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Oleg G. Dobroserdov
Southwest State University, Faculty of Construction and Architecture, Department of Real Estate Management, Mining, Kursk, Russian Federation

Sergey N. Frolov
Southwest State University, Faculty of Construction and Architecture, Department of Real Estate Management, Mining, Kursk, Russian Federation

Aleksey N. Shitov
Southwest State University, Faculty of Construction and Architecture, Department of Real Estate Management, Mining, Kursk, Russian Federation

Ludmila A. Semenova
Southwest State University, Faculty of Construction and Architecture, Department of Real Estate Management, Mining, Kursk, Russian Federation

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MEASUREMENT AND EVALUATION OF THE EARTH'S MAGNETIC FIELD PARAMETERS USING THE ECUADOR-UTE SMALL CAMERAS (HC1PX)

Oleg G. Dobroserdov, Sergey N. Frolov, Aleksey N. Schitov, Ludmila A. Semenova*
Southwest State University, Faculty of Construction and Architecture, Department of Real Estate Management, Mining, Kursk, Russian Federation

The paper deals with the use of the small spacecraft ECUADOR-UTE (HC1PX) designed to conduct space experiments in autonomous flight conditions and, in particular, to measure the Earth's electromagnetic field and study the ionosphere. The spacecraft has a built-in target load module, including a precision magnetometer that measures the Earth's magnetic field. The measurement results are used to study the properties and state of the circumterranean environment including magnetic anomalies. The latter may indicate certain tectonic structures in the sedimentary stratum, which are indicators of oil and gas, and magnetic pole displacement processes. Measurement results can also be used for prediction and forecasting efforts in anomalous zones. The compiled analytical dependences for the anomalous zones can serve as a forecasting device when studying the magnetic tension of the Earth's geographic regions by means of a spacecraft. Measuring the magnetic anomalies of the Earth's surface is should prove necessary for factoring them in and developing national industries.

Key words: approximation, prediction, forecast, space experiment

INTRODUCTION

Mathematical models for measuring and evaluating the Earth's magnetic field are of extreme theoretical and applied importance. Precise knowledge of the components of the Earth's magnetic field is crucial both for navigation and metal and mineral exploration, including that of iron ore deposits. Studies of magnetic anomalies are closely connected to finding deposits of oil, natural gas, and other extractable resources, and can indirectly show provenance of certain metals. The well-established fact of a correlation between human health and proximity of a magnetic field makes its evaluation an urgent and up-to-date matter, turning it into an important medical and social problem.

The Earth's magnetic field makes it possible to orient the satellite in space. Especially relevant is the stabilization of the spacecraft with the help of magnetorker and gyrodines in a pre-known magnetic field located on the track of the satellite device. Knowing the magnetic field will allow you to stabilize the satellite in the most favorable areas of the Earth's magnetic field. The article [1] notes that the study of the Earth's magnetic field made it possible to diagnose radio interference and to correct the GPS/GLONASS signal during geomagnetic storms. The article also notes the adverse effect of a sharp change in the Earth's magnetic field on transformer substations and power transmission lines.

In modern society, the need for geomagnetic measurements is increasing (this task is especially relevant in connection with the implementation of various programs for the development of the Arctic). In connection with the development of ground-based measurement points and the launch of special geomagnetic satellites, the volume of data is increasing avalanche-like. This is evidenced by the report "Geoinformatics and observations of the Earth's magnetic field: the Russian segment" at the meeting of the Presidium of the Russian Academy of Sciences on April 28, 2015, presented by Academician, Director of the Geophysical Center of the Russian Academy of Sciences Alexey Germanovich Gvishiani.

The most famous magnetic anomalous zone of Russia is the Kursk Magnetic Anomaly (KMA), the world's largest iron ore basin. The area of the KMA reaches 160 km^2, with its geomagnetic field intensity exceeding the norm up to three times in some areas.

Another magnetic anomalous zone, exceeding 8km^2 in the Southern Hemisphere, is referred to as Brazilian/South American Magnetic Anomaly, or BMA (Figure 1).

Figure 1 also shows the mantle stream area beneath South America and the South Atlantic. Due to a number of general physical reasons, such as the direction of the mantle stream, higher radiation levels over the magnetic anomaly, etc., the magnetic field is significantly weaker in this area compared to its regular level.

These anomalies are systematic and may serve as a ba-

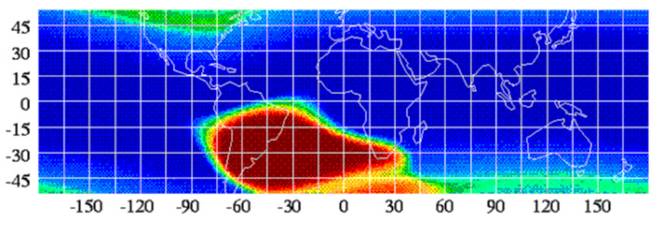

Figure 1: The outline of the Brazilian Magnetic Anomaly (BMA)

*a.n.schitov@mail.ru

sis and reference point for studying physical, geological, and other objective laws and patterns, as well as for calculating predictions in resource exploration.

Thus, the article by Yu. N. Kirichenko "The impact of the environment on the population's health in the iron ore deposits area of the Kursk region" presents statistics on the negative impact of the environment on the health of the population. Based on this article, the relevance of the problem posed by Yu. N.Kirichenkov in the issue of globalization and the accumulation of information about changes in the magnetic field for understanding the nature of the impact of KMA on the human body becomes obvious.

The paper deals with applying the informational and evaluative approach to the analytical descriptions of the patterns of fluctuations in the intensity of the magnetic field, as well as using the two anomalies in question as a reference for exploring other anomalous zones with identical or similar characteristics [2, 3].

PROBLEM STATEMENT

One problem the paper focuses upon is drawing highly accurate magnetic maps with contour lines of identical magnetic-field intensity. It should be noted that the Earth's magnetic field is constantly being refined, and the map of the Earth's magnetic fields can be used both for studying the favourable habitat of flora and fauna, and for studying minerals, as well as for the needs of the military-industrial sector [4].

In the work of Agajanyan N. A., Makarova I. I. "The Earth's magnetic field and the human body" it is stated that the effect of magnetic fields on biological objects during a long time caused noises in the cells of living organisms themselves. Nevertheless, biological objects are complex open nonlinear systems, in the reaction of which their own state can be a decisive factor, and not only the influence of the Earth's magnetic field. Thus, it should be noted that in very few cases there is a simple reaction of increasing or decreasing the values of physiological parameters under geomagnetic disturbances of different intensity. Most often, not directed reactions are observed, but an increase, then a decrease, and again an increase, that is, complex nonlinear processes, the study of which is an urgent task [5].

For a spacecraft to be used for mapping, it needs high stabilization action at any given moment in time, as well as a high-precision measuring apparatus. The other problem is connected to obtaining and evaluating mean values of the magnetic fields across the geographic areas on the Earth's surface in order to search for and/or predict magnetic anomalous zones. This requires big statistical data arrays on magnetic field fluctuations rather than precision. Such statistics would allow for obtaining generalized analytical evaluations of the magnetic field that could serve as the base for statistical analysis and, consequently, for search in previously unexplored geographic areas. The aim of the search would be predicting and forecasting magnetic anomalies and calculating deviations of current measurements from theoretical ones.

The second problem can be effectively addressed by means of a small unmanned spacecraft whose measuring apparatus does not have high precision. In studies of the Earth's magnetic field, much attention is paid to satellite and spacecraft data.

Experimental evidence on measuring the magnetic field in anomalous zones on the Earth's surface shows that use of small spacecraft (SS) to monitor it is quite plausible. The spacecraft used by the team, ECUADOR-UTE, has the following equipment:

1. A sensor for measuring the Earth's electromagnetic field:
- measuring range-from - 4800...+4800 μT;
- quantization scale - 14 bits;
- measurement sensitivity-0.6 μT;
- display / calibrate data-from -500...+500 μT;
2. An SSTV and telemetry module (Figure 2):
- frequency range -437.05 MHz;
- maximum transmission power - 1W;
- radiation class - 16K0F3E;
- modulation-single-channel FMn;
- the transmission channel is half-duplex.

This article is concerned with one function of SS ECUADOR-UTE, namely with measuring the physical conditions of the Earth's magnetic field. To measure the Earth's magnetic field, a single magnetometer was installed on the ECUADOR-UTAH satellite, the measuring equipment of which was directed perpendicular to the Earth's surface to achieve greater accuracy. As a result of measuring the Earth's magnetic field during a single satellite orbit (ECUADOR-UTE), the information accumulated during a single satellite orbit around the Earth was transmitted to a ground point for data collection, processing and analysis. Other functions of this SS include but are not limited to space experiments such as evaluating parameters of vacuum, video and frequency-imaging transmission, network organisation for an SS fleet, and

Figure 2: SS ECUADOR-UTE (HC1PX), type CubeSat 3U

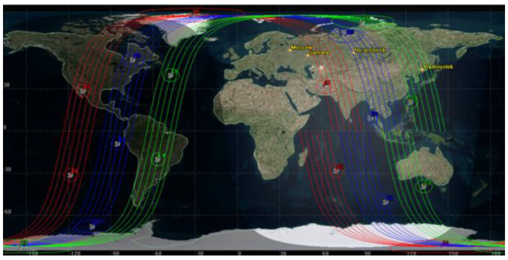

Figure 3: The orbit of the ECUADOR-UTE satellite

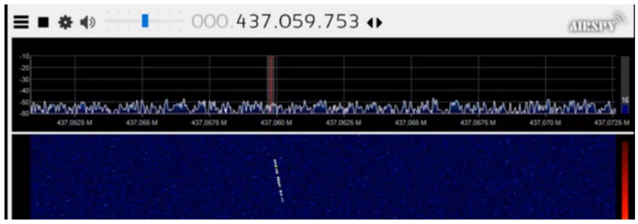

Figure 4: First signal reception of the HC1PX beacon (05.07.2019 12:13 UTC)

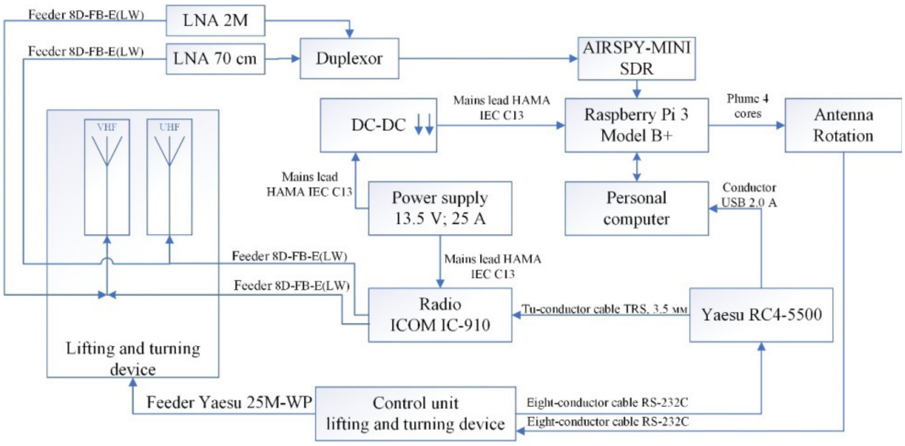

Figure 5: A chart diagram of the land station of amateur radio communications

data broadcasting [6, 7].

SSECUADOR-UTEwas launched on 5th July 2019 from the Vostochny Cosmodrome (Russian Far East) by means of the Soyuz 2.1b expendable launch vehicle, and was placed into the heliosynchronous orbit at the altitude of 530 km (Figure 3). Because the launch of a small spacecraft was carried out in automatic mode, the probability of its rotation is no more than 10%. Telemetry data obtained from Ecuador-UTE confirms the absence of satellite rotation [8, 9].

The parameters of the signal transmitted are as follows: transmitted signal: 437.05 MHz working frequency, FM modulation, 25 kHz channel bandwidth, modulated analogue waveform (mono). Telemetry uses the AX.25 analogue protocol with the DataStream rate of 1200 baud/s. Images are transmitted via the SSTV protocol in the BW12 format. The first communications session started at 12:13 UTC (Figure 4).

The telemetry was received by the land station of amateur radio communications that consisted of a spiral UHF antenna and a Yagi VHF aerial installed on a revolving gear, a low-noise amplifier, a duplexer, an SDR receiver, a transceiver, and a system on a chip. This manner of assembly enhances efficiency of communication with satellites by means of synchronizing reception and control procedures along with wider coverage of communication zones of synchronized ground-based observatories considered in the works (Frolova, 2019) (Figure 5) [10, 11].

During its second orbit pass, the ECUADOR-UTEsatellite transmitted telemetry data comprised of the vector of successive measurements of the Earth’s magnetic field with the 30 second interval (Figure 6). The data was recorded and processed via SDRSharand MULTIPSK software [12, 13].

For better visualization, the measurements were given in relative normalized units. As the SS ECUADOR-UTE was passing around the designated territory, the spacecraft’s measurements were obtained, processed, and trans-

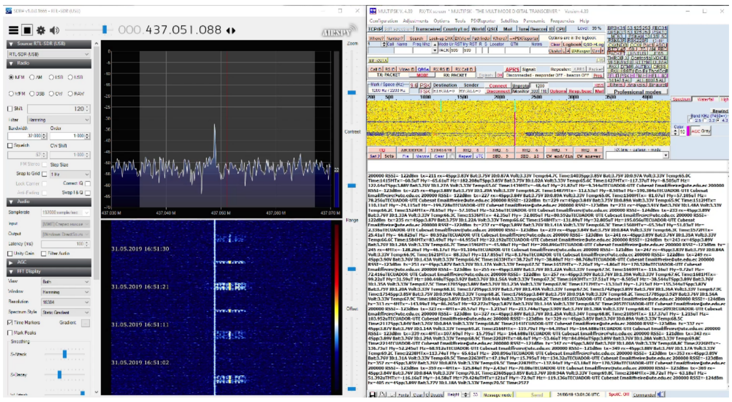

Figure 6: Telemetry data of the ECUADOR-UTE satellite

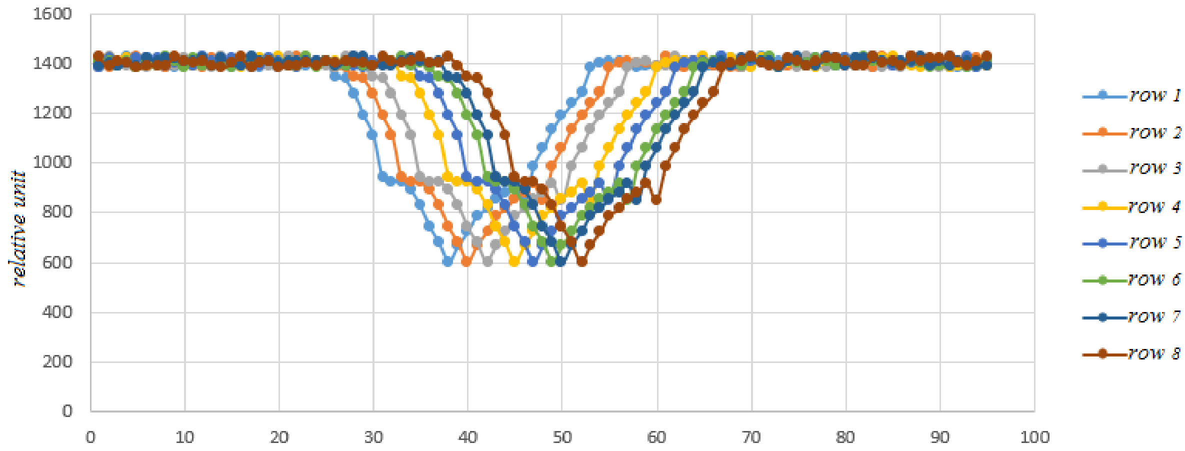

Figure 7: Fluctuations of the Earth's magnetic field on the South American Continent and in the Atlantic Ocean (BMA)

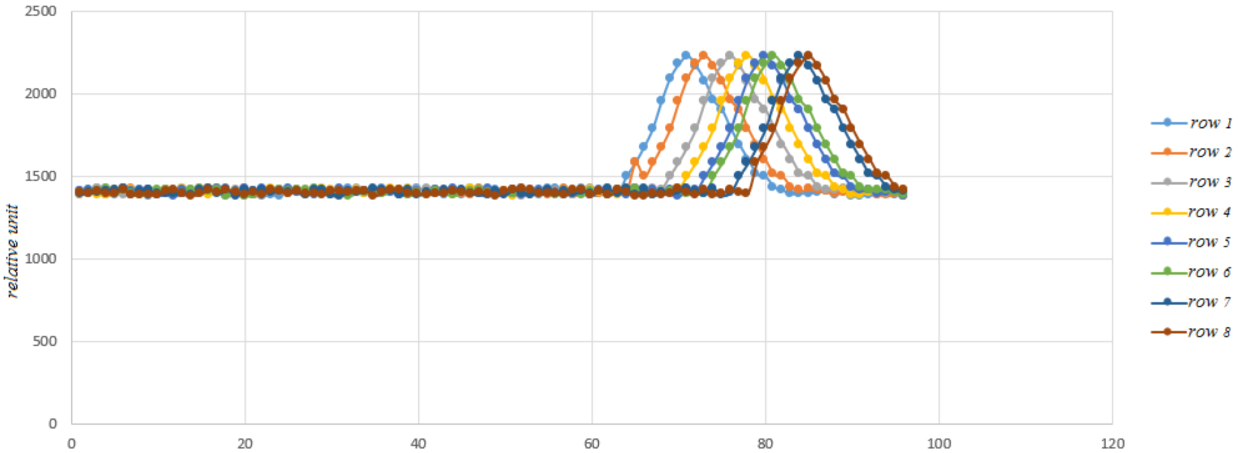

Figure 8: Data on the Earth's magnetic field in Russia's Central Black Soil Region (KMA)

formed into relative units for calculations' correctness.

Discussion and results

The graph on Figure 7 presents the Brazilian Magnetic Anomaly (BMA), which has an averaged second-order polynomial function calculated for it with data approximation (1):

$$y=8,4895x^2–431.6712x+7898.375 \quad (1)$$

Approximation validity was found via the determination coefficient R^2=0.8923.

The other anomalous zone analysed via the SS ECUADOR UTE was located in the Central Black Soil Region of Russia (Figure 8).

For this zone, a parabolic analytical pattern was revealed, also via data approximation. The determination coefficient value for it would be R^2=0.8346(2).

$$y=-22,671x^2+3435,7x–128087 \quad (2)$$

Unlike anomalous zones, regular areas of the Earth's surface varying between 3000 and 9000 km may be presented by an averaged linear function with the determination coefficient of R^2=0.5038(3).

$$y=0,0043x^4-0,515x^3+31,637x^2-975,11x+13291 \quad (3)$$

Based on the sum of orbit passes, an area of the most constant magnetic field values was selected, which is presented on Figure 9.

Studying the anomalous zones, namely KMA and BMA, calls for revealing patterns of presenting those zones as parabolic graphs. Consequently, their parabolic models are used as quite an accurate tool for prediction when

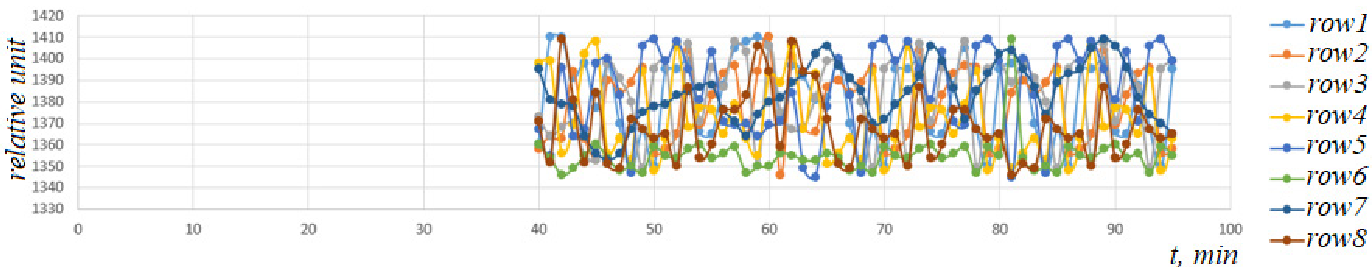

Figure 9: The selected area of the Earth's surface with the normal magnetic field levels

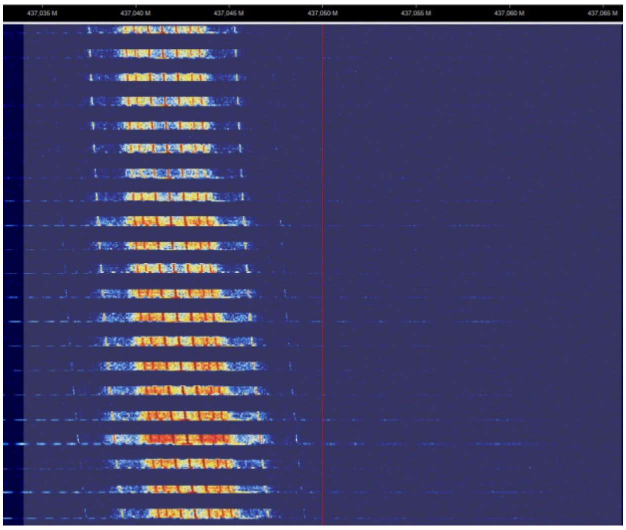

Figure 10: Spectre of telemetry broadcasting on 14th July, 219, 12:14 UTC

checking current data of magnetic intensity of previously unexplored areas of the Earth, which can be clarified using the tool used in the works (Zakharenkova, 2019).

Between 5th July, 2019 and 28th August, 2019, an two-week interval between communications sessions was established for efficient data retrieval (Figure 10).

The findings have led to the theoretical result of calculated equations for revealing and recognition of previously unknown magnetic anomalies, and automatic recognition models for magnetic intensity.

As a result of the measurement of KMA and BMA, a series of passes of the satellite device was performed, demonstrating the uniformity of the magnetic field effect on the satellite data collection system (sensor) over certain areas of the Earth's surface (the values of the magnetic field obtained during different passes of the satellite device over the same area at different times coincide, the variance tends to 0). The data obtained with the help of the Ecuadorian UTE satellite allows not only calculating the magnetic field, but also demonstrates the relevance of using small spacecraft to build maps of the magnetic field of the earth's surface.

CONCLUSION AND RECOMMENDATIONS

A small spacecraft flotilla of 4 satellites deployed on one orbit would be able to present data on the entire Earth's magnetic field in the span of 7 orbit passes within 24 hours as evidenced by the results (Shilenkova, 2012a, 2018b, Atakishcheva, 2020). This approach can be considered as the use of reconnaissance satellites (groups of satellites) to determine the anomalous zones of the Earth's surface and changes in the Earth's magnetic field over a certain period of time (up to 1 year). These measurements can allow us to accumulate information for building mathematical models and improving the on-board equipment of satellites for predicting and measuring the Earth's magnetic field. The cost characteristics of small spacecraft make it possible to refine the Earth's magnetic field by upgrading and refining the measuring equipment (due to the relatively short service life of the satellite) and to identify the dynamics of changes in the electromagnetic environment on the flora and fauna of a certain region of the Earth's surface.

That could enable researchers to obtain and analyse data on the magnetic field every 24 hours, making graphs of its fluctuations in time. This would result in defining the technique for generalized analytical evaluations of the magnetic field.

The functions presented above, which describe anomalous and non-anomalous zones of the Earth's surface, strongly suggest using satellites of the 3UCubeSat type for locating anomalous zones via automatic recognition techniques, partially considered in the works(Drone, 1993, Teterina, 2017 a, 2017 b, 2018 c).

It is evident that effects of ore deposits on anomalous magnetic fields are manifested as micromagnetic anomalies, areas with high-frequency magnetic fields of strongly contrasting amplitude superimposed over the background of smoothly changing mid- to low-frequency anomalies.

The experimental data and the mathematical functions calculated on that basis are sufficient for developing an anomalous zone location model that would enable locating new natural resource deposits. Studies of the zones located in this manner would open up new prospects in detection and prevention of harmful effects of magnetic fields with varying degrees of intensity, primarily those of the Kursk Magnetic Anomaly, on human body, using systems of artificial intelligence and the method of structural recognition of images presented in the works (Frolova, 2015, Titenko, 2009).

Studies of high-potential areas in the south-west of West Siberia show that manifestation of such zones over deposits of various types is quite unique. Specialized variation and spectral energetic analyses based on Fourier transformation enable distinction and high-quality presentation of micromagnetic anomalies, as well as formation of a complex prediction parameter conforming to the detection rate anomalies consistent with deposit location.

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