Software-hardware complex for scanning and analyzing of drill cores

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Abstract— A software-hardware complex for scanning and analyzing the lateral surface of drill cores was designed. A scan contains visual information on the lateral surface of a drill core, is easy to store and the risks of losing, mixing and destroying a drill core are minimum. The structure and design of the complex, scanning options and methods of control are described. Algorithms for constructing 3D scanning models, assessing mineral composition and other characteristics of a drill core and compressing a scan in the MATLAB computer mathematical system were developed. The complex was tested on drill cores from the Kostomuksha iron deposit. The accuracy characteristics of the algorithms were assessed on simulated images.

Keywords—Algorithm, analysis, control, drill core, lateral surface scan, scanning, software-hardware complex,

I. INTRODUCTION

A rock consists of mineral grains differing in shape, size, boundaries and substance. The petrographic study of thin sections and polished sections of rocks under the microscope using integration tables and optical-electronic attachments gives local, often inaccurate estimates of their composition and properties. Obtaining the estimates takes a long time and is hard to automate [1]. The disadvantages of a conventional approach become especially conspicuous when large numbers of drill cores are to be analyzed and data on the rock constituents of drill cores are urgently needed [2].

These disadvantages can be eliminated by scanning rock samples, e.g. scanning the lateral surface of drill cores. Scanning operations reduce the risks of mixing, losing and chemical decomposition of drill cores. In contrast to a drill core, its scan is easy to demonstrate, compress, store, reproduce, send and transform. A scan with a high spatial and spectral resolution, used as a digital model of the lateral surface of a drill core, stores visual information about a drill core.

In some software and hardware systems, the angles under which the sample is scanned are determined by the rotations of the sample [3]. Such complexes are characterized by high power consumption and long sweep formation time.

Scanning the core sample in different spectral ranges raises the information content of the analysis, helps to reveal the hidden details [2]. Designed to search for oil reservoirs and conduct detailed mineralogical research, software and hardware complexes are equipped with sources and detectors of penetrating radiations. Using tomography methods, these complexes reconstruct the structure of pores and cracks inside the core samples. As a rule, these complexes are specialized, expensive, require the protection of working personnel [4].

The goal of our research is the creation of a convenient, simple, economical, high-speed and relatively inexpensive software and hardware complex for obtaining and processing the scanning of the lateral surface of core samples. Achieving the goal was made possible by the design of controlled optical-mechanical device, which scanned the core samples, and algorithms provided its analysis, transformation and compression. As rocks are not accurately identified petrologically and there is no general-purpose identification algorithm, the study of a scan is based on analysis of the distribution of mineral grains with regard for their properties.

II. MATERIALS AND METHODS

Drill cores from the Kostomuksha iron deposit and the Museum of Precambrian Geology at the Institute of Geology, Karelian Research Centre, RAS, were used. The mobile parts of the device are driven by the quantisized step motors 42BYGHW208 [5]. Images of core zones are registered by SVEN IC-957HD web-cameras [6]. To control the optical-mechanical device of the complex, a Raspberry Pi mini-computer was selected [7]. The management program is written in Python language. Images are registered into a computer and pre-processed by Linux system utility program [8]. As a result of the operation of the management program, a digital scan of the lateral surface of a drill core, consisting of images, is obtained. The scan is then processed in the MATLAB computer mathematical system [9], forming its 3D model [10], identifying the mineral compared and color clusters and estimating the mineral composition of the rock constituents of the drill core by calculating the percentages of pixels in color clusters. To construct mineral grain distributions, based on the size, shape and orientation of grains, morphological analysis was made to assess the characteristics of grain contours (smoothing procedure). The

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accuracy of grain selection algorithms was estimated on images simulated in a special manner. The layering and fracturing parameters of a drill core were determined using approximation methods [11] Radon [12] and Hough transforms [13]. To compress the scan, a Haar batch wavelet was employed [14].

III. RESULTS

Executive device. A scheme of the software-hardware complex for scanning the lateral surface of a drill core is shown in Fig.1a. The complex comprises an executive optical-mechanical device, control and image processing units and an image and accompanying information database. In a conventional device [3], a drill core is fixed in the clamp of a

lathe, connected by a belt transmission with the motor shaft (Fig.1b), and is turned at the desired angle. Images are made by a camera which is mounted below and is shifted step-by-step along the guides.

In the other option of the device a drill core is immobile. Moving along the drill core is a ring with cameras mounted on its sides (Fig.1c). As the various parts of the drill core are scanned simultaneously, it takes just a few minutes to register a scan.

Windows-compatible SVEN IC-957HD web-cameras, scanning the drill core, have a 0.9 MP matrix, a video resolution of 1280 x 720, a built-in microphone, automatic focusing and connection to USB 2.0 ports [6].

42BYGHW208 quantisized step motors, which drive the device, are small, have a permanent magnetic resistance and four connecting cables. The motor operates at a voltage of 12 V and a nominal current of 0.4 A over the temperature
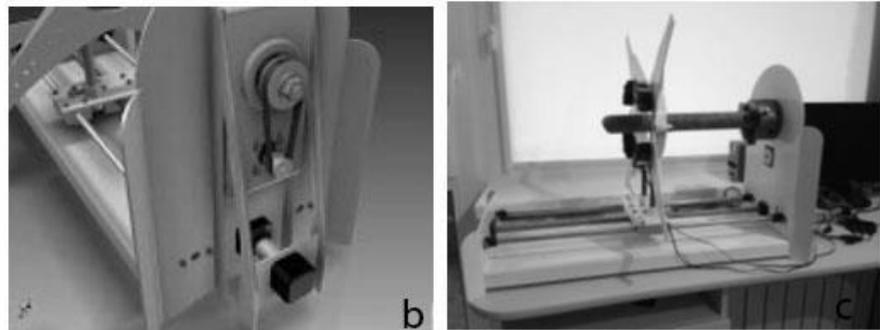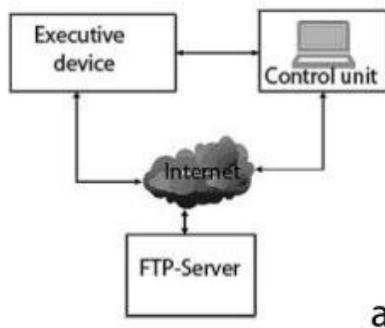

Fig.1 Scheme of a software-hardware complex (a) and an executing optical-mechanical device for scanning the lateral surface of a drill core with a mobile (b) and immobile (c) sample

range $-20°C \div +50°C$ and makes 200 steps per revolution [5]. A conventional scheme comprises two motors: one is used for rotating a drill core and the other for moving a camera. When a drill core is fixed, the ring with cameras on it is moved by one motor.

Controlling the device. The device is controlled by a Raspberry Pi mini-computer (Fig. 2a). Unlike similar computers, it has a size comparable with that of a credit card, a Raspbian operation system and an optimized easily distributed Debian Linux-based distributed disk [7]. As the mini-computer is connected to the Internet, scans are easily sent and processed using specialized software packages. The rotation of the quantisized step motor shaft is controlled by phase switching and by sending a signal to the coils, as shown in Table1. Signals sent, according to the table lines, from top to bottom and in an opposite direction, from bottom to top, correspond with the complete cycle of the motor (four shaft rotation steps in forward direction).

The driver of the quantisized step motor was assembled on a L298N microcircuit, 33x50 mm in size, a board power supply of 5V, a motor power supply of $2.5 \div 46$ V, an operating current of up to 2A per channel and overheating protection [15]. The abbreviations in the scheme, showing the connection of the driver to the motor and the microcontroller

(Fig.2b), are: MCU = microcontroller; VSS =driver power supply; VS = quantisized step motor power supply; ENABLE1, ENABLE2 = switching on/off the first and second coils, respectively; INPUT1, INPUT2, INPUT3, INPUT4 = controlling the rotation direction and speed of the motors; OUTPUT1, OUTPUT2, OUTPUT3, OUTPUT4 = outputs for connecting motor coils; GND = «ground». To form signals on the motor coils (Table1), signals are sent to the inputs ENABLE1 ENABLE2, INPUT1, INPUT2, INPUT3 and INPUT4 of the quantisized step motor driver in accordance with the diagram. (Fig. 2c).

Signals on motor coils. Table 1.

Coil1		Coil2	
A	A'	B	B'
+«1»	«0»	Not connected	
Not connected		+ «1»	«0»
«0»	+ «1»	Not connected	
Not connected		«0»	+ «1»

Signals sent from the left to the right correspond with the forward rotation of the motor shaft and those sent from the right to the left correspond with its backward rotation. The device management program uses Python language; its interpreter is buil-in in a Raspbian distributed disk. The program is accessed by connection to the computer via a safe *SSH* protocol. The function of the program *SetStep(a,b,in1,in2, in3, in4)* forms logical signals at the inputs of a L298N driver along the lines

ENABLE1, ENABLE2, INPUT1, INPUT2, INPUT3 and INPUT*4*. The forward and backward rotation of the motor is provided by the functions *forward(delay, steps)* and

backward(delay,steps) with such parameters as a delay in making a step by the motor (sec) and the number of steps.
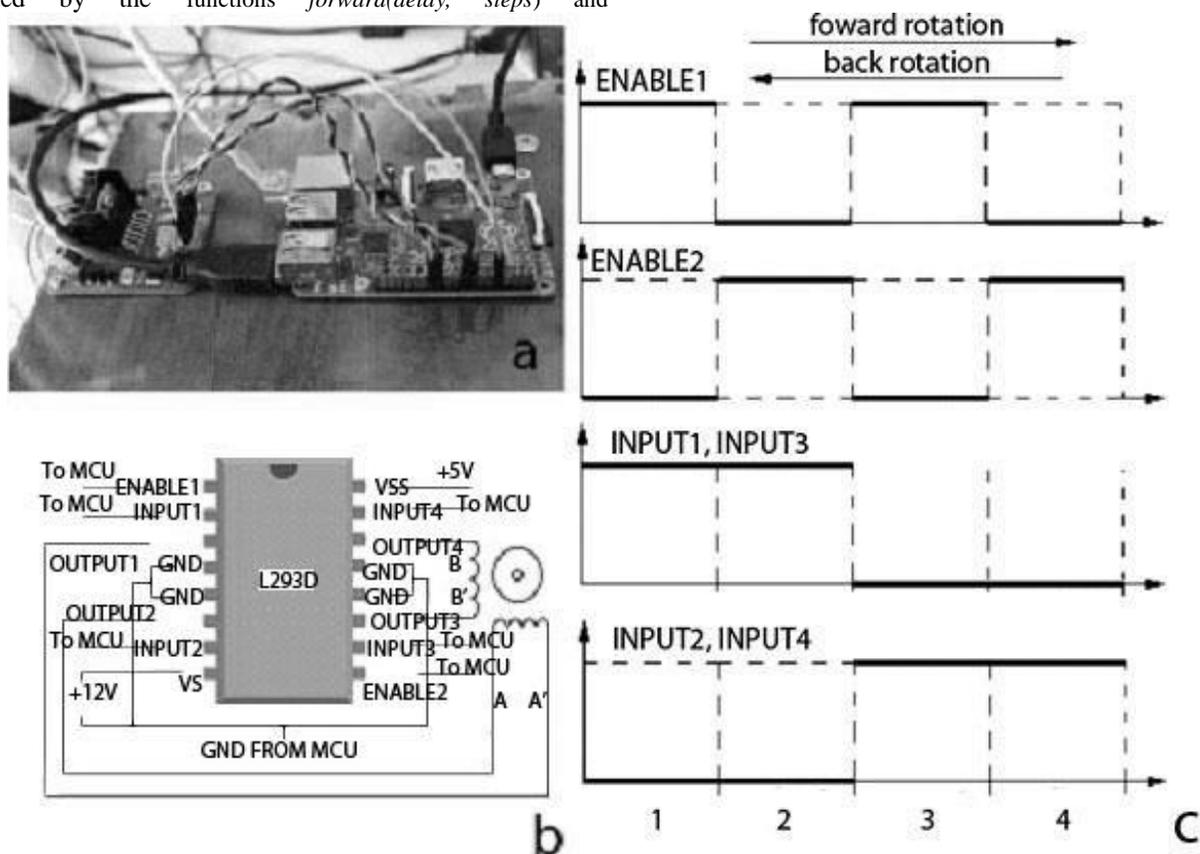

Fig. 2. Raspberry Pi computer with «L298N» circuit which operates the device (a); a scheme showing the connection of the driver to the quantisized step motor and the computer (b), diagram of the signals formed on the coils of the quantisized step motor (c).

Drill core surface fragments are photographed by the function *make_photo* using the system utility program Linux *fswebcam* of UNIX class [16]. Video camera number, resolution, image size and storage file name are utility options. To operate the management algorithm in the conventional option of an executive device, the rotation angle of a drill core and the end positions of the web-camera, determined by overlapping the boundaries of the previous and next photos, should be set. If a drill core is fixed, then the end positions of the ring are indicated.

Forming a scan and its 3D model.. Once the photos are registered, the management program equalizes their illuminance in color temperature, glues them to form a scan and sends it at the desired address for further processing in the MATLAB computer mathematical system.

The scan of the lateral surface of a drill core is expanded by a cylindrical 3D model. A transition from a scan, which has length *l* and width *d*, to a cylinder, which has length l and radius ρ, was conducted by re-writing *x*- and *y*-coordinates of pixel in a rectangular coordinate system into ρ-, φ- and *y*-coordinates of a cylindrical coordinate system [10].

y - coordinate, which presets the position of an element from scan length, was not changed. Cylinder radius ρ and angle φ were estimated from the formulas:

$$\rho = \frac{d}{2\pi}, \quad \varphi = \frac{2\pi x}{d} \tag{1}$$

Core samples of rhyodacite and gneiss with quartz veinlets and ferruginous quartzites from Kostomuksha iron deposite [17], their scans and 3D-models of the scans are shown in Fig. 3.

Scan analysis. One of the main procedures in describing a drill core is estimating the mineral composition and identifying the rock constituents of a drill core. The mineral composition of a drill core scan was estimated by the color of mineral grains. For this purpose pixels were segmented in the color space and the areas of the color clusters obtained were calculated using an algorithm based on K-mean method [18]. The quartz, K-feldspar and oligoclase clusters, identified in a scan of rapakivi granite (Fig. 4), have areas of 26, 46 and 28 %, respectively, which show the volumetric concentrations of these minerals in the rocks.
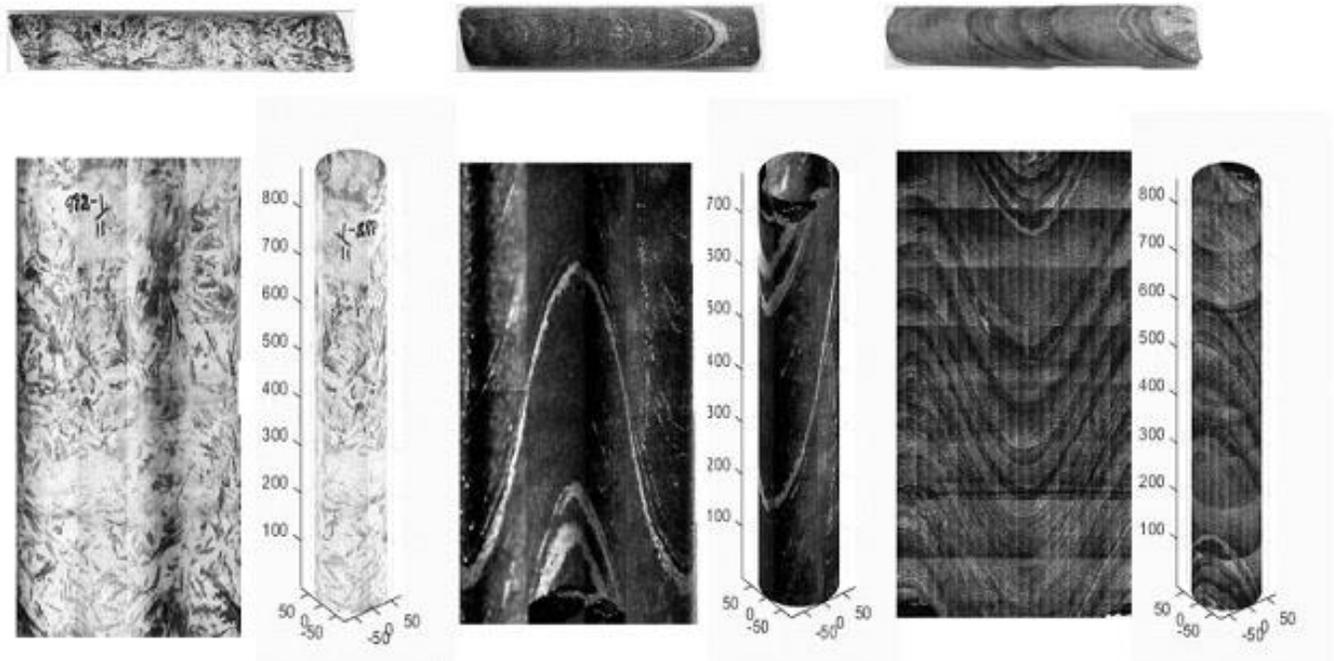
Fig.3 Drill cores, scans and 3D models of rhyodacite (a), gneiss (b) and iron formation (c) from the Kostomuksha iron deposit
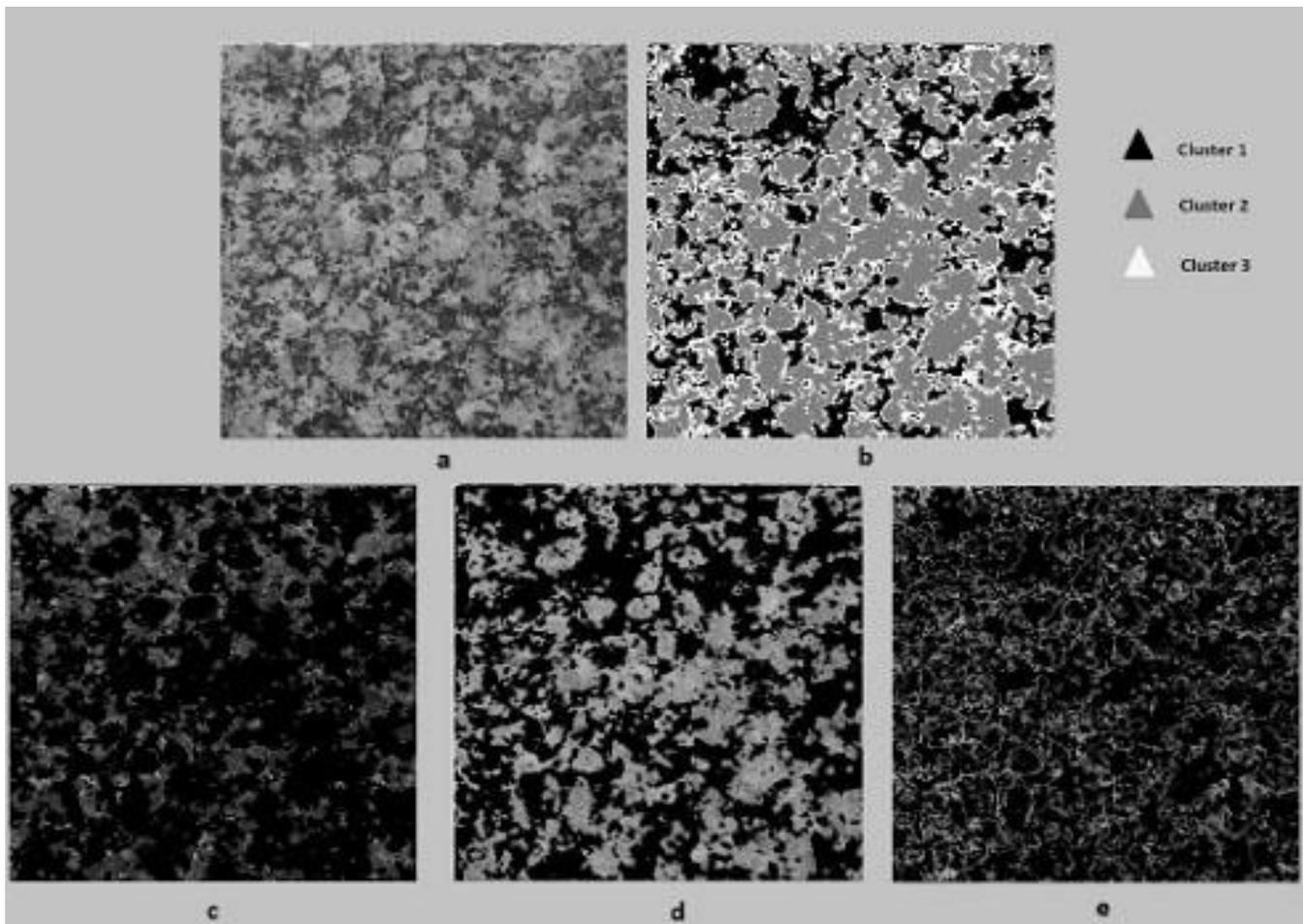

Fig.4 Images of rapakivi granite (a) and its mineralsв (b): quartz (c), K-feldspar (d) and oligoclase (e).

Mineral grains and their clusters in the drill core scan were identified, their position, shapes, sizes, orientation and boundaries were described and the data obtained were processed statistically using MATLAB algorithms. To select grains by size, the consecutive operations of morphological analysis, such as erosion and dilatation, were carried out by the commands *imerode* and *imdilate* [19]. Grains of preset size were obtained in the subtractive picture of the source image and the image in which these grains were destroyed by erosion. The grains identified were equalized in intensity and considered as clusters centers were identified as gravity centers. The command *imfeature* assesses each grain separately. Its shape and orientation are assessed using the main component method

triggered by the command *princomp,* It is used to estimate the largest and smallest grain sizes and the angle of inclination of the grain to the scan axis. After processing all the grains, their distributions in size and shape parameter δ (the relation of the smallest grain size to the largest) and inclination angle θ were constructed (Fig.6b). For a simulated image, the results of selecting grains by the procedures *imerode, imdilate* and the distributions constructed on their basis are shown in Fig.5. The shape and inclination angle parameters of the grain, calculated from (l and m) distribution with Student coefficient 2.11 at p=0.05 and 17 degree of freedom, were: δ = 0.57 ± 0.04 and θ = 136.4 ± 3.6º, respectively, at the values 0.56 and 135º used for modeling.
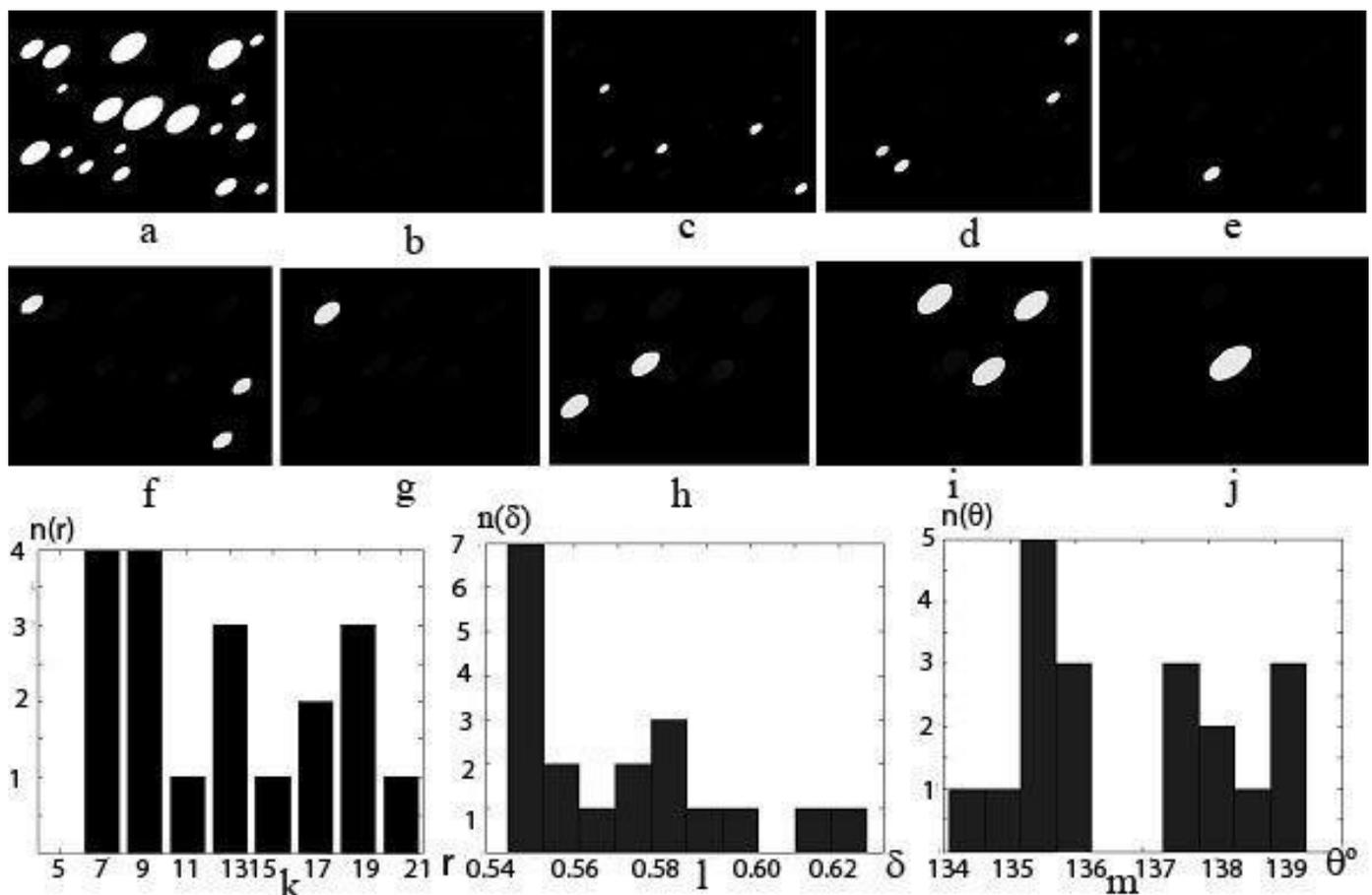

Fig.5 Model grain distribution (a) and the results of selecting grains by size (circle radius) (b-j), grain distribution in size (k), shape (l) and orientation (m).

Mineral grain boundaries affect the strength and mechanical properties of a rock, its behavior in external fields and recrystallization in solid state. The variability of the boundaries is described by its mean-square deviation from the grain contour obtained by smoothing (Fig.6).

Layering and fracturing in drill cores also carry essential geological information. Layering parameters are used in facies analysis and paleogeographic reconstructions, for subdividing and correlating sedimentary rock sequences and mineral prospecting. Fracturing affects rock strength, the stability of

quarries and hydrological regime, and is considered in drilling and forming drill holes with a high hydrocarbon discharge. The length, direction, dip angle, morphology, openness and filling of fractures are described. Layering and fracturing are analyzed on an oriented drill core.

To analyze scan lineaments, Hough and Radon transformations in the form of the commands *hough* and *radon* were used. One of their distinctive features is the ability to show a direct line to a point [12,13]. A high-intensity point object corresponds with the integral image of a lineament. It is

easily separated by this property from other image elements, represented separately by inverse transformation and its parameters are estimated. Lineament length can be estimated as the norm of vector (xmax - xmin, ymax – ymin) composed of maximum xmax, ymax and minimum xmin, ymin coordinate values. When describing layering, one should remember that

the ellipse, obtained in the cross-section of a cylindrical drill core by an inclined plane, is represented by sinusoid in the drill core scan. The layer line is approximated by a sinusoid to estimate its parameters and to determine the spatial position of the cut plane. Approximation is done using a pattern search algorithm in the form of the command *patternsearch* [20].
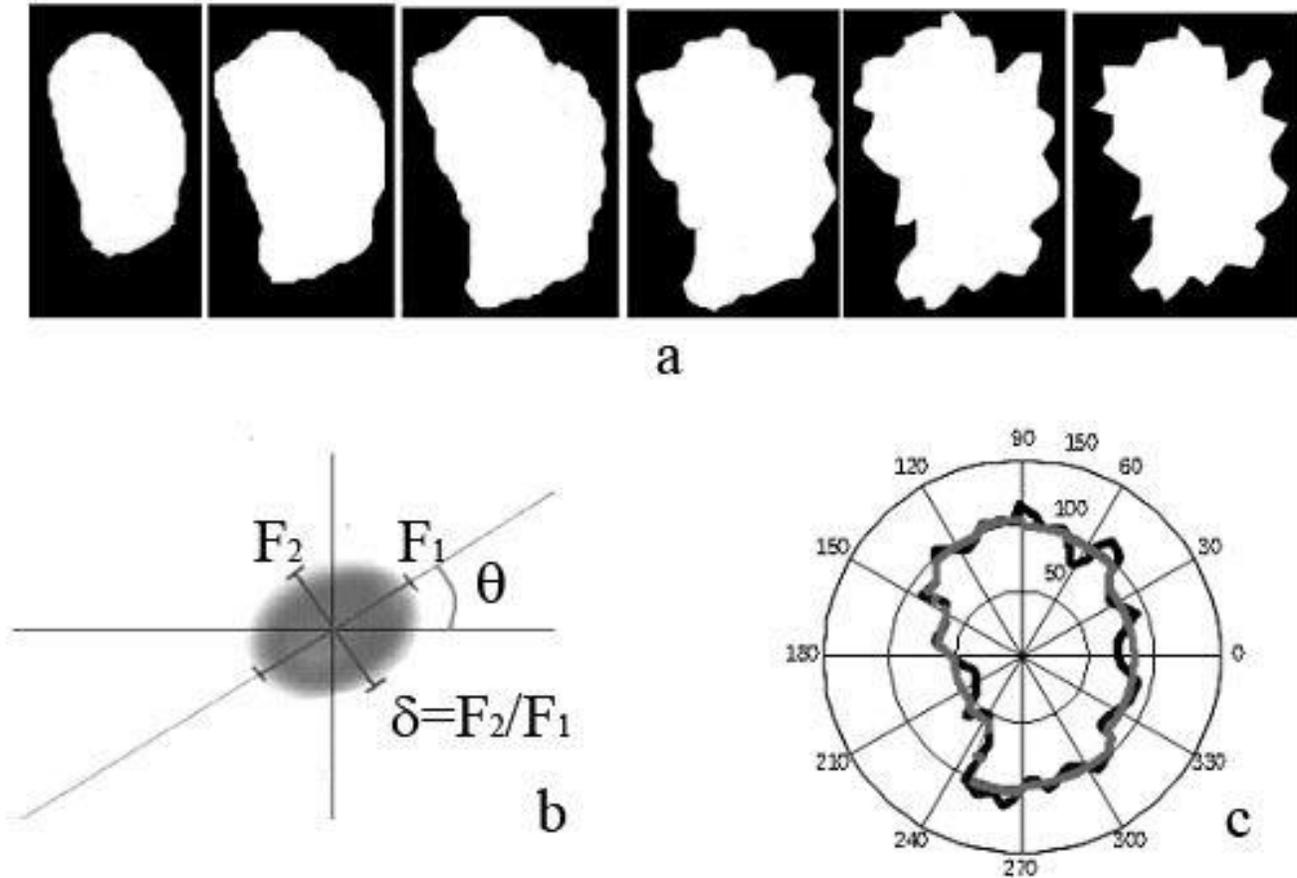

Fig.6 Grain analysis: mineral grains showing various degrees of roundness (a), grain shape and orientation parameters in the main component method (b), variability of grain boundaries indicated by deviation from the curve obtained by smoothing with a median filter.

IV. DISCUSSION

Let us now discuss the advantages and disadvantages of the software-hardware complex and the ways of its possible updating. The executive device for scanning drill cores is small and light. Owing to its light-weight design and a simple reliable control unit, it can be used in the field.

Its version with a fixed drill core, in which one quantisized step motor, characterized by a smaller power consumption for moving a light ring with cameras in comparison with power consumption for the rotation of a massive drill core, is better than other versions. Simultaneous photography of various surface zones of a drill core in this version of the device decreases the time taken for formation of drill core scan from about 20-30 minutes in a conventional version to 2-3 minutes,

and a scan of better quality is obtained (Fig.3).

To support long massive drill cores, which can be destroyed because they are heavy, an extra support is needed. Changing drill cores manually in both versions of the executive device takes a few minutes. Scanning can be accelerated and the complex can be made fully autonomous by automating photography and mounting operations.

A 3D model of a scan adequately presents a drill core in volumetric form commonly dealt with by geologists. Using animation and graphic MATLAB functions, one can impart dynamic properties to the model, enlarge its individual fragments and make the model approach, move away, rotate and become contrasting.

The clusterization method *kmeans*, employed for estimating the mineral composition of a drill core, has one disadvantage: the *a priori* unknown number of colour clusters is preset.

Algorithms without this disadvantage, e.g. a mining clusterization algorithm operated by the command *subcluct*, seem more suitable for estimation. The different colors of the numerous varieties of one mineral and the similar colors of different minerals make recognition complicated. The indistinct clusterization algorithm *cmeans* and *fcm* which takes into account that a pixel belongs to two or more clusters, could probably give better results than *kmeans*.

The method for identifying minerals and rocks from infrared spectra, employed for the remote sounding of the Earth, could be useful [21].

When a drill core is not illuminated uniformly and its lateral surface is not smooth, the scan obtained is granular and small mineral grains prevail. Excess granularity can be eliminated by additional blurring of the scan.

V. CONCLUSION

The software-hardware complex, designed for scanning the lateral surfaces of drill cores, has a high speed, high spatial and spectral resolutions, a small size and weight and a low power consumption. Scan constituents are identified by their composition, shape and size and their parameters are estimated quantitatively using analytical algorithms. The volume of the memory occupied by the scan of a stored drill core can be decreased by three orders of magnitude by compressing the scan by means of wavelets without deteriorating scan quality [22, 23].

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