration of Helsinki by the World Medical Association.

During the procedure, the patient is comfortably sitting, and his head is fixed on the chin rest. The LED applicator is disinfected, then placed in the patient's oral cavity. The patient's head is placed under a screen protected from external lighting. Then the sinuses are probed by the light at wavelengths 650 and 850 nm. The registration of diaphanograms by a CMOS camera UI-3240CP-NIR-GL Rev.2 with Pentax C1614-M (KP) lens (Pentax, Japan) is carried out concurrently with the sinus probing. Camera is located opposite the patient's face (fig. 1). The registered diaphanograms are pseudo-colored. Depending on the degree of light absorption, pseudo-coloring makes it possible to better visualize the maxillary sinuses with the presence of a pathological change.

A diaphanogram obtained for a conditionally healthy volunteer (Fig. 2) shows the presence of weak absorption of probing light in the right and left maxillary sinuses that is related to airiness of the sinuses in normal conditions.

The registered diaphanogram for a patient with left-sided sinusitis (Fig. 2), as well as the result of pseudo-coloring, show a low-intensity region in the area of the left maxillary sinus, which indicates a decrease in its transparency and the presence of a pathological change. The right sinus is normal.

For the classification of the states of the maxillary sinuses, a test model implementing the CNN ResNet-50 was developed on the NetCore platform in the Visual Studio 2022 environment (Microsoft Corporation). There are functions to reduce the risk of retraining. To test the model, diaphanograms, recorded at the wavelengths of 650 nm and 850 nm, were manually selected. The areas of maxillary sinuses were identified by deleting uninformative fragments of images (fig. 3), and the first training and test samples were formed. The samples included 3 classes of 10 images: for patients with sinusitis, patients with cystic fluid, and conditionally healthy volunteers.

III. EXPERIMENTAL RESULTS AND DISCUSSION

For the experiment, 18 diaphanograms of patients with sinusitis, 12 with cystic fluid, and 49 diaphanograms from conditionally healthy volunteers were selected. The best result was recorded for the case of diaphanograms recorded at a wavelength of 850 nm, while the false negative result was significantly reduced at a fixation threshold of 80% (Table I).

A model for the classification of maxillary sinus conditions has been developed, consisting of an automatic decision-making unit and a medical decision support unit (fig. 4) with an additional training function, including an image classification model based on the CNN ResNet-50.

A decision threshold of 0.8 is set for the main classification model. The results of the diaphanograms classification with a probability exceeding the specified threshold can be used by the operator as reliable. The rest of the images are subject to additional classification to establish belonging to a particular class. This information can be used by the doctor during an additional examination of the patient, and after establishing the diagnosis, the model is further trained.

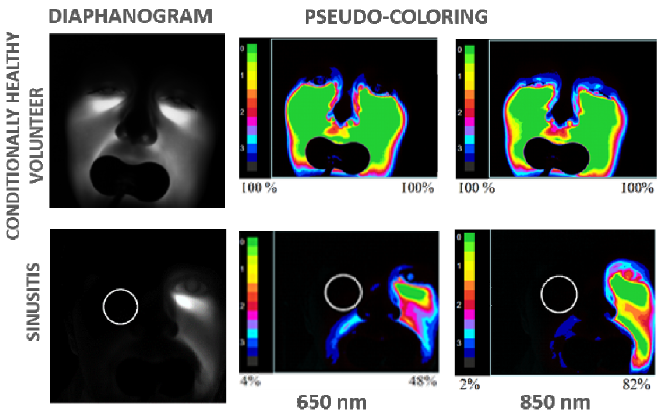

Fig. 2. Examples of registered diaphanograms, the results of digital image processing for a conditionally healthy volunteer and a patient with left-sided sinusitis

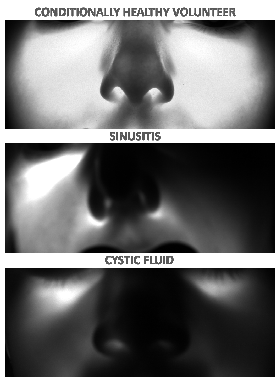

Fig. 3. Examples of preprocessing of registered diaphanograms

TABLE I. THE RESULTS OF TESTING THE DEVELOPED MODEL

Sinus condition[a]	**The first sample** (threshold for fixing the result – **70%**)		**The second sample** (threshold for fixing the result – **70%**)		**The second sample** (threshold for fixing the result – **80%**)	
	Wavelength, nm					
	650	850	650	850	650	850
S (18 d.)	S–5 C–2 A–1 N–10	S–25 A-1 N–10	S–17 N–1	S–17 N–1	S–14 N–4	S–14 N–4
C (12 d.)	C–7 N–5	C–6 N–6	C–6 S–1 N–5	C–10 N–2	C–3 S–1 N–8	C–7 N–5
A (49 d.)	A–47 C–2	A–42 C–2 N–5	A–38 C–1 N–10	A–38 C–1 N–10	A–33 C–1 N–15	A–36 N–13

[a] S – sinusitis, C – cystic fluid, A – absence of pathology, N – not defined the sinus condition, d – diaphanogram

Thus, the application of the proposed classification model based on the CNN reduces the probability of a false negative result and increases the speed of decision-making.

Further development of the research consists in dividing the functionality of the developed model into two components: static and dynamic.

The main function of the dynamic component of the model (Fig. 5) is the formation of the database of machine learning models (ML-models) for the classification of the *i-th* pathology (disease).

To detect each pathology, a separate *i-th* ML-model is created, the training and additional training of which is carried out on pre-prepared diaphanograms. Performance monitoring and additional training of ML-models to the required level of accuracy are carried out on diaphanograms of newly admitted.

At the same time, the total training time of each ML-model depends on the quantity and quality of the initially collected images. With a sufficient number and quality of images, the full training of the ML-model takes several minutes (on a PC with an Intel Core i7 12700 processor and 32 GB DDR4 RAM). A fully trained *i-th* ML-model is transferred for permanent use as part of the static component of the model as a classifier of the *i-th* pathology.

The static component of the model (Fig. 6) is used in the diagnosis of maxillary sinus pathology. The model includes an image classifier, which is used as a tool to support medical decision-making in the diagnosis of the *i-th* pathology.

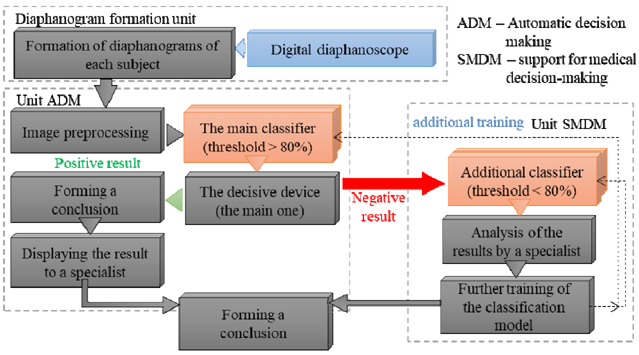

Fig. 4. The model for classification of maxillary sinus conditions based on CNN in digital diaphanoscopy

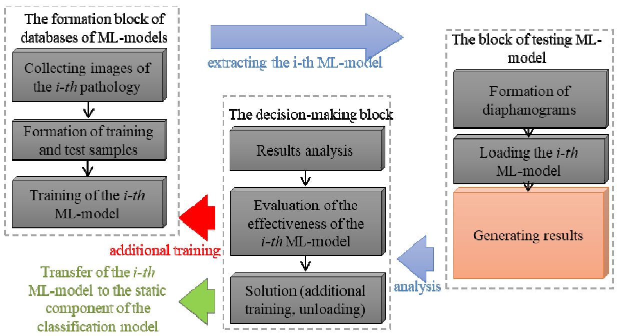

Fig. 5. Dynamic component of the maxillary sinus pathology detection model

During the initial examination, the doctor registers the necessary set of patients' diaphanograms using a digital diaphanoscope. Then, using a software tool, it is selected the necessary trained ML-model and the classification of the generated images is carried out.

Then, taking into account the result obtained, the doctor decides on the formation of a treatment plan, or gives a conclusion on the absence of pathology. If the doctor decides to conduct an additional examination, the process of forming and classifying the necessary set of patients' diaphanograms is repeated.

The proposed static and dynamic models of classification of maxillary sinus conditions can be widely used in various fields of medicine to classify pathological changes in organs and tissues, detect and classify various types of cancer.

Conclusion

The paper considers the application classification method based on CNN for detecting maxillary sinus pathologies. The obtained results showed that the use of CNN makes it possible to detect the presence of sinusitis and cystic fluid in maxillary sinuses, reducing the false negative result.

The analysis of the experiments made it possible to establish the following requirements for the registered images:

– a representative sample for training and testing the model must contain at least 100 diaphanograms in each class;

– registered diaphanograms should contain clearly defined facial features and a pronounced area of the maxillary sinuses, occupying the main field of the image;

– the number of diaphanograms in each class should be approximately the same to avoid shifting the model;

– recording diaphanograms obtained under various conditions, such as foreshortening, increases the stability of the model.

The correct approach to the selection and division of diaphanograms into classes is a major factor in achieving high classification accuracy using CNN. It directly affects the ability of the model to generalize and accurately predict new, previously unknown data.

Thus, taking into account the established requirements, the developed classification model will be actualized by increasing the dataset. It is also planned to use pseudo-colored diaphanograms as samples.

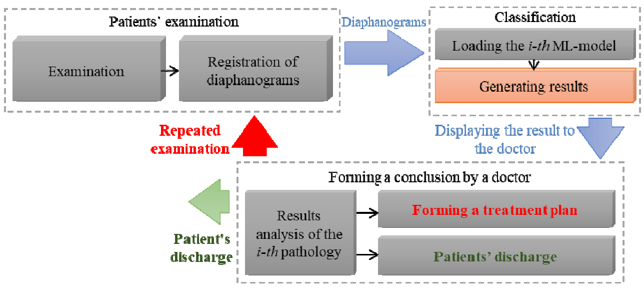

Fig. 6. Static component of the maxillary sinus pathology detection model

In addition, the proposed approach to dividing the model into static and dynamic components will be tested. So, the model can be used to develop a system to support medical decision-making.

As part of the further project development, an additional diagnostic channel for detecting pathologies of the oral mucosa is planned based on the method of fluorescent imaging. The need to develop this channel is due to a high correlation between the development of oral mucosa and maxillary sinus pathologies due to the close proximity of tissues. It is known that squamous cell carcinoma of the oral mucosa is rarely primary, more often, the tumor grows from the maxillary sinus, nasal cavity or nasopharynx into the oral cavity [17].

It is known that the development of oral mucosa lesions is characterized by changes in the endogenous fluorophore's concentration [18]. Preliminary experimental studies have shown that the FAD signal makes the greatest contribution to the formation of the high level of autofluorescence intensity observed in pathology in the blue-green spectrum [19].

It has been shown that the high-level intensity of FAD can be a marker of a precancerous condition, and the low-level intensity of FAD – a marker of the beginning of the process of cell degeneration into the tumor (malignancy process) [20].

Using the fluorescent imaging method autofluorescence images will be obtained by excitation of FAD in the oral mucosa using micro-LEDs of the blue spectrum and subsequent visualization of autofluorescence using a micro-camera. The autofluorescence images of the oral mucosa recorded on patients of dental and oncological profiles will be used to develop a classification model based on CNN. Thus, the problem of binary classification of the condition of the oral mucosa (presence or absence of pathology) will be solved.

The use of the developed CNN model for the classification of diaphanograms and oral mucosa autofluorescence images recorded by the additional diagnostic channel of the device will allow for more systematic assess the functional state of the tissues of the head, and it will eliminate the subjectivity of the diagnosis (reduce a false negative diagnosis) and thereby increase diagnostic effectiveness.

Thus, the technology of complex optical diagnostics, together with the classification model based on the CNN, can be applied both in the framework of public health screening (for early detection of pathology) and in the framework of diagnosis and control of the effectiveness of prescribed therapy in otolaryngology, ENT oncology and dentistry, as well as in telemedicine.

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