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Mission to Mars: Adaptive Identifier for the Solution of Inverse Optical Metrology Tasks

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Abstract A human mission to Mars requires the solution of many problems that mainly linked to the safety of life, the reliable operational control of drinking water as well as health care. The availability of liquid fuels is also an important issue since the existing tools cannot fully provide the required liquid fuels quantities for the mission return journey. This paper presents the development of new methods and technology for reliable, operational, and with high availability chemical analysis of liquid solutions of various types. This technology is based on the employment of optical sensors (such as the multi-channel spectrophotometers or spectroellipsometers and microwave radiometers) and the development of a database of spectral images for typical liquid solutions that could be the objects of life on Mars. This database exploits the adaptive recognition of optical images of liquids using specific algorithms that are based on spectral analysis, cluster analysis and methods for solving the inverse optical metrology tasks.

Keywords Liquid solutions · Mars · GIMS technology · Spectroellipsometers

1 Introduction

Various types of spacecrafts for manned mission to Mars have been discussed in USA, Europe, Russia, China and India. Implementation of such a mission implies utilization of specific system that includes four functional sections such as spaceship, interplanetary

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space-tug, and two landing systems (e.g., Krimigis et al. 1977, 1999; Krimigis and Decker 2015). A Martian mission is planned to have duration of about 2.5 years although this issue turns out to be more complicated than was considered earlier.

Mars is under investigation for millennia because, among other reasons, every 2 years it is close enough to Earth and thus visible in the night sky. The atmosphere of Mars is thin compared to that of Earth's (its atmospheric pressure is about 1 % of the Earth's at sea level) and therefore liquid water is very rare on its surface. The atmospheric greenhouse effect (Kondratyev and Varotsos 1995a, b, 1996; Varotsos 2002; Varotsos et al. 2006, 2007, 2013a, b, 2014, 2015) is present given that the Martian atmosphere is mostly composed of CO_2 (96 %) being also quite dusty due to the presence of particulates of about 1.5 μm in diameter. Remarkably significant amounts of CH_4 (30 ppb) have also been observed in the Martian atmosphere. The mean surface temperature of Mars is much lower than what we experience on Earth (mainly due to its greater distance from the Sun), i.e., about −46 °C, reaching a low of −143 °C over the poles in wintertime, and a high of 35 °C during summer at the equator (Cracknell and Varotsos 2011; Efstathiou et al. 2011; Tzanis and Varotsos 2008; Varotsos and Cracknell 2004; Varotsos and Kirk-Davidoff 2006).

National Aeronautics and Space Administration (NASA) claims that a Mars mission can be carried out in 2030, exploiting Moon (NASA 2015). In this context, various designs of future Mars mission have been proposed. For example, Mission—Mars One—involves landing humans on Mars in April 2025 with the following people landings in 2027 and 2035 (http://www.mars-one.com/). These three steps will enable us to equip the living base and preparing reliable conditions for habitation. Human settlement of Mars, as followed from this project, will allow permanent human colony with long period of residency.

European Space Agency (ESA) has formed an Aurora program whose aim is a human mission to Mars in 2033. This program is related to similar programs of NASA, China and India. In any way, human mission to Mars requires solution of numerous scientific, technical and medical issues (Schulze-Makuch et al. 2008). Of course, an important issue is to guarantee the safety of the crew including their drinking water (Krapivin et al. 2014a, b; Sun et al. 2013). The water that exists on Mars' surface is likely to be pure enough for human needs. But the microbial and chemical structure of the Martian water is uncertain (Aseyev 2001; Baker 2001, 2007; Mahaney and Dohm 2010). The Martian climate is hospitable to primitive bacterial-like life. Although the water on the Martian surface is in a frozen phase, it is assumed that liquid water exists below the surface of the planet and in considerable quantities in the polar caps (Christensen 2006). Recently, new findings from NASA revealed that liquid water is present seasonally on Mars surface. As these findings are very recent, there is a lot of research to be done in order to trace its sources and gather data about its chemistry (Ojha et al. 2015).

Therefore, the crucial problem with the drinking water on Mars is its pumping, making use of new non-traditional tools (Dohm et al. 2008; Heldmann et al. 2005). It is known that Red Planet contains a wealth of water locked in ice. The extracted water should be diagnosed for assessing its quality and usefulness for its further use. This paper proposes a simple and reliable tool for solving this problem.

2 A New Diagnostic Tool for Detection of Liquid Solutions

2.1 Instrumental Technology

During the last years, optical and microwave devices were used intensively for the investigation of the characteristics of liquid and solid media. Spectroellipsometry, in particular, is considered the cutting edge of optical polarization. The establishment of multi-polarization optical instruments and employment of spectroellipsometric technology is extremely important for real-time ecological monitoring of the aquatic environment. Spectroellipsometric instruments can make highly accurate measurements, while their multi-channel observations in an aqueous environment provide the basis for the implementation of modern algorithms specialized on recognizing and identifying pollutants. The multi-channel spectrophotometers and spectroellipsometers deliver spectral images of test objects with high speed and accuracy. The use of different algorithms and models in processing images allows adaptive identification of liquid solution composition and is the major difference from conventional approaches (Krapivin et al. 2012a, b).

Combined application of instrumental tools and software for the operational monitoring of the water even on Earth was insufficiently developed because of the complexity of the monitoring system. Krapivin et al. (2014a) proposed a new global technology for solving these tasks based on the polarimeters precision and training algorithms for recognition of spectral images.

Spectral measurements of the water content provide information on the use of appropriate algorithms and models for the identification and recognition of the water pollutants (Krapivin et al. 2015). This is the first time that the combined use of spectroellipsometry and microwave measurements in real-time and data processing methods have been made in different versions of the multi-functional adaptive information-modeling system (MFAIMS). The latter is a principal scheme which is shown in Figs. 1, 2, 3, 4, 5, 6 and 7.

The MFAIMS versions considered here enable to assess liquid solutions. More specifically, MFAIMS-128 and MFAIMS-35 can be accommodated to the measurements in laboratory conditions. The tank filled with liquid sample is placed in the window cuvette of MFAIMS. In particular, both MFAIMS-8 (which uses sunlight) and MFAIMS-512 versions can be used in the field and laboratory measurements. In more detail, measurement procedure includes both the recording light characteristics with its passage through liquids and the environment brightness. Of course, a suitable algorithm is used for forming a final spectral image of the liquid sample. Sky-light adapter is used, in particular, when measurements are made on-site. The MFAIMS-512 which is a global tool can be used both in the laboratory and field measurements by means of an array of LEDs and digital light sensors in liquid environment. It should be noted that the microwave measurements extend the MFAIMS database, allow the treatment of problems related to the detection of pollutants in the surface water and classify the surfaces of frozen areas (Mkrtchyan and Krapivin 2013).

A series of long-term hydrochemical experiments have concluded that the use of different versions of MFAIMS allows saving time and other resources to obtain detailed assessments of water quality for various tanks located in different climatic zones (Krapivin et al. 2008, 2012, 2013; Mkrtchyan et al. 2013). As the MFAIMS learning procedure, through the enrichment of its database with spectral etalons of different water samples, is developed, water chemical analysis during hydrochemical investigations conducted in remote regions will be made unnecessary. The presence of MFAIMS as special device on the spaceship board will enable the crew to have reliable and operational control of drinking water, liquid medical solutions and liquid fuel quality. Such problem-oriented devices can be synthesized in the Earth's conditions using additional experiments on the International Space Station in order to examine deeper how the lack of gravity affect system's performance.

In this context, the use of an achromatic compensator on the basis of Fresnel rhomb made of fused quartz enhances the precision of measurements (Perov et al. 1994). This

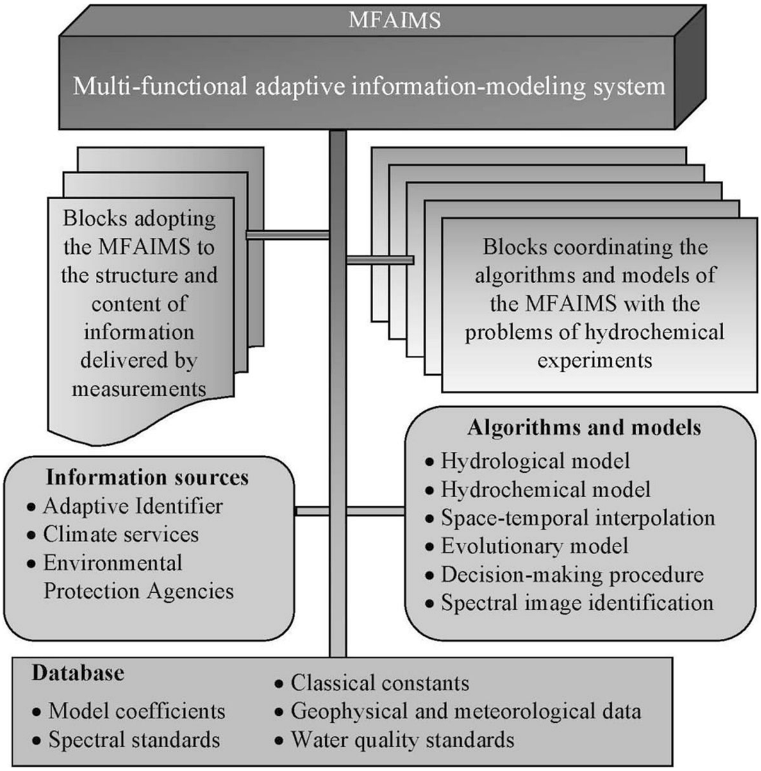

Fig. 1 Conceptual structure of multi-functional adaptive information-modeling system for hydrochemical monitoring

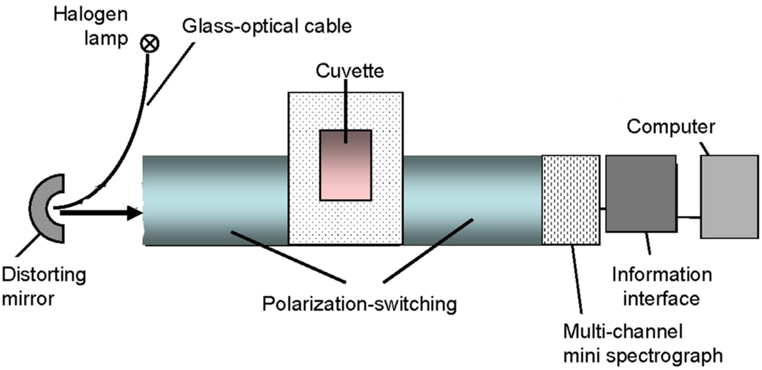

Fig. 2 Principal scheme of the optical system based on high precision real-time 128-wavelengths spectroscopic ellipsometer with binary polarization modulation. The OS characteristics are shown in Table 6. Real MFAIMS-128 version is shown in Fig. 3

kind of compensator is used in the presented system. The microwave system, illustrated in Fig. 7, is used for measuring geophysical parameters and diagnosing the water or the surface state of the ice (Krapivin et al. 2015).

Fig. 3 The MFAIMS-128 based on the 128-channel spectroellipsometer and oriented to the laboratory analysis of liquid samples

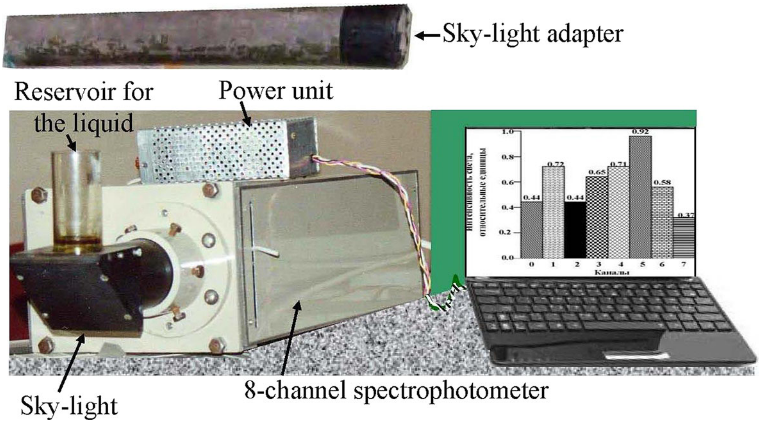

Fig. 4 Global version of the MFAIMS based on 8-channel spectrophotometer (MFAIMS-8) and fragment of its interface

Fig. 5 The MFAIMS based on the 35-channel spectroellipsometer (MFAIMS-35)

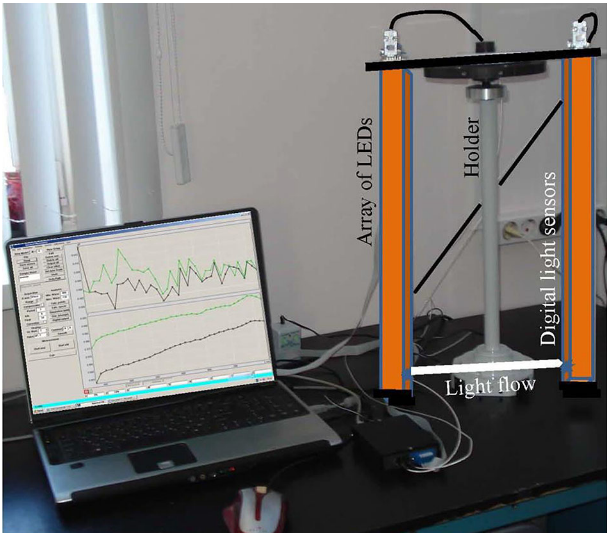

Fig. 6 Principal structure of the 512-channel MFAIMS (MFAIMS-512). LEDs are light-emitting diodes

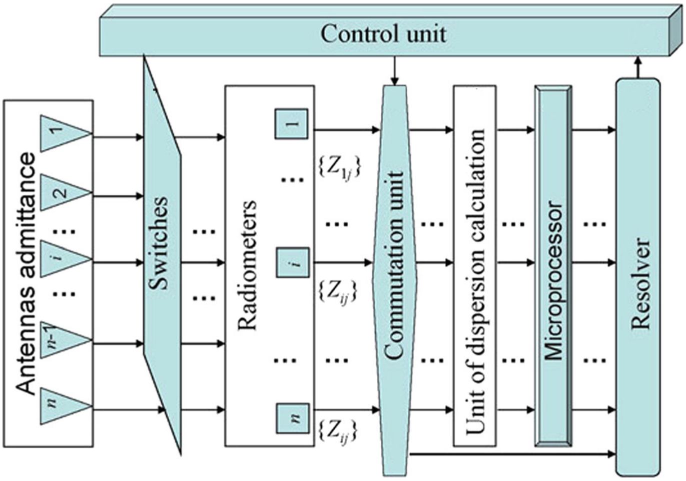

Fig. 7 An arrangement of multi-channel microwave system (MS) to measure the geophysical and hydrochemical parameters. *Notation Zij*—is radio-brightness temperature of studied object delivered by the *i*-th channel at the *j*-th time moment. Real versions of the MFAIMS-MS are mainly realized with the combined use of radiometers by wavelengths of 0.8, 1.35, 2.25, 5.5, 6, 8.5, 18, and 21

2.2 Multi-Functional Adaptive Information-Modeling System

Optical and microwave methods employed by MFAIMS allow a wide range of investigations of liquid solutions. Meanwhile, the adaptive information systems provide information on solution characteristics which is limited in space and time. For example, complex analysis of water system functioning on large area needs a common use of instrumental and ecoinformatics tools including specific models and data processing algorithms. Such composites ensure the success of diagnostic water systems. A problem of the complexity of the operational multi-aspect diagnostics of water quality and hydrochemical system state is specified by its spatial heterogeneity and presence of physical, chemical and biological factors affecting water quality.

Therefore, MFAIMS is synthesized to solve the above mentioned problem of complex diagnosis of hydrochemical system (i.e., Fig. 6). In this context, the realization of the conceptual structure shown in Fig. 1 implemented as defined by the MFAIMS versions based on the GIMS technology (GIMS = Geographical Information System (GIS) + - Model) (Krapivin and Shutko 2012). A balanced use of instrumental, model and algorithmic tools gives significant economy of time and financial allocations. The GIMS technology supports the optimal distribution of the sampling points within the region of the hydrochemical system.

Figure 8 illustrates special MFAIMS structure with a detailed description of various blocks. Database information level consists of series of subject identifiers of hydrochemical system spatial elements having geographical coordinates (φ, λ) and pixel structure $\Delta\varphi \times \Delta\lambda$, where φ and λ are latitude and longitude, respectively.

It should be kept in mind that the basic functions of the MFAIMS consist in implementing the following actions:

- Reduction in the unique system of spatial information handled by different sources: geographical maps, satellite images, remote sensing and in-site measurements.

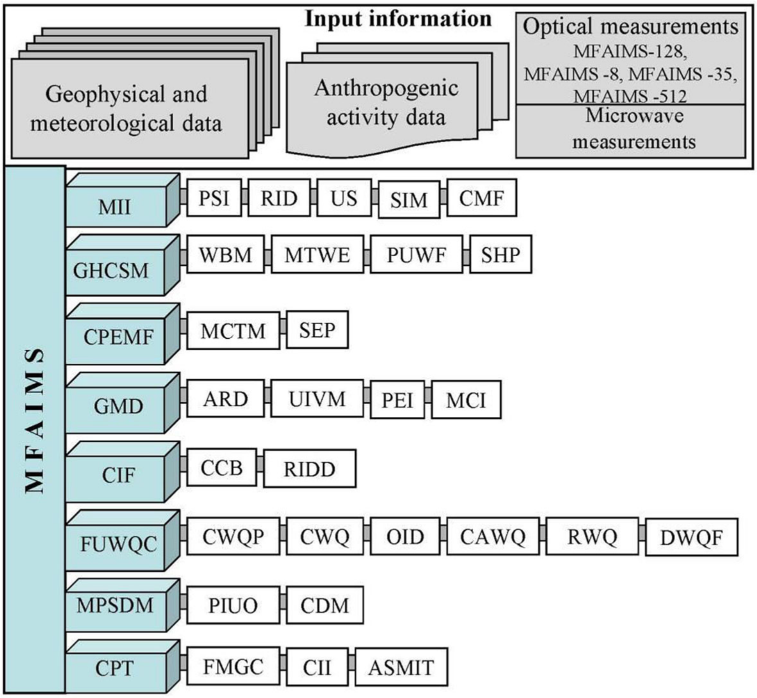

Fig. 8 Functional structure of the MFAIMS blocks a description of which is given in Tables 2 and 3

- Creation of geometrical description of land surface within the compatible topological structures.
- Tightening the series of models and software for the transformation between the vector and expanded data.
- Overcoming uncertainties information arising from the assessment of water quality.
- Supporting the coordination of geophysical and geochemical characteristics of the water system for each spatial level.
- Synthesis of symbolic map scheme for the distribution of environmental characteristics.
- Forecasting the water system evolution with classification of its phases and detection of its critical states.

One of the fairly complex tasks of hydrophysical and hydrochemical surveys is the necessity to overcome the non-removable information uncertainty arising from the areas that are inaccessible for making measurements and when existing data are highly non-steady state. In this regard, the problems arising are solved by the evolutionary technology held in the PIUO block, where adaptive selection of an appropriate model is implemented basing on the available prehistory that cannot satisfy the stationary conditions. Blocks UIVM and ARD help to identify the data provided by external sources. This function of the MFAIMS is very important for the Martian conditions.

Obviously, the water cycling in the Martian geologic past and its present state has changed. In addition, the parameterization of the hydrological cycle on Earth and Mars has significant differences (Machtoub 2012). Unlike the Earth, the lack of basic information on the currently available resources of water on Mars is confusing. Nevertheless, empirical approaches and theoretical principles of geology are common to both Earth and Mars. Therefore, the parameterization of the water cycling on these planets can be performed in a single theoretical mode (Tables 1, 2, 3).

MFAIMS block sets perform the function of the expert system of adaptive identification of liquid solutions. The update and expansion of the database of spectral images of liquid solutions is a central element of MFAIMS. Block CDM provides decision-making procedure that is based on specific algorithms for the recognition of spectral images or the

Table 1 Basic characteristics of different versions of the MFAIMS

Parameter	Value			
	MFAIMS-128	MFAIMS-8	MFAIMS-35	MFAIMS-512
Spectral range (nm)	380–930	400–740	380–930	360–800
Minimal measurement time (s)	0.5	1.0	0.6	3.0
Precision in		0.05		
Psi	0.003	–	0.003	0.003
Delta	0.01	–	0.01	0.01
Polarization rotation angle (°)	0.001	–	0.001	0.001
Long-term stability (°)	0.01	0.05	0.01	0.01
Weight of measuring device (kg)	4.0	5.0	4.5	3.0
Polarization block	2.0	–	2.3	1.5
Analyzer block	2.0	–	2.2	1.5

Table 2 The MFAIMS first level blocks

Block	Block functions
MII	Multipurpose information interface
GHCSM	Generation of the hydrological cycle simulation model. Management by models and algorithms for the description of hydrophysical, hydrochemical and hydrological processes
CPEMF	Control of the parameterization of the energy and matter flows in the hydrochemical system. Realization of the transformation mechanisms for chemical components in the water medium
GMD	Generation of the MFAIMS database taking into account possible mechanisms of the water mining on Mars
CIF	Control of information flows between the MFAIMS blocks
FUWQC	Formation and using the water quality criteria
MPSDM	Management by the procedures of statistical decision makings
CPT	Control of the phase transitions in hydrophysical system

solution of spectroellipsometry inverse task. In this case, the following decisions are possible:

- Liquid corresponds to a standard quality accepted for use.
- Liquid does not correspond to the standard quality accepted for use.
- Concentration of chemicals in the controlled liquid is given by tables, curves or maps depending on the operator demands.

A variety of possible situations when water quality assessment is needed depends on many conditions both on Earth and Mars. Functional and block structure of MFAIMS allows modifications in minimal structural intervention. One of such modification can affect the blocks ASSIT or MCTM when user adds new algorithm or model. The MFAIMS functions were adapted to the following cases:

- The diagnostics of a single-component solution takes place through recognition algorithms for spectral images. In this case, the spectral image of a solution is presented by a single vector for MFAIMS-8 and MFAIMS-MS and by two vectors for MFAIMS-128, MFAIMS-35 and MFAIMS-512. The recognition task is solved by searching the nearest spectral images in the database and the subsequent interpolation between them.
- The diagnostics of a multi-component solution is performed by means of the inverse operations for optical and microwave ranges.

2.3 The MFAIMS Validation and Testing

The MFAIMS functions were controlled by comparing the actual solutions and their assessments by means of optical and microwave measurements during series of ecological expeditions in the following geographical areas:

- South Vietnam when water quality was assessed in rivers, reservoirs and South-China Sea. The spots of oil products, salt and other pollutants on the water surface were detected and identified. Sea water salinity in the delta areas of rivers was also assessed. The task of water quality control in Nuoc Ngot Lagoon was solved by means of using the MFAIMS functions (Krapivin et al. 2015).

Table 3 The MFAIMS second level blocks

Block	Block functions
PSI	Producing the subject identifiers for the MFAIMS adaptation to the hydrophysical system configuration taking into account of its geophysical and ecological characteristics
PEI	Perception of experimental information delivered by the MFAIMS with required scaling and recording to the database
RID	Realization of the interests to the database and servicing the regulation queries
US	User support under the choice and change of information interface
SIM	Synthesis of information maps for spatial distribution of the water quality on the hydrophysical object territory
MCI	Modification of the cartographic information scales delivered by the MFAIMS
CMF	Control of the MFAIMS functions. Coordination of information flows between the MFAIMS blocks. Detection of the defective inquiries and reports. Warning the incorrect or unallowed user operations. User help
DWQF	Detection of the water quality failure
WBM	Water balance model of the hydrological object (Krapivin et al. 2015)
MTWE	Model of the topographic water evolution
PUWF	Parameterization of the used water flows (Krapivin et al. 2015)
SHP	Simulation of the hydrophysical processes (Krapivin et al. 2015)
CWQP	Calculation of the water quality parameters
MCTM	Modeling the chemicals transformation mechanisms in the water environment (Kondratyev et al. 2002)
SEP	Simulation of the exchange processes on the boundaries of hydrophysical body (Nitu et al. 2013)
ASSIT	Algorithms for the solution of spectroellipsometry inverse tasks (Krapivin et al. 2014a)
UIVM	Updatable information about volumes and mixture of chemicals delivered to the environment by the anthropogenic processes and objects
ARD	An assessment of reliability of data delivered by external information sources
ASMIT	Algorithms for the solution of microwave inverse tasks (Krapivin and Shutko 2012)
RID	Reduction of information and data delivered by different sources to the unique standard
CCB	Co-ordination control of block inputs and outputs and their interfaces with database
CWQ	Control of the water quality realization
OID	Operative information documentation concerning the water medium quality
RWQ	Registration of the water quality analyses delivered by different tools
CAWQ	Complex assessment of the water quality. Formation of the water quality statistics
CDM	Choice of the decision-making procedure and its realization (Krapivin et al. 2015)
PIUO	Procedure of information uncertainty overcoming
FMGC	Forming the meteorological and geophysical characteristics in their dynamics
CII	Calculation of instability indicators for hydrophysical system

- Middle Asia when the diagnostics tasks were performed for the Aral Sea and Kara-Bogaz-Gol Gulf. The MFAIMS functions allow the classification of phase states of these reservoirs with the classification by the water, moist and dry salt. This can be realized in the Martian conditions in detecting ground water or classification of surface formations (Krapivin et al. 2015).

In addition, measurements were taken in the laboratory, using a number of specific solutions under different climatic conditions. A learning process refers to the configuration database of spectral patterns by digitizing the chemical concentration data (i.e., by ten sections in the range up to nontransparent state-saturated solution). For example, the solubility of the calcium sulfate is limited by 0.2036 g per 100 ml of water at 20 °C. Certain amounts of $CaSO_4$ were discovered on Mars in a vein of the surface. Barium sulfate and hydrogen oxalate is poorly soluble, maximal solubility of which is 0.0015 and 0.107 g/l, respectively, at 18 °C. The MFAIMS precision was assessed as a result of recognition and concentration evaluation for new water solution. Several new water solutions were considered, and final assessment of the MFAIMS precision was made by averaging the results. Tables 4, 5 and 6 describe the MFAIMS precision.

Table 4 The precision of the MFAIMS different versions under the diagnostics of single-component liquid solutions

Water solution	The MFAIMS version and its error (%)			
	MFAIMS-128	MFAIMS-8	MFAIMS-35	MFAIMS-512
$CuSO_4$	7.1	12.0	8.2	4.3
NaCl	6.5	9.1	7.3	2.7
$CaCl_2$	4.4	6.7	5.3	1.9
$AlCl_3$	4.6	6.8	6.1	1.8
$NaHCO_3$	5.4	8.7	7.2	2.3
NH_4OH	5.3	7.9	6.6	2.1
$ZnSO_4$	4.9	8.1	5.1	1.9
Furacilin	4.4	6.3	4.6	1.7
Bifidumbacterium	3.7	9.3	4.1	2.1
Potassium iodine	5.2	8.8	3.9	1.8
Nitrofural	5.1	8.7	5.4	1.8
$Al(NO_3)_3$	4.5	8.6	5.5	1.9
MgF_2	6.7	11.3	7.1	3.1
Na_3PO_4	3.3	10.2	3.9	2.7
$BaSO_4$	6.2	7.8	6.6	1.8
HgC_2O_4	5.6	8.5	6.3	1.3
$CaSO_4$	4.5	9.5	5.2	1.1
Propolis	3.8	4.9	5.0	0.9

Table 5 The precision of the MFAIMS different versions under the diagnostics of multi-component liquid solutions

Water solution	The MFAIMS version and its error (%)			
	MFAIMS-128	MFAIMS-8	MFAIMS-35	MFAIMS-512
$HNO_3 + C_6H_5OH + H_2S$	12.9	14.1	14.2	8.9
Na + Cu + Zn + Mn + glucose	14.3	15.2	14.4	9.3
$H_2S_2O_3 + SCl_2 + H_2SO_4$	13.1	14.9	13.8	7.6
$P_2H_4 + H_3PO_2 + PCl_3$	14.4	15.5	12.9	8.3
$P_4O_{10} + HNO_3 + H_3PO_4$	12.6	13.7	13.1	7.7

Table 6 Comparative results of chemical analysis and measurements by means of the MFAIMS of water in Nuoc Ngot Lagoon junction (dry season, low-tide)

Chemical component	On-situ measurement (ppm)	MFAIMS-8 (ppm)	Error %	MFAIMS-35 (ppm)	Error %
$CaCO_3$	110.01	121.45	10.4	103.74	5.7
PO_4^{-3}	0.01	0.0115	15.2	0.0108	8.1
HCO_4^-	134.23	121.08	9.8	140.4	4.6
SO_4^{-2}	1818.83	1675.14	7.9	1738.8	4.4
NH_4^+	0.009	0.0103	14.6	0.0097	7.8
Mg^{+2}	534.86	578.18	8.1	507.58	5.1
Ca^{+2}	190.38	172.87	9.2	199.71	4.9

3 Conclusions

The MFAIMS structure described in this paper may be produced as a set of compact devices learned to determine the limited range of solutions including various solvents. The use of these devices to the outer-space conditions needs series of theoretical and experimental investigations. The most important problem is the study of variations in spectral images produced by transfer from the Earth's conditions to the Mars environment (Krapivin et al. 2014b).

Liquids change their physical parameters deriving from the transfer from Earth to Mars. In the optical part of the spectrum, the spectral characteristics of the liquid can be changed in accordance with current Martian environmental conditions, also. Reconciling the use of optical and microwave sensing is best suited for diagnosis of liquid on Mars. The MFAIMS functions allow such possibility.

Implementation of the MFAIMS versions and the related devices will enable us to solve a wide range of diagnostic functions for liquid solutions from both contacts and remote sensing methods. The MFAIMS-128- and MFAIMS-35-oriented measurements when used with well-known optical spectrum. In this case, the stability of this spectrum is significant. The MFAIMS-8 and MFAIMS-512 are used both in cell and locally when sky-light adapter or LED array and digital light sensors are submerged in liquid or are directed at its surface. Undoubtedly, there are questions about the circulation of liquid water on Mars. The proposed tool has the necessary structure, allowing the evaluation of the quality of water in Martian conditions.

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