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Smart Station for Data Reception of the Earth Remote Sensing

Mykhaylo Palamar
Department of Devices and Control-Measurement Systems,
Information Technique and Intelligent Systems Research Laboratory
Ternopil National Technical University
Ukraine

1. Introduction

The technology of remote sensing (ERS) provides huge information resources and has the potential to influence the socio-economic development of both security and defence. However, the mass use of remote sensing technologies demands the creation of a network with the technical means of reception and online access to remote sensing data for consumers. The primary source of data for remote sensing is an aerial station (AS), with the reception of information coming from a spacecraft (SC). Typically, these stations are special objects (mainly military), intended to receive, process and disseminate remote sensing data.

For the effective use of ERS data, it is necessary to bring it closer to the end user. This requires universal compact antenna stations of a consumer class, including mobile ones.

This chapter reviews the principles, structures, models and analysis of various technical solutions and the key features, basic functions and control algorithms that are used to create universal automatic ASs (terminals with remote control) and software to control such ASs so as to get remote sensing information from the spacecraft.

The idea of intelligent "personal" aerial station for information receiving is offered proceeding from its function. Such station can be used by small groups or individual researchers directly engaged in contextual information processing i.e. university laboratories, scientific centers, and other organizations interested in such information.

The results of the author's practical experience in creation of remote sensing AS with different types of rotary support devices and with various diameters (from 3 to 12 m) of parabolic reflectors are given. Experimental results of operation of control systems of remote sensing stations using algorithms of artificial neural networks are presented.

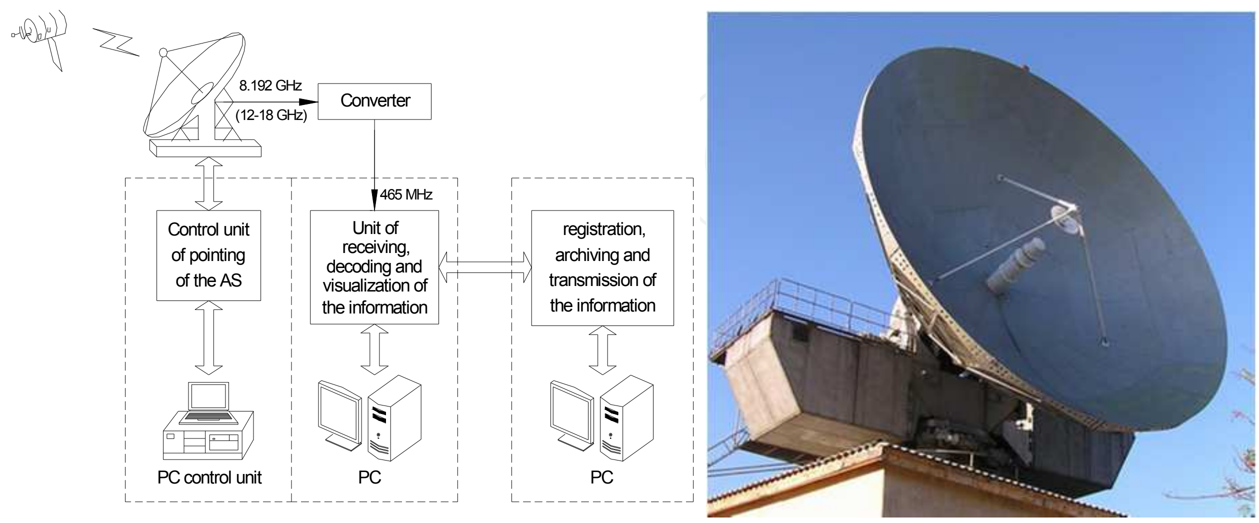
2. The structure and principle of the functioning of terrestrial antenna stations for remote sensing data reception

The following conditions are necessary for an ERS system to function:

1. Low-orbital satellites with filming and recording equipment onboard;

2. Onboard data transmitters via a radio channel;
3. Terrestrial antenna stations for data reception, its processing and distribution to users.

The general scheme of a satellite monitoring system is shown in Fig. 1.



a) Structure of ERS system b) Receiving ERS antenna

Fig. 1. General scheme of a satellite monitoring system (a). Receiving antenna where the reflector has a diameter of 12 m (b).

According to NASA reports at present 6130 artificial satellites are launched into space. 957 among them are operating on different Earth orbits. Nearly 7 % i.e. more than fifty of them are intended for remote sensing. Nearly 40 countries are directly involved in programmes involving satellite observations and their number is constantly growing. The trend is that the number of spacecraft is growing and the resolution of recharging equipment is increasing (several tens of cm). New technologies of satellite monitoring have appeared (e.g., the miniaturisation of equipment, the usage of micro- and nano-satellites, satellite clusters and the integration of different projects). University (students) satellites and those of other branch research organizations are being launched. New technologies of making survey of necessary territories ordered by customer are applied (Hnatyshyn & Shparyk, 2000).

Ground infrastructure remote sensing systems consist of centres receiving and processing data from spacecraft, with web portals to access the catalogues, archives and operational information from space. The necessary components are: the marketing of software products for thematic data processing systems and the training of qualified personnel.

High-sensitive antenna systems and equipment for reception, demodulation, the decoding of the electromagnetic microwaves from spacecraft and the allocation of the data streams that are encrypted in order to receive data from satellites are all also necessary.

The technology of ERS data reception is more difficult than data reception from geostationary satellites due to the need for tracking remote sensing spacecraft.

Antenna systems with hardware and software controls should automatically direct the focal axis of the reflector of the antenna system into a predictable location point for the spacecraft so as to ensure its tracking. The signals from the satellites are received by the antenna during the spacecraft's tracking.

The structure of the remote sensing antenna complex includes the following main blocks:

- A supporting-rotating device with a pointing mechanism;
- A reflector system mounted on a rotating part of the mechanism;
- A control system for pointing and tracking;
- A system for the receiving, decoding and visualisation of information;
- A system of registration, processing, archiving and the transmission of data.

Satellite trajectories - which are calculated for the next session - are loaded into the PC control unit in a table view before the session with the spacecraft. The control data includes codes for the antenna's angular position and velocity codes for the change. They are transferred to the high-level equipment of the antenna control system from the PC via a communication interface. The PC monitors the antenna position by broadcasting the angular coordinates received from the respective antenna sensors. Moreover, it is necessary to monitor the status of limit switches, the track time, speed and other parameters. The control system needs to be synchronised with a GPS time system in order to ensure the management of the antenna system in real-time.

Information is transmitted via the communication network to the computer after the session's end. The computer has to perform zero-level processing (unpacking the flow and binding the onboard time to terrestrial time) and referencing to geographical coordinates.

2.1 The concept of smart "personal" earth stations for remote sensing

As was noted in the studies of the India Space Department, more often than not remote sensing technology has not yet been effectively used, despite the whole complex of remote sensing satellites available for the country.

The main causes of this are the isolation of consumers from the remote sensing data processing centre, the lack of remote sensing receiving stations and the difficulties involved in gaining access to RS data. Moreover, the important factors are: an insufficient amount of software products and qualified staff in the field of contextual RS data processing, though partially this is a consequence of the reasons already addressed.

Currently, a mainly centralised access method for remote sensing information is used. This approach involves the receiving, processing and dissemination of data only through big centres for space information receiving, often involving military organisations. Such data centres can be compared with the big computer centres from the 1970s that acted as service providers for complex calculations on request. These were non-dynamic structures and ineffective for a wide range of customers. As such, the genuine active development and implementation of informational technologies into daily life began with the popularisation of personal computers, when a wide range of interested consumers became involved in working with information.

However, other technologies related to the distributed method of reception and processing of information are emerging. This information is received locally by organizations interested in such information by means of their own aerial terminals. In such cases the information reaches the user more quickly and more users can work on data processing and analysis concerning their subject-matter. To use this technology, it is necessary to provide users with inexpensive and easy-to-use 'personal' RS data receiving stations. Such stations can significantly change their activities in relation to a number of areas connected to the use of space informational technologies, as with the appearance of the PC.

Personal RS data receiving station is relatively cheap, automated, simple in use (including mobile version) host antenna station designed for use by groups directly engaged in concerned with their subject-matter data processing and decision making (or guidelines in decision-making for management departments). These may be universities, research laboratories, institutes or departments in control organisations. The key characteristic features of such stations should be:

- Compactness and simplicity of operation and maintenance;
- Integration with processing technologies and the storage and thematic analysis of data;
- The use of standard PC configurations;
- Affordable price.

Personal stations allow for the reduction of the access time to remote sensing data and the cheapening and loosening of access for a wide range of users. This solves one of the main requirements of remote sensing data – the efficiency of the acquisition of actual space information about the earth's surface and its objects.

Connecting a wider range of consumers - including the involvement of university science departments and the practical training of staff in the area of thematic data processing - allows for the more effective usage of the satellite in monitoring data for the stable growth and security of countries (according to the GEOSS and GMES programmes, etc.).

The availability of such systems will make remote sensing data an effective information tool for accessing situations and decision-making.

Important features of a personal remote sensing data receiving antenna station should include:

1. The prediction and calculation of the trajectory of spacecraft which are selected by their orbital data from the spacecraft catalogues and the coordinates of the station;
2. Software calibration and the accompaniment of the selected spacecraft on its trajectory with the minimal acceptable error;
3. The tracking of the signal maximum from the spacecraft during its accompaniment and correction of the calculated accompaniment trajectory if necessary;
4. The reception and demodulation of radio-signal selection of the information flow;
5. Real-time data processing;
6. Data visualisation, archiving and storage;
7. Self-checking and the self-diagnosis of the units and the station as a whole;
8. Adaptiveness to the effects of various factors, both external and internal;
9. Connectivity with other stations and external terminals for synchronisation and coordination.

Such functionality would allow the staff to focus on online access and contextual information processing instead of focusing on hardware.

Further, technical problems we had to solve while creating the series of antenna stations for satellite tracking and receiving of remote sensing data as well as broadcasting command information to satellite are described.

2.2 Features and problems that must be addressed during the station's creation

Since the position of the spacecraft for low-orbit remote sensing changes all the time, both hardware and software tools for the controlling and tracking of a satellite in its orbit play an important role in the structure of terrestrial receivers. The required accuracy and acceptable errors in coordinate tracking depends on the chart direction of the aerial and the diameter of its mirror.

Problems involved in AS creation for tracking the remote sensing satellite are caused by the following factors: the low-orbital trajectory of the remote sensing satellite requires the use of a high-dynamic supporting-rotating device for the antenna with the relevant control systems. Increase of image dimensional resolution from the satellite requires the acceleration of the information flow transmission rate which in its turn leads to the enlargement of the reflecting surface diameter of antenna reflector (diameters varying from 3m up to 12m) and its weight as well (Garbuk & Gershenson, 1997).

The speed of information flow is defined as:

$$C = \frac{L \cdot V}{r^2} \cdot I \cdot N \cdot K\ , \tag{1}$$

where:

L – the width of the Earth's view;
V – the velocity of the sub-satellite point;
I – the number of bites per pixel of the image;
N – the amount of information channels;
K – the coefficient of the coding noise immunity type;
r – the resolution of the Earth's surface survey capability:

$$r \cong \frac{\lambda}{D} \cdot H\ , \tag{2}$$

where:

λ – the wavelength;
H – the height of the spacecraft;
D – the diameter of the lens.

The larger the diameter of the reflector, the narrower antenna direction chart becomes, which leads to the need to increase dynamic pointing accuracy. For instance, for the AS TNA-57 used for receiving data from the remote sensing Ukrainian satellite 'Sich-2' in the Centre for Space Information Monitoring and Navigation Field Control (CSIM and NFC), the diameter of the antenna reflector is 12 m, its weight is 5,500 kg, while the total weight of the AS is close to 70,000 kg (Fig.1,b). The width chart of the antenna orientation on the level of the 3 dB level is equal to 14 arcmin. Thus, it is necessary to provide speeds of up to 10 degrees / sec with a dynamic tracking error of not more than 1.5 arcmin.

The provision of a large dynamic range of motion for large antennas (a reflector with a diameter of 3m to 12m) and the need to ensure a small dynamic error for spacecraft guidance and tracking are contradicting requirements. Thus, this leads to a more complicated structure and management system for the AS, which increases the cost of the station.

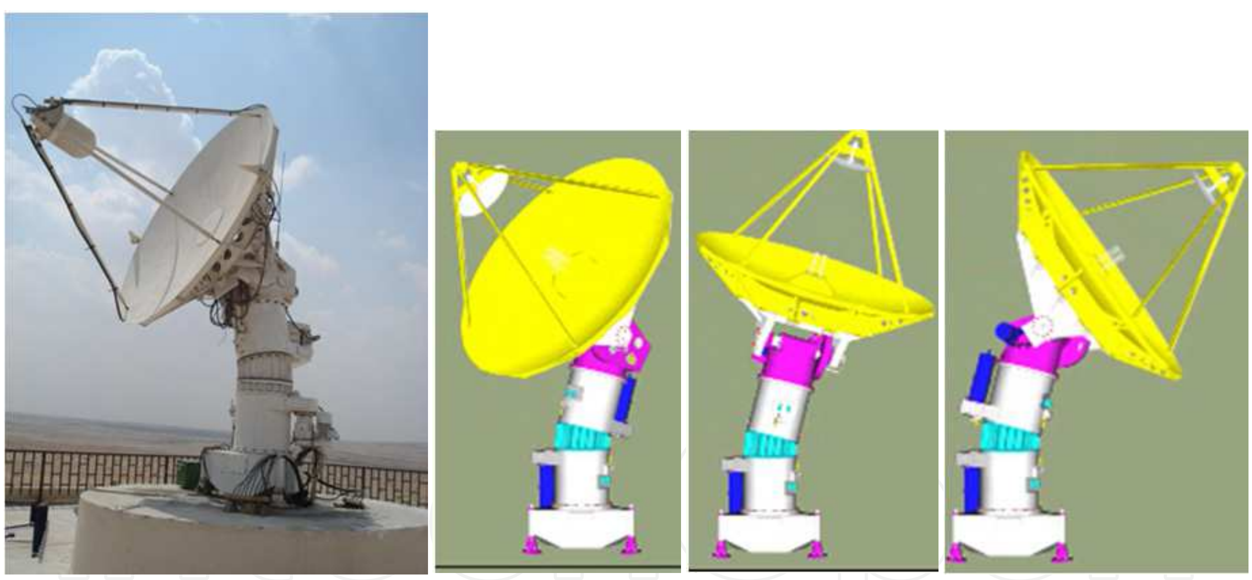
In addition, for classical azimuth-elevation supporting-rotating devices (Fig.1b) there are "dead" zones for spacecraft tracking, for those trajectories that are close to the zenith relative to the location of the terrestrial stations (Belyanstyi & Sergeev, 1980).

3. Structure and algorithms for new constructions of ERS stations

This section discusses some variants of the construction and algorithms of station control systems – as designed by ourselves - which solve the above mentioned problems in order to create effective stations for receiving information from remote sensing spacecraft. The experimental results of their work are given.

3.1 Principles for the functioning of an AS with 3 axes pointing without 'dead zones' accompanying the spacecraft through the zenith

To reduce the high speeds of ASs and to avoid signal loss in the "dead zones" we developed an AS with a 3-axes Support-Rotating Device (SRD) with an implemented additional azimuth axis of E1 with a slope $\gamma \cong 15°$ relative to the direct azimuth axis E3 and a rotation range in the horizontal plane the same as the basic azimuth axis ± 170 ° (Fig.2a).



a) antenna "EgyptSat-1" b) simulation model "EgyptSat-1"

Fig. 2. An AS with a 3-axial SRD (a) and a simulation model of spacecraft accompaniment through the zenith (b).

The aerial control system should perform an orientation of the chart direction of the reflector towards the spacecraft in real-time according to the rule about the spacecraft's motion towards the AS's coordinates. As the basis for the calculation of the orbital motion of the spacecraft, a Keplerian model of the point motion around the static attracting object is accepted. The satellite trajectory is described through Keplerian orbit elements (Fig.3), where:

i – the inclination of the orbiting satellite;

Ω – the longitude of the ascending node from Greenwich during the moment of the epochal time moment *T;*
ω – the angular distance of the perigee from the ascending node;
p – the orbit parameter dependent on the large semiaxis a: $p=a^*(1-e^2)$);
e – orbit eccentricity;
T – epochal time (or time moment). The satellite passes through the point of the ascending node (the intersection of the equator when moving from south to north).

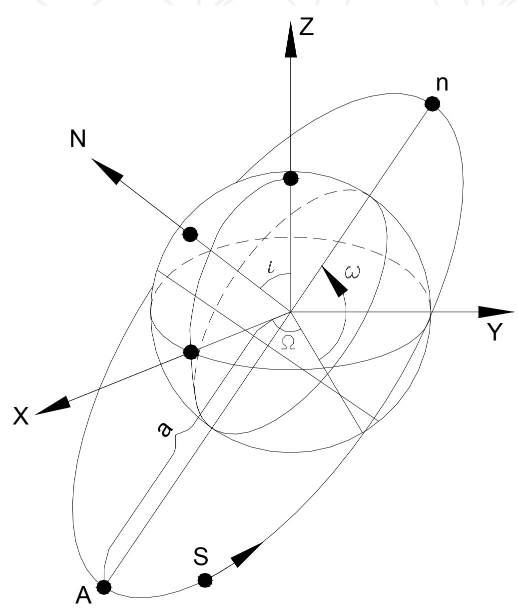


Fig. 3. Parameters of Satellite orbits

However, in reality the movement of the spacecraft is affected by a series of disturbing factors, the most significant of them being: a perturbation of the gravitational anomalies of the Earth, the effect of friction in the upper atmosphere, the influence of the gravity of the Sun and the Moon and the pressure of sunlight. The equation of the spacecraft's motion is described by the system through six differential equations of the first-order with consideration of varying factors. The task of forecasting the spacecraft's movement at every moment of time is reduced to the numerical integration of differential equations of the sixth-order with initial conditions at a given time t_0 (Reshetnev at al., 1988).

Continuously updated data on the spacecraft's orbital parameters is presented in a two-line format (*. TLE) since the calculation of the trajectory can be obtained from the informational satellite catalogues, for instance, on-site http://celestrak.com/NORAD.

The control system calculates the trajectory according to the orbital parameters data in a topocentric coordinate system in an aimer table view **R[**t_j,α_j,β_j], where α_j, β_j – the azimuth angle and the angle of the beam pointing direction of the aerial on the spacecraft at a time t_j.

The control system needs to perform the transformation of input coordinates α_j, β_j in order to accompany the spacecraft with this antenna, from a topocentric azimuth-elevation coordinate system into the local coordinate system of each axis of the AS (array **R**[$t_j,\alpha1_j,\alpha2_j,\alpha3_j$]), where $\alpha1_j$, $\alpha2_j$, $\alpha3_j$ - the rotation angles of each axis E1, E2, E3 from ERD at time t_j.

To target the spacecraft, the control system controller performs a coordinate conversion according to the algorithm:

$$\alpha 2 = arctg\left(\frac{\cos\gamma\cdot\sin\beta - \sin\gamma\cdot\cos\beta\cdot\cos(\alpha-\alpha 3)}{\sqrt{1-(\cos\gamma\cdot\sin\beta-\cos\beta\cdot\cos(\alpha-\alpha 3)\cdot\sin\gamma)^2}}\right)+\gamma \tag{3}$$

$$\alpha 1 = \begin{cases}\alpha_1', \text{ if } X_A \ge 0;\\ \alpha_1' + 180^\circ, \text{ if } X_A < 0 \text{ and } Z_A \ge 0;\\ \alpha_1' - 180^\circ, \text{ if } X_A < 0 \text{ and } Z_A < 0;\end{cases} \tag{4}$$

where:

$$\alpha_1' = arctg\left(\frac{\cos\beta\cdot\sin(\alpha-\alpha 3)}{\cos\gamma\cdot\cos\beta\cdot\cos(\alpha-\alpha 3)+\sin\gamma\cdot\sin\beta}\right) \tag{5}$$

$$X_A = \cos\gamma\cdot\cos\alpha 3\cdot\cos\alpha\cdot\cos\beta + \sin\gamma\cdot\sin\beta + \cos\gamma\cdot\sin\alpha 3\cdot\cos\beta\cdot\sin\alpha\ ,$$

$$Y_A = -\sin\gamma\cdot\cos\alpha 3\cdot\cos\beta\cdot\cos\alpha + \cos\gamma\cdot\sin\beta - \sin\gamma\cdot\sin\alpha 3\cdot\cos\beta\cdot\sin\alpha\ ,$$

$$Z_A = -\sin\alpha 3\cdot\cos\beta\cdot\cos\alpha + \cos\alpha 3\cdot\cos\beta\cdot\sin\alpha\ ,$$

α1 – the rotation angle of the main azimuth at axis E1,
α2 – the rotation angle of the elevation axis E2, and
α3 – the rotation angle of the azimuth at vertical axis E3.
$\gamma \cong 15°$ - the angle of the axis E1 relative to the axis of E3.

The range of angle changes:

α - (0÷360°),
β - (0÷90°),
α1, α3 - (0÷±170°),
α2 - (0÷120°).

During the execution of the accompaniment of a spacecraft with a given aimer table (array **R[**t_j,α_j,β_j]), the controller control system has to convert them into a format of local coordinates (array **R**[$t_j,\alpha 1_j,\alpha 2_j,\alpha 3_j$]).

To determine the real data about the AS's position and to compare with a given aimer table and issue them in the control and information processing centre, it is necessary that the inverse transformation of the "local" coordinate axes in the system topocentric coordinates pointing to the spacecraft accord with the correspondences below:

$$\alpha = \begin{cases}\alpha', \text{ if } X_B \ge 0,\ Z_B \ge 0;\\ \alpha' + 360^\circ, \text{ if } X_B \ge 0 \text{ and } Z_B < 0;\\ \alpha' + 180^\circ, \text{ if } X_B < 0;\end{cases} \tag{6}$$

Where:

$$\alpha' = arctg\left(\frac{\cos\gamma \cdot \sin\alpha 3 \cdot \cos(\alpha 2 - \gamma) \cdot \cos\alpha 1 - \sin\gamma \cdot \sin\alpha 3 \cdot \sin(\alpha 2 - \gamma) + \cos\alpha 3 \cdot \cos(\alpha 2 - \gamma) \cdot \sin\alpha 1}{\cos\gamma \cdot \cos\alpha 3 \cdot \cos(\alpha 2 - \gamma) \cdot \cos\alpha 1 - \sin\gamma \cdot \cos\alpha 3 \cdot \sin(\alpha 2 - \gamma) - \sin\alpha 3 \cdot \cos(\alpha 2 - \gamma) \cdot \sin\alpha 1}\right)$$

$$X_B = \cos\gamma \cdot \cos\alpha 3 \cdot \cos(\alpha 2 - \gamma) \cdot \cos\alpha 1 - \sin\gamma \cdot \cos\alpha 3 \cdot \sin(\alpha 2 - \gamma) - \sin\alpha 3 \cdot \cos(\alpha 2 - \gamma) \cdot \sin\alpha 1;$$

$$Y_B = \sin\gamma \cdot \cos(\alpha 2 - \gamma) \cdot \cos\alpha 1 + \cos\gamma \cdot \sin(\alpha 2 - \gamma); \quad (7)$$

$$Z_B = \cos\gamma \cdot \sin\alpha 3 \cdot \cos(\alpha 2 - \gamma) \cdot \cos\alpha 1 - \sin\gamma \cdot \sin\alpha 3 \cdot \sin(\alpha 2 - \gamma) + \cos\alpha 3 \cdot \cos(\alpha 2 - \gamma) \cdot \sin\alpha 1 .$$

$$\beta = arctg\left(\frac{\cos\gamma \cdot \sin(\alpha 2 - \gamma) + \sin\gamma \cdot \cos(\alpha 2 - \gamma) \cdot \cos\alpha 1}{\sqrt{1 - (\sin\gamma \cdot \cos(\alpha 2 - \gamma) \cdot \cos\alpha 1 + \cos\gamma \cdot \sin(\alpha 2 - \gamma))^2}}\right) \quad (8)$$

The control system of such an AS needs to calculate and execute the required angle α3 vertical azimuth axis E3 after every calculation or after receiving - via the communication channel - the trajectory of spacecraft, taking into account the mechanical limits of the rotation range of this axis, as follows:

$$\alpha 3 = \alpha_M \text{, if } 0 \le \alpha_M \le \alpha_{\theta^+};$$

$$\alpha 3 = \alpha_{\theta^+} \text{, if } \alpha_{\theta^+} < \alpha_M \le 180°;$$

$$\alpha 3 = \alpha_{\theta^-} \text{, if } 180° < \alpha_M < 190°;$$

$$\alpha 3 = \alpha_M - 360° \text{, if } 360° + \alpha_{\theta^-} \le \alpha_M \le 360°;$$

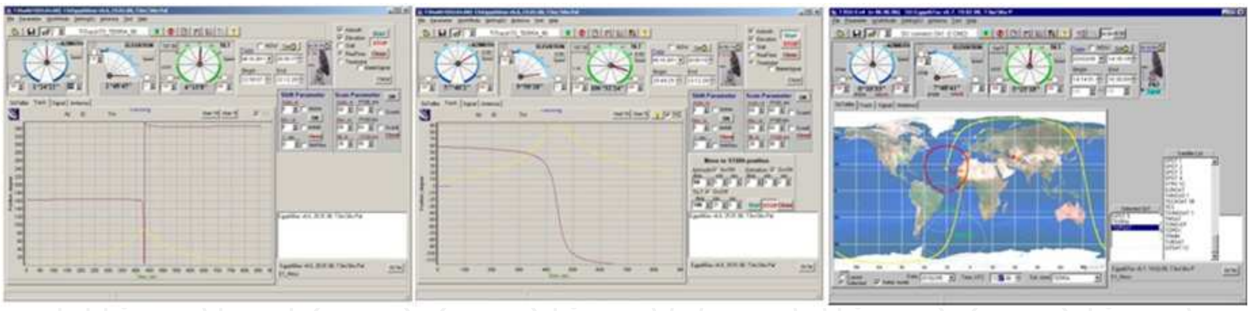
where:

α_{θ^+}, α_{θ^-} - the angles of triggering the limit switches the constraint turn of the antenna on the angle $\alpha 3$ (around an axis E3) into "plus" and "minus" respectively ($\alpha_{\theta^+} \approx 170°$; $\alpha_{\theta^-} \approx -170°$);

α_M - a value of azimuth counting with a maximum angle of the elevation of the spacecraft ($\alpha_M = \alpha(t)$ at $\beta(t) = \beta_{\max}$), determined from the pointing-table that is calculated for the selected spacecraft.

The calculation of the angles α1(t) i α2(t) is performed by the use of angles α(t), β(t) and α3.. Such an AS design and algorithm are implemented in the terrestrial bilateral An AS to manage and control the spacecraft telemetry RS «EgyptSat-1" is installed and operated in Egypt (Fig. 2a).

Fig.4a shows the diagram of "Terra" spacecraft's tracking trajectory through zenith (the maximum lifting angle = 90°) in the system of azimuth-elevation coordinates **R** [t, α, β] of topocentric coordinate system. The crimson diagram represents targeted angles on azimuth and the yellow one - on angular altitude. Fig.4b represents diagrams of tracking after



a) **R[**t,α,β] b) **R**[t,α1,α2], α3=const c) Trajectory into Map

Fig. 4. Graphs of the trajectory of spacecraft tracking via the zenith: (a)- for a 2-axis AS in topocentric coordinates **R[**t,α,β]; b- for a local axis E1, E2, **R**[t,α1,α2,α3]. The axis E3 is fixed at 107º during the session.

trajectory conversion from topocentric coordinate system into coordinate system of antenna axes **R** [t, α1, α2, α3]. The bottom straight azimuth axis E3 before the beginning of session for the given trajectory is to rotate the antenna system on azimuth towards the direction of the maximum elevation of the spacecraft for chosen trajectory constituting in this case the angle 106° 30 min.

As can be seen from the graphs, at a spacecraft's zenith point a velocity of an azimuth axis for a classic 2-axial AS tends towards infinity (Fig.4a). After the conversion to a 3-axis coordinate system (Fig.4b), the maximal accompaniment speed of the inclined azimuth axis is not more than 2.5 degree / sec. This enables the reduction of dynamic errors during the tracking of the spacecraft.

With the exception of the software method for tracking on a pre-calculated trajectory of the spacecraft, the AS control system implements the tracking of the spacecraft by an auto-tracking method of a signal finder with the goal of supporting a maximum value of the signal. It is also possible to use a compound method of software tracking with automatic correction of tracking table according to the signal and additional manual control.

Total-difference (monoimpulse) type of aerial-feeder device (Fig.5) is used in the designed aerial system for the execusion of satellite automatic tracking according to direction finder signal. Besides the main total informational signal the difference signals on each coordinate forming aerial direction finder characteristic are received on its output. The differencing signal provides information about the value and the sign of an error deviation of the AS from the signal maximum.

Fig.6 shows a graph of the error of the antenna beam's angular deviation from the desired trajectory in angular minutes (over the time t = 220 s) which is not exceeding - as seen from the graphs - 4 angular minutes.

In general, the total combined error of the tracking is a function of time and depends upon the parameters of the control system and the characteristics of the controlling and disturbance signals that affect the system during the process of tracking the spacecraft. As such, the maximum efficiency of remote sensing information reception is achieved with the minimum total tracking error.

Subsection 4 is devoted to a search for the structures and algorithms for efficient system operation employing the use of artificial neural networks.

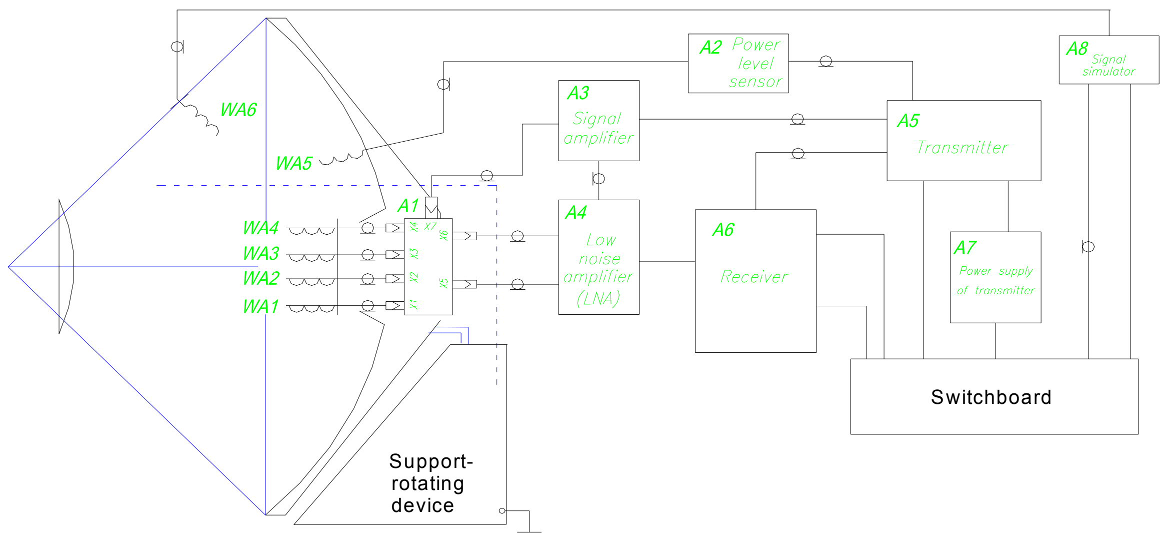


Fig. 5. Block-scheme of an antenna-feeder device of a total-difference (mono-impulse) type.

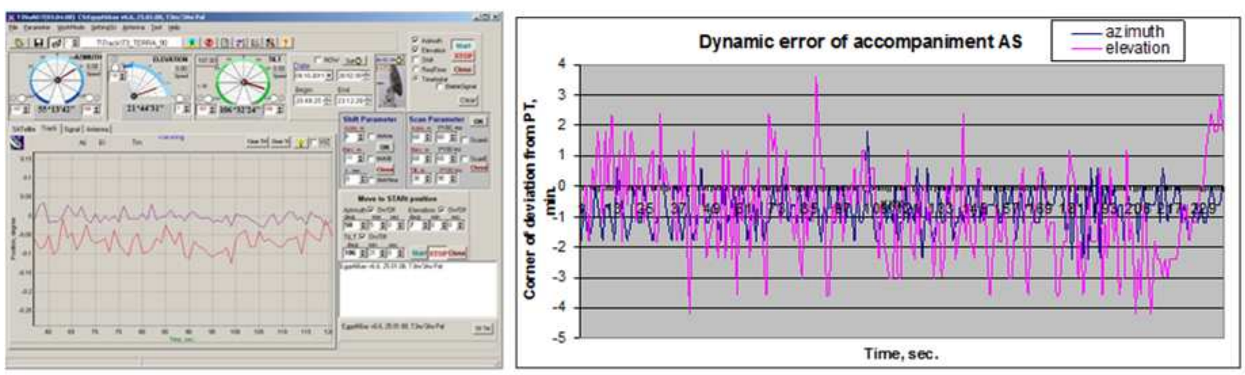


Fig. 6. Graph of the error of the antenna beam's angular deviation from the desired trajectory in angular minutes (over the time *t*=220 s).

Due to the enhancement of AS design and control algorithms, the speed of moving object tracking in the culminating moment of the spacecraft is significantly reduced, which reduces the requirements for the electromechanical components of the AS and allows the reduction of the dynamic errors involved in tracking. Structural and algorithmic solutions are implemented and tested in AU "Egyptsat-1".

3.2 Antenna System with a rotary device based on the six-axis Stewart platform (Hexapod scheme)

The disadvantages of all types of classic two-axial and modified three-axial SRD constructions of ASs involve their complexity and the high requirements for the accuracy of rotating mechanisms with a large diameter. This makes antenna systems too ponderous, their support-rotating devices too complex for manufacturing and assembling, and their cost too expensive.

Recently, for tracking along complicated trajectories mechanisms of manipulators with parallel kinematic units especially based on six-axis Steward platform (Fig.7) are widely used in robotics, machine-tool constructions, benches and other equipment (Stewart, 1965;

Fichter, 1986). Such mechanical systems consist of platforms connected by a system of variable (controlled) length sections, and they have a certain advantages over rotary mechanisms. For example, a combination of hardness and compactness, reliability, ease of design, manufacturability and studies (Nair & Maddocks, 1994; Kolovsky at al., 2000; Afonin at al., 2001). The Stewart platform is the subject of many scientific studies. There are examples of their use in some of the application problems provided by the data from the booklets of companies and technical exhibits, but the use of parallel kinematic mechanisms based on the Stewart platform in the mechanisms of the SRD of ASs for tracking various spacecraft trajectories - including low-orbital remote sensing satellites - has not yet been investigated.

Below we consider the construction and imitation of a model of the AS support-rotating device based on the six-degree Stewart platform (Hexapod scheme) as an alternative to traditional support-rotating devices. We investigated the possibilities and features of such an AS in performing the tracking of low-orbital satellites.

3.2.1 Specifics of the schema and construction of an AS with a support-rotating device Hexapod

A support-rotating device based on a linear drive (Fig.7) consists of two platforms, one of them is the basis of SRD and the other is the basis for binding the reflector of the satellite and six actuators, each attached to the upper and lower platform via a cardan joint.

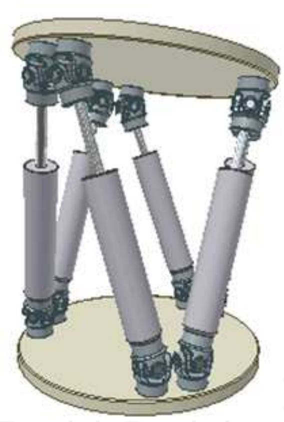


Fig. 7. Six-axis Stewart platform.

In our laboratory, we developed a research model for the construction of an AS with a support-rotating device based on the Stewart platform (Hexapod) and a control system for it (Fig.8).

The carcass of this support-rotating mechanism has six points of freedom which allows it rotate the reflector in the air with high accuracy.

A support-rotating device of this construction has benefits comparative with classic rotary mechanisms:

- Simplicity of mechanical construction, toughness, easy access to mechanical units of aerial, absence of cable twisting;
- No "dead" zones during satellite tracking;

Fig. 8. Antenna System with a support-rotating device based on the Stewart platform (Hexapod).

- No restrictions on rotation on the azimuth axis;
- The low speed of driving actuators for any tracking trajectories of a satellite;
- High accuracy in aiming;
- The ability to work in difficult conditions;
- Relatively low cost.

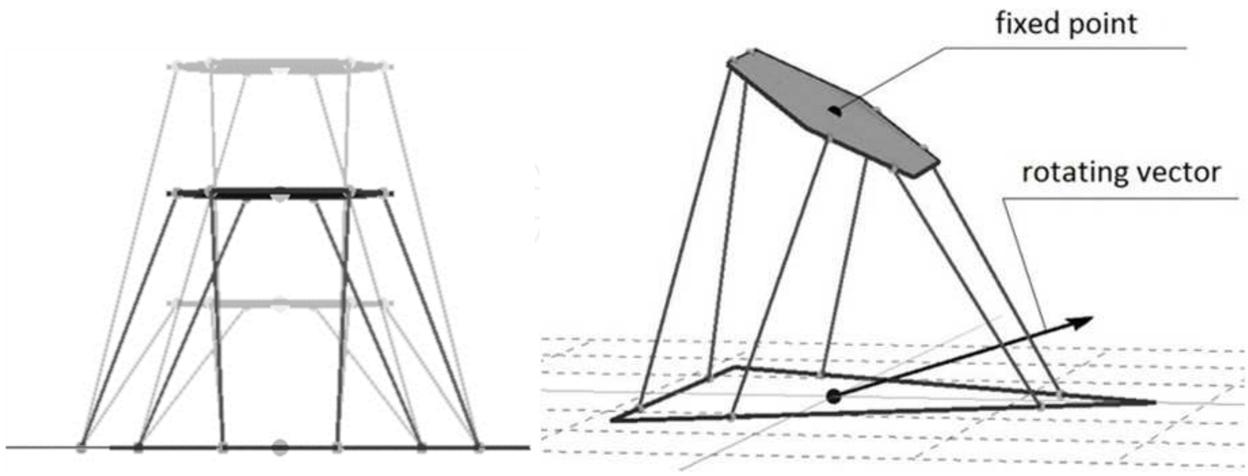
The main disadvantages of this type of support-rotating device include some limitations at low tilt angles of the reflector and the complexity of the simultaneous motion control of six actuators. Unlike classical AS support-rotating devices, the control of the support-rotating device based on a linear drive demands the precise coordination of the parallel movement of all six actuators simultaneously. The closing of every actuator must always lie in corresponding areas, otherwise the construction may be destroyed or the actuators may fail.

3.2.2 Algorithm to control AS based on linear circulating platform

In common case to point the aerial beam on the given azimuth and location angle it is necessary to set the lengthening of each actuator on certain value. In order to find the motion laws of actuators let us solve the inverse problem.

Let us define a plane of the support-rotating device in a Cartesian coordinates system with x, y, z, axes to which the reflector of the antenna is mounted. Since the physical size of the upper platform and the mount points of the actuators on it are known, it is possible to find the coordinates of the hinges. Similarly, let us set the base of the support-rotating device (the lower platform) basis and determine the coordinates of the lower hinges.

At the maximal lengthening of the actuators, the planes will be maximally remote from each other. At the minimum lengthening the distance between them, it will be at the minimum (Fig. 9). In extreme positions, the planes can be located only when parallel to each other.



a b

Fig. 9. Location of the platform plane at the different lengthening of actuators.

It is clear that the upper platform has to be in the middle position in order to achieve the maximal possible turn of the antenna reflector. As such, the equal motion of the actuator is kept both upwards and downwards.

Let us perform a turn of upper plane with the hinges mounted accordingly into it, making use of affine isometric transformations of the coordinates.

Three parameters are needed to perform the arbitrary rotation in space:

- A fixed point of transformation;
- A vector that is the centre of the rotation;
- A rotation angle value φ.

Let us choose a point in the centre of the upper platform as a fixed point that passes into itself (as a result of rotation) (Fig.9b). Consider a vector (i.e., the centre of rotation) set by two points p1 and p2:

$$\mathbf{v} = p2 - p1 \tag{9}$$

The direction is determined by the order of using these points. Only the direction of this vector is important. Its position in space does not affect the rotation result.

Let us perform a rotation axis vector normalisation to simplify the operation's execution: replace it with the vector of unit length. The second vector has the same direction in space as the first one:

$$\begin{aligned} S &= \sqrt{X^2 + Y^2 + Z^2} \\ X_N &= X/S \\ Y_N &= Y/S \\ Z_N &= Z/S \end{aligned} \tag{10}$$

The rotation is partly simplified if the fixed point (together with the rotation object) is in the zero point of the coordinates. Thus, the first operation of transformation is T(-p0), and the last is T(p0). Where T(-p0) and T(p0) are the appropriate matrices of transformation (Shikin & Boreskov, 1995):

$$T(P_0) = \begin{bmatrix} 1 & 0 & 0 & \alpha_x \\ 0 & 1 & 0 & \alpha_y \\ 0 & 0 & 1 & \alpha_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (11)$$

$$T(-P_0) = \begin{bmatrix} 1 & 0 & 0 & -\alpha_x \\ 0 & 1 & 0 & -\alpha_y \\ 0 & 0 & 1 & -\alpha_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (12)$$

Thus, the matrix of a complex transformation will have such a form:

Rotation around an arbitrary axis reduces in relation to the consequent rotation around the particular coordinate axes. The main problem is to find the rotation angles for every axis.

Let us execute the first two rotation operations to combine the rotation axis **v** with the coordinate axis Z. Next, rotate the object around the axis Z to a necessary angle and execute the previous two turns in reverse order.

Accordingly, the matrix of the complex transformation has the form:

$$\boldsymbol{M} = \boldsymbol{R}_x(-\theta_x)\boldsymbol{R}_y(-\theta_y)\boldsymbol{R}_z(\theta_z)\boldsymbol{R}_y(\theta_y)\boldsymbol{R}_x(\theta_x) \quad (13)$$

The determination of the matrices $\boldsymbol{R}_y(\theta_y)$ and $\boldsymbol{R}_x(\theta_x$ form the most difficult part of the calculations.

We will consider the components of vector **v**. As **v** is the vector of unit length, then:

$$a_x^2 + a_y^2 + a_z^2 = 1 \quad (14)$$

Let us draw a segment from the beginning of the coordinates to the point (a_x, a_y, a_z). This segment will have a unit length and the same direction as the vector **v**. Drop the perpendiculars from a point (a_x, a_y, a_z) to every coordinate axis as it is represented by Fig. 10. Three direction angles - φ_x, φ_y, φ_z - are the angles between the vector **v** and the coordinate axes. The correlation between direction cosines and the components of vector **v** are:

$$\begin{aligned} \cos \varphi_x &= a_x \\ \cos \varphi_y &= a_y \\ \cos \varphi_z &= a_z \end{aligned} \quad (15)$$

Only two direction angles are independent, because:

$$Cos^2\varphi_x + Cos^2\varphi_y + Cos^2\varphi_z = 1 \quad (16)$$

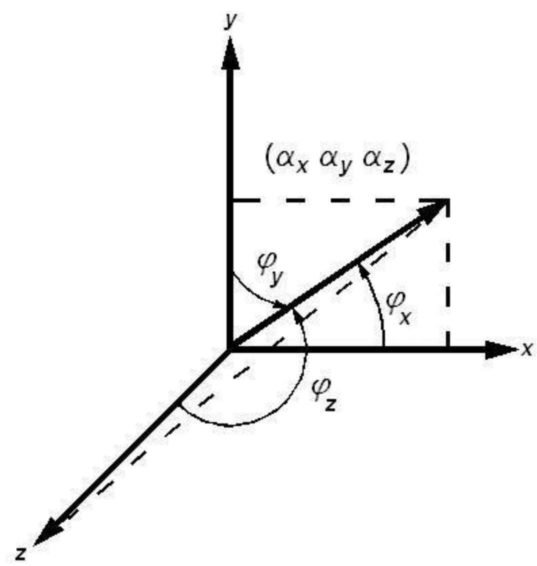


Fig. 10. Direction angles of elevation.

Knowing the values of the direction cosines, it is possible to calculate the value of the Θx and Θy angles. As we see in Fig.11, the rotation of point (a_x, a_y, a_z) will lead to the segment rotation where it will be located on the plane y=0. The length of the segment projection (before the turn) on the plane x=0 is equal to d.

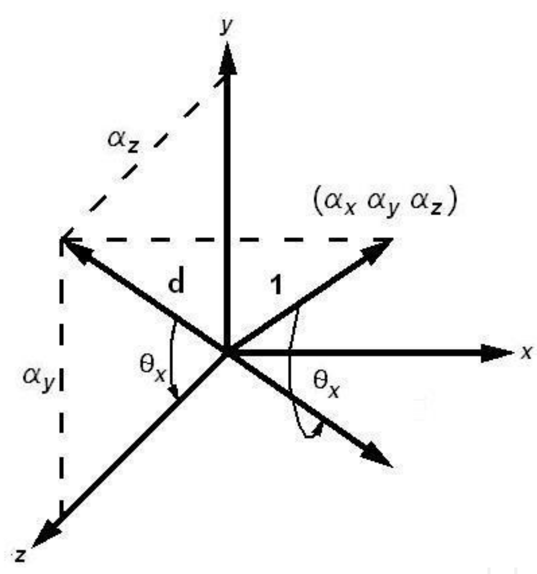


Fig. 11. Rotation angle placement according to the X axis.

Since the rotation matrix contains sines and cosines instead of angles, there is no need to find the Θx value itself, so the rotation matrix Rx(θx) will be:

$$R_x(\Theta_x) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \alpha_z/d & -\alpha_y/d & 0 \\ 0 & \alpha_y/d & \alpha_z/d & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{17}$$

And the inversed rotation matrix Rx(–θx) will be:

$$R_x(-\Theta_x) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & \sin\theta & 0 \\ 0 & -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \alpha_z/d & \alpha_y/d & 0 \\ 0 & -\alpha_y/d & \alpha_z/d & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (18)$$

The elements of the $R_y(\theta_y)$ matrix are calculated in a similar way (Fig.12).

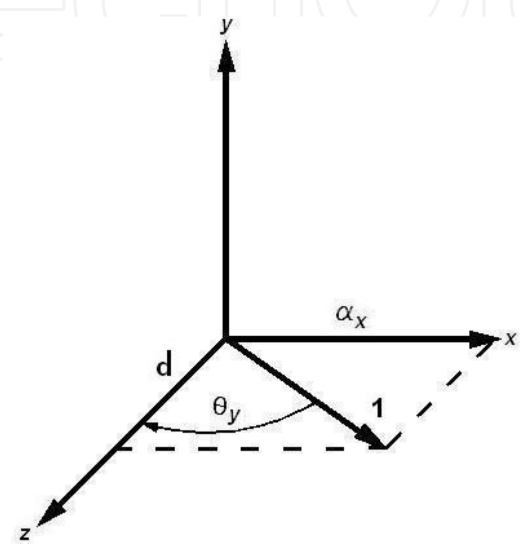


Fig. 12. Rotation angle placement according to the Y axis.

The corresponding rotation matrices are:

$$R_y(\Theta_y) = \begin{bmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} d & 0 & -\alpha_x & 0 \\ 0 & 1 & 0 & 0 \\ \alpha_x & 0 & d & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (19)$$

$$R_y(-\Theta_y) = \begin{bmatrix} \cos\theta & 0 & -\sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ \sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} d & 0 & \alpha_x & 0 \\ 0 & 1 & 0 & 0 \\ -\alpha_x & 0 & d & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (20)$$

Thus the rotation axis (vector **v**) coincided with the axis Z. Then let us perform the rotation on needed angle elevation (angle of the aerial reflector beam pointing):

$$R_z(\Theta_z) = \begin{bmatrix} \cos(\Theta) & -\sin(\Theta) & 0 & 0 \\ \sin(\Theta) & \cos(\Theta) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (21)$$

After that we carry out the reverse transformations: ***R**y(–θx)*, ***R**x(–θy)*, ***T**(–p0)* and obtain the top plane rotated on the given pointing angle corresponding with the aerial beam elevation angle. As a result of the multiplication of all the discovered transformation matrices, we will get the complex matrix ***M***:

$$\mathbf{M} = \mathbf{T}(-p_0)\mathbf{R}_x(-\theta_x)\mathbf{R}_y(-\theta_y)\mathbf{R}_z(\theta_z)\mathbf{R}_y(\theta_y)\mathbf{R}_x(\theta_x)\mathbf{T}(p_0) \tag{22}$$

The multiplication of an arbitrary point in a three-dimensional space on a specified complex matrix will cause it to turn around to some fixed point in the same space.

After the rotation of the upper platform, we receive new coordinates of the upper ends of actuator hinges used to mount to the platform. Having the coordinates of the upper and lower hinges in space, we calculate the distance between them using a correlation (23) (the actuator lengthening that it was necessary to find):

$$S = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \tag{23}$$

On the basis of the resulting algorithm, the simulation work program is developed. This program provides the calculations and represents the position of the actuators and the rates of their movement depending on the azimuth and elevation angle with the reflection of three-dimensional model of the supporting-turning device and antenna (Fig.13). In this model, it is possible to set the different geometrical parameters of the support-rotating device's construction (Fig.14). Different dimensions of the construction for determination of various optimum correlation between minimum values of the inclination angles, speeds and accuracy of work and control actuator motion while constructing the control system can be set in the model.

The control of a supporting-rotating device of a Hexapod-type requires precise (coordinated in time) cooperation between the position sensors and the delivery system of the control signal for all six drives. It is needed in order to preserve the system's integrity and to avoid

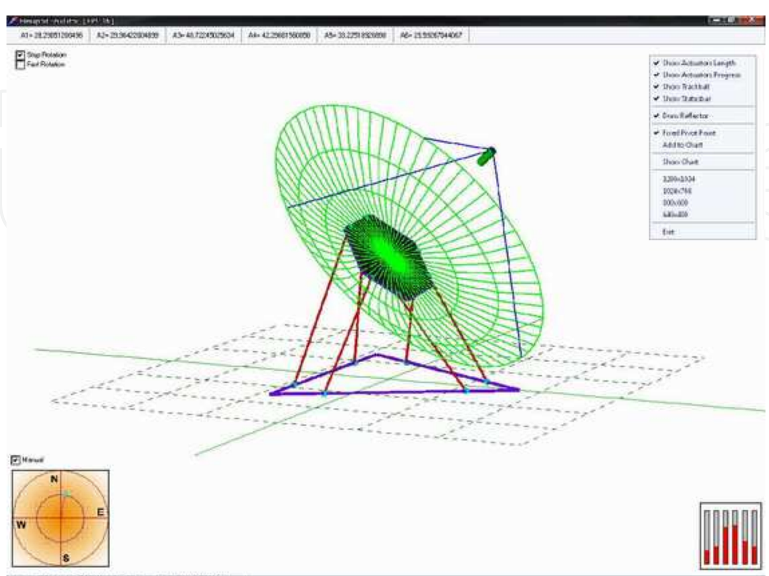


Fig. 13. A three-dimensional model of the support-rotating device.

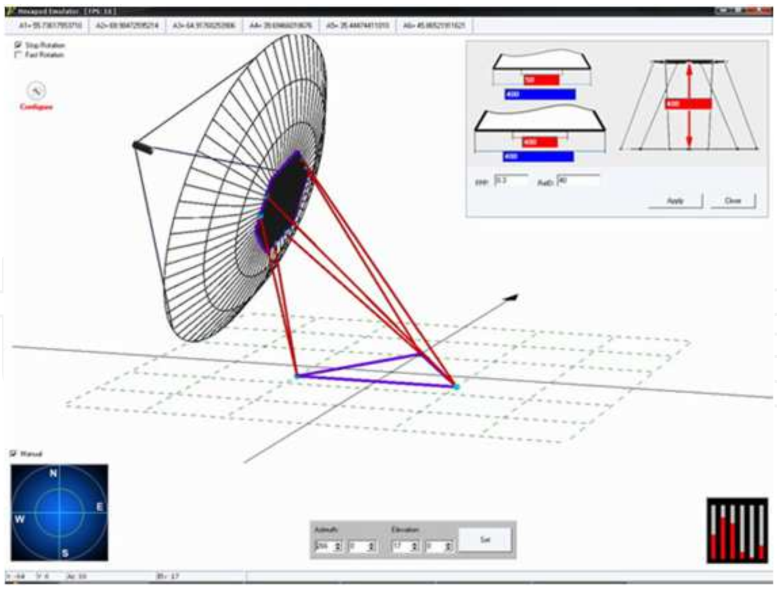


Fig. 14. Modelling of the constructional parameters of the support-rotating device.

physical damage. The six actuators form a single system. The control system must provide the simultaneous coordinated parallel control of 6 drives. The developed control system implements the algorithms of parallel work on the basis of a FPGA programmable logical integrated circuit. The block diagram with the cooperation chart of the control system's basic nodes is represented in fig.15.

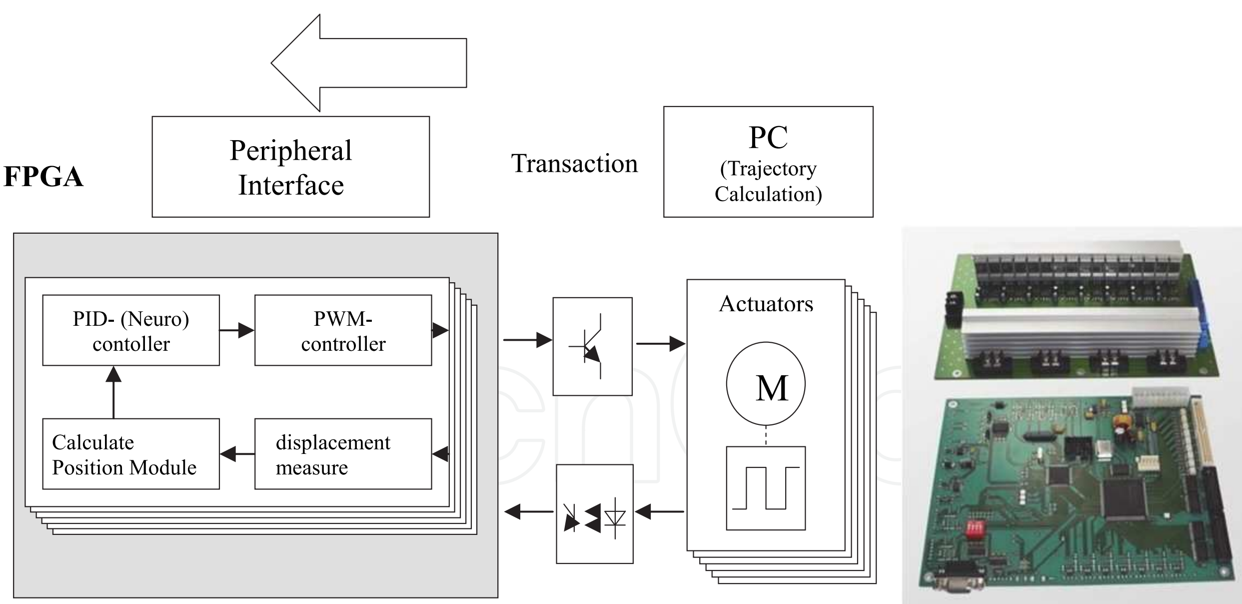


Fig. 15. Interaction scheme between the main units of the AS control system with a Hexapod.

The computer for the control system generates the array of the points for each actuator which create the trajectory. Every point is transacted to an FPGA that has six logical channels generated for it. Every channel is responsible for the work of a corresponding actuator, and consists of a PID regulator, a PWM inspector, a processing module for actuator sensor signals and a calculation module for the actuator's current position. In order to call the resources of every channel, a module is created. It provides an interface to access the periphery and provides its own address space for every channel and ensures the integrity of the data passed. Additionally, an interrupt controller is created so as to increase the reaction of all the system. This controller signals to the control processor regarding emergency events.

All of the channels of the control block work synchronously. This provides for simultaneous data reading from the sensors with processing and control actions for all of the actuators. It provides work for all 6 actuators as a single system for tracking the pointing trajectory of the spacecraft.

The graphs of the aimer table transformations from the topocentric system are shown in Fig.16. A trajectory is set by the arrays of the azimuth and elevation coordinates (**R**[t_j,α_j,β_j]). These arrays are transformed into the local movement coordinates for each actuator (array **R**[t_j,$\alpha1_j$,$\alpha2_j$,$\alpha3_j$,$\alpha4_j$,$\alpha5_j$,$\alpha6_j$]).

Fig. 16. Graphs of the aimer table transformation in the topocentric coordinate system (**R**[t_j,α_j,β_j]) and in the local coordinate system **R**[t_j,$\alpha1_j$,$\alpha2_j$,$\alpha3_j$,$\alpha4_j$,$\alpha5_j$,$\alpha6_j$].

The control program on the control system computer provides the visualisation of a movement diagram for each actuator and their speed; it also provides the calculation of trajectory tracking errors (fig.17).

So, the supporting-rotating device of an aerial system constructed on the basis of a Stewart platform (parallel kinematics structure Hexapod) considerably simplifies the mechanical construction of the AS, but increases the requirements for the schema and algorithms of the control system.

4. The use of neural network technology in the control systems of ERS aerial stations

The calculations of an AS's dynamic parameters for the construction of apparatus-programming devices for aerial guidance control according to the classical method - especially for six-wheeled or six-drive traversing mechanisms Hexapod - are connected with

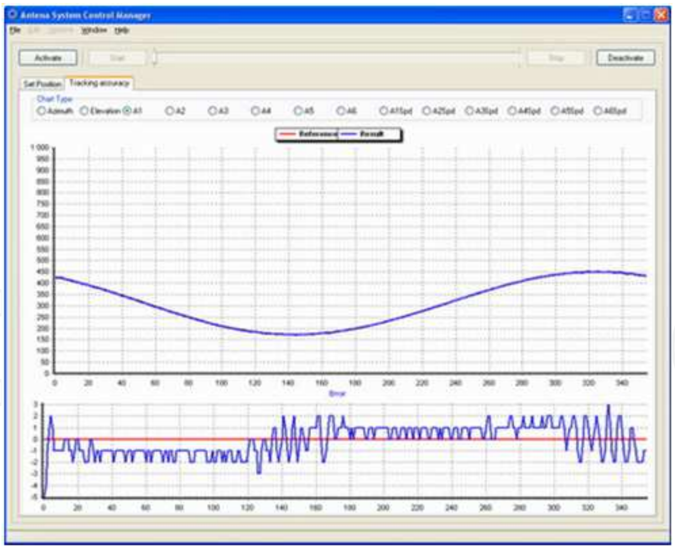


Fig. 17. Graph of the tracking of axis 1 of the actuator.

technical difficulties relating to the determination of the series of the AS's real parameters. These include, modulus inertia moments, changes of resistance friction depending on the inclination angle and the ratio of the aerial modulus position for various axes, the rigidity changes of mechanical transmissions, clearances, the instability of electric drive characteristics, the stochastic influence of wind loadings, the possible instability of time-sampling and program data processing during coordinates transformation, etc. Such mechanical systems essentially have a non-linear character. The methodological maintenance for the control of multidimensional interconnected dynamic units of such mechanical systems has not been solved sufficiently.

4.1 The AS model and its separate elements in the control system

One of the most effective and important methods for the control of dynamic objects with indistinctly determined parameters is the use of an algorithm of a proportional-integral-differential (PID) controller with the adaptive adjustment of PID-coefficients:

$$u(t) = K_p\left[\varphi(t) + \frac{1}{T_I}\int_{T-\Delta t}^{T}\varphi(t)dt + T_D\frac{d\varphi(t)}{dt}\right], \tag{24}$$

This expression is converted into digital form, convenient for program-realisation on the microcontroller:

$$u(t) = u(t-1) + K_P(e(t) - e(t-1)) + K_I e(t) + K_D(e(t) - 2e(t-1) + e(t-2)) \tag{25}$$

where u(t) – the regulator output signal;

$\varphi(t)$ – the deflection of angular position from the needed target;
K_p – the amplification factor in the return circuit;
T_I, T_D – the time differentiation and integration constants;
$e(t) = r(t) - y(t)$, - the regulation error;
$r(t)$, $y(t)$ – the target and the value of output signal for the object quidance;
K_P, K_I; K_D – PID coefficients requiring optimal adjustment.

The discrete transfer function of such a controller is determined by the expression:

$$W_p(z) = k_p\left[1 + \frac{T_0(1+z^{-1})}{2T_I(1-z^{-1})} + \frac{T_D}{T_0}(1-z^{-1})\right] \tag{26}$$

T_0 - is the quantisation time, able to adjust adaptively depending on the divergence angle while approaching a given coordinate.

However, in dynamic processes with variable parameters and interferences, it is rather difficult to ensure optimal coefficient adjustments. Very often, parameters for adaptive control should be chosen by a method of trial and error. There are a wide range of methods and algorithms for PID-controller self-adjustment, mostly resulting in the complication of algebraic calculations and requiring the introduction of many new system parameters (Kuncevych, 1982).

One of the alternatives to the classical models and methods is the creation of a control model based on the use artificial neural networks (ANNs). ANNs are a group of algorithms described and modelled according to principles analogous to the work of human brain neurons. A neuron network is able to compare its output signal with a given training signal and carry out self-adjustment according to certain criteria by means of the automatic selection of various internal weighting factors aimed at minimising the difference between the actual output signal and the training signal.

The functional characteristics of neuron networks show that this technology can provide control results much better than those obtained by means of classical controls and software (Miroshnik at al., 2000; Callan, 2001). The great value of ANN use lies in its universal solution for various types of control objects distinguished by the different parameters set, i.e., the different electro-mechanical modulus of ASs and the various types of mounting-traversing device structures and loadings (Golovko, 2001; Zaichenko, 2004). ANNs are not programmed but taught, which is why their solution quality depends mainly upon the data quality and the quantity of data needed for teaching.

4.2 Neural network use for the optimisation of control parameters

The idea the use of ANNs in aerial movement control systems is that the main control parameters (PID-coefficients, etc.) are ANN outputs adjusted while working through a series of test orbits of AS movements, i.e., ANN teaching (Omata at al., 2000). The scheme of ANN use in an AS's axes control circuit is shown in Fig.18.

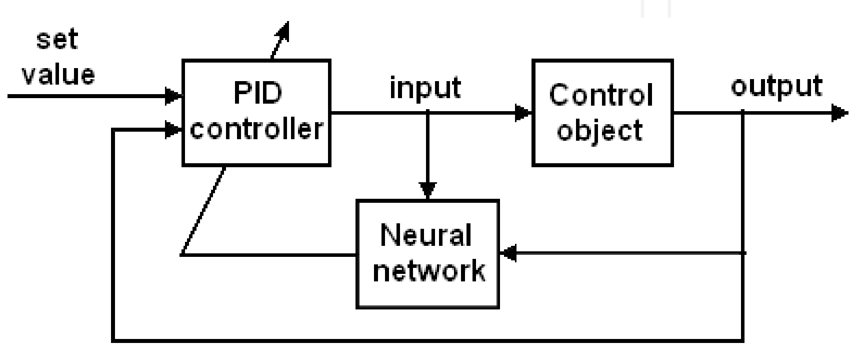


Fig. 18. A scheme for neuron control with self-adjustment.

Fig.19 reflects the structural scheme of a 3-contour AS control system for each of 3 axes of the aerial station “EgyptSat-1” using a neuro-controller for optimal coefficient adjustment in an external control contour.

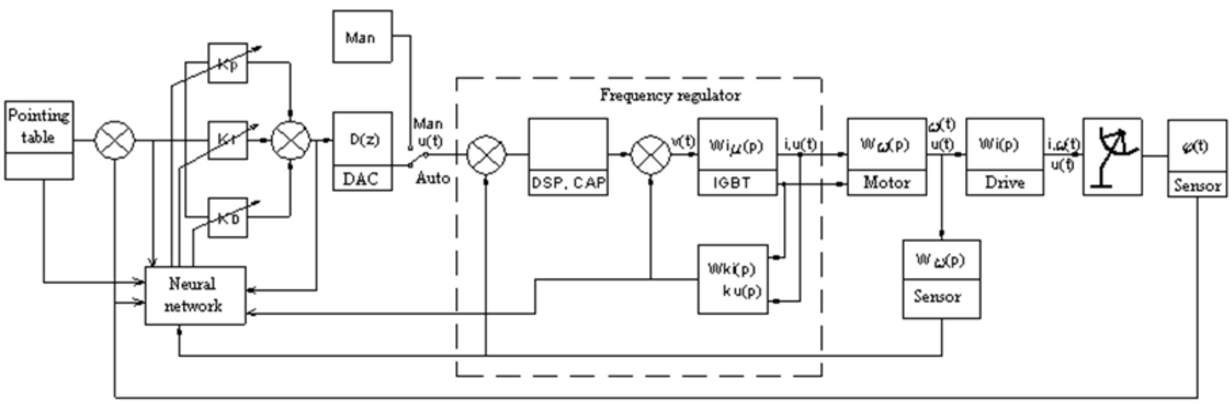


Fig. 19. Structural-algorithmic scheme of an AS control contour with a neuro-controller.

The internal contour is directly closed in the frequency regulator which controls the voltage and the current of the electric drive for local rotation control. The second is the contour of the AS’s axes rotation speed control. The external control contour is closed on the angular position of the AS axes.

A model of an AS control system and the submodels of its separate units (aerial, controller, frequency regulator, motor, Fig.20) are constructed due to the program complex MatLab/Simulink.

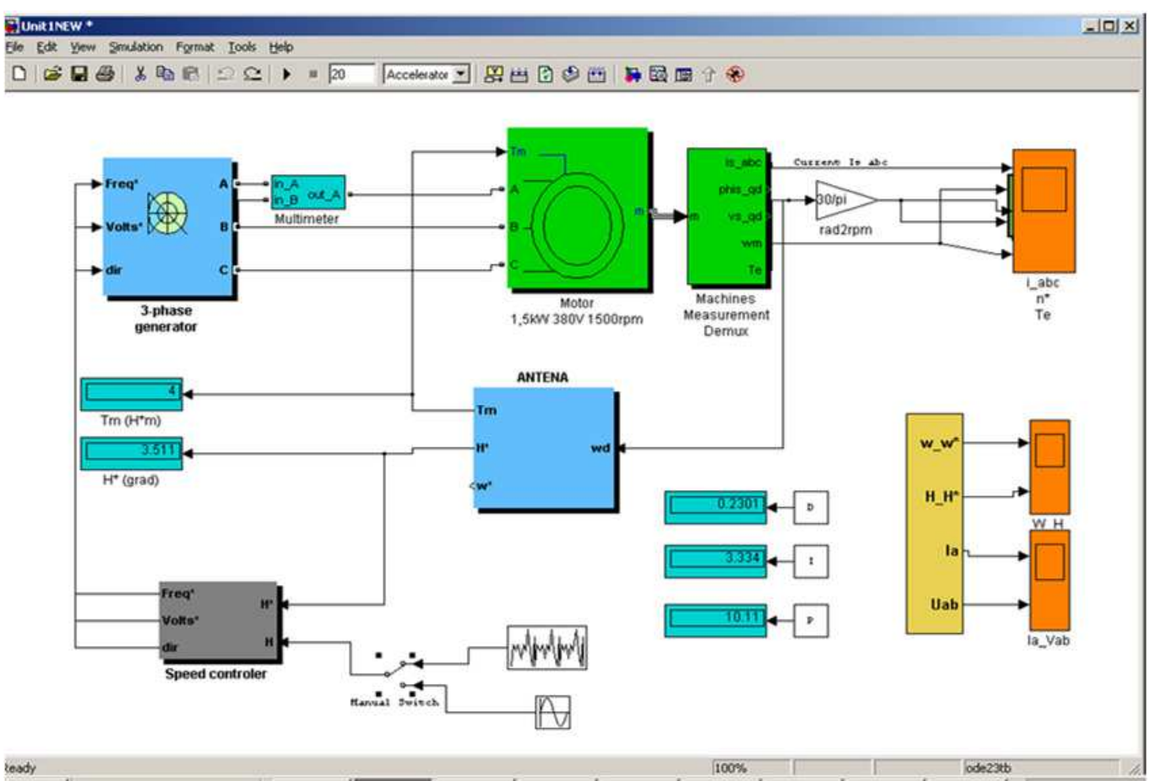


Fig. 20. General AS model with a control system.

The unit for the adjustment and optimisation of the PID-controller's parameters Optimum_1 is introduced into a submodel of the controller Speed controller (Fig.21).

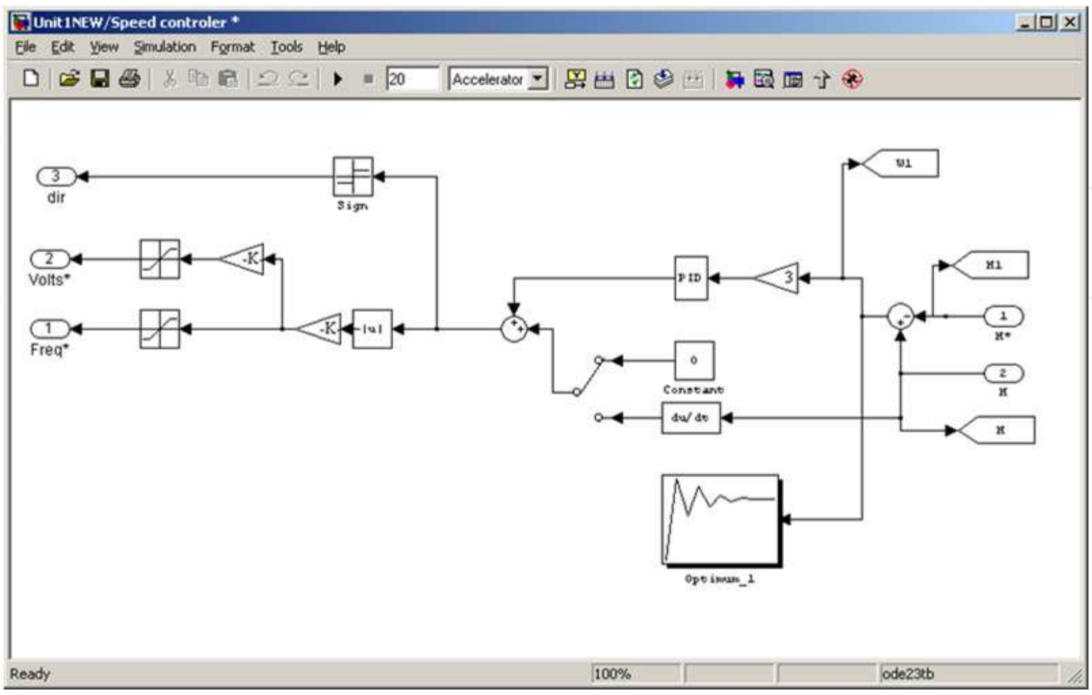


Fig. 21. Model of a guidance controller.

Error limits on AS movement deviations from the test sinusoidal guidance table provided within the limits of 0.2 degrees are set in the optimisation unit Block Parameter (Fig.22).

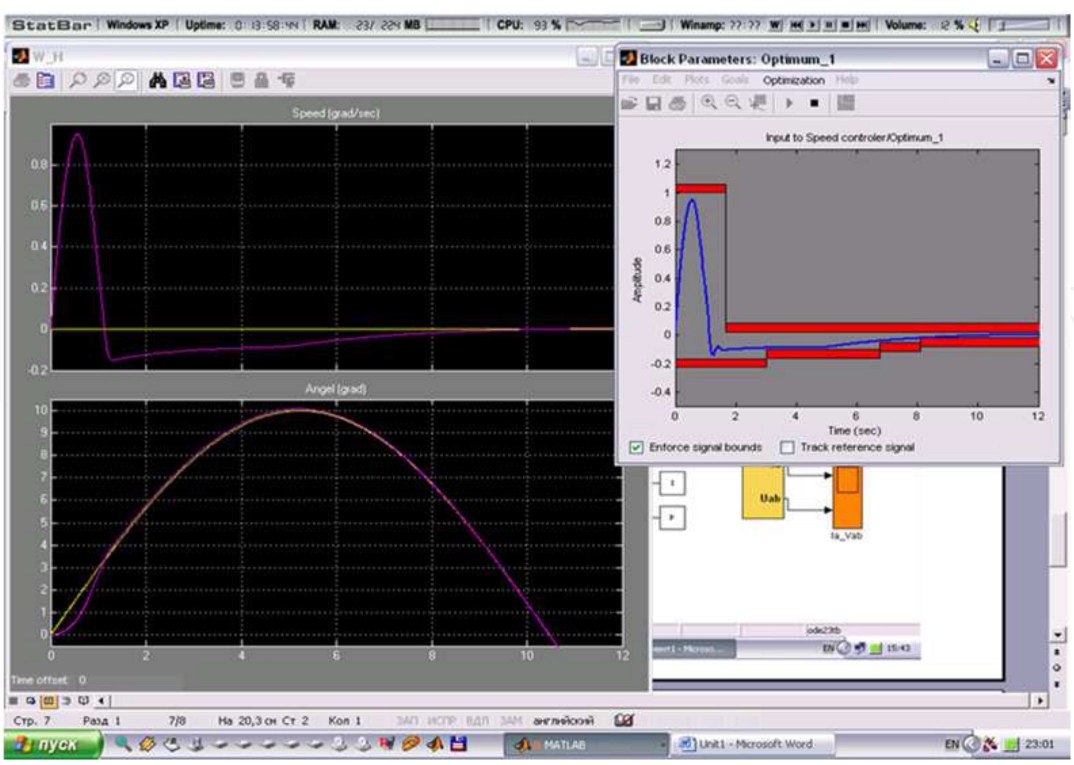


Fig. 22. The process of PID-control coefficients optimisation.

From the previous results in initial sections of GT, we can observe that considerable deviations occur as a result of the dynamic resistance moments during the AS's acceleration. To perform an optimal coefficient adjustment, the error limits are extended on the initial orbit section up to 1.0 degree (Fig.22), otherwise the ANN cannot adjust.

As the result of modelling, the deviation error diagram from the GT can be obtained (Fig.23).

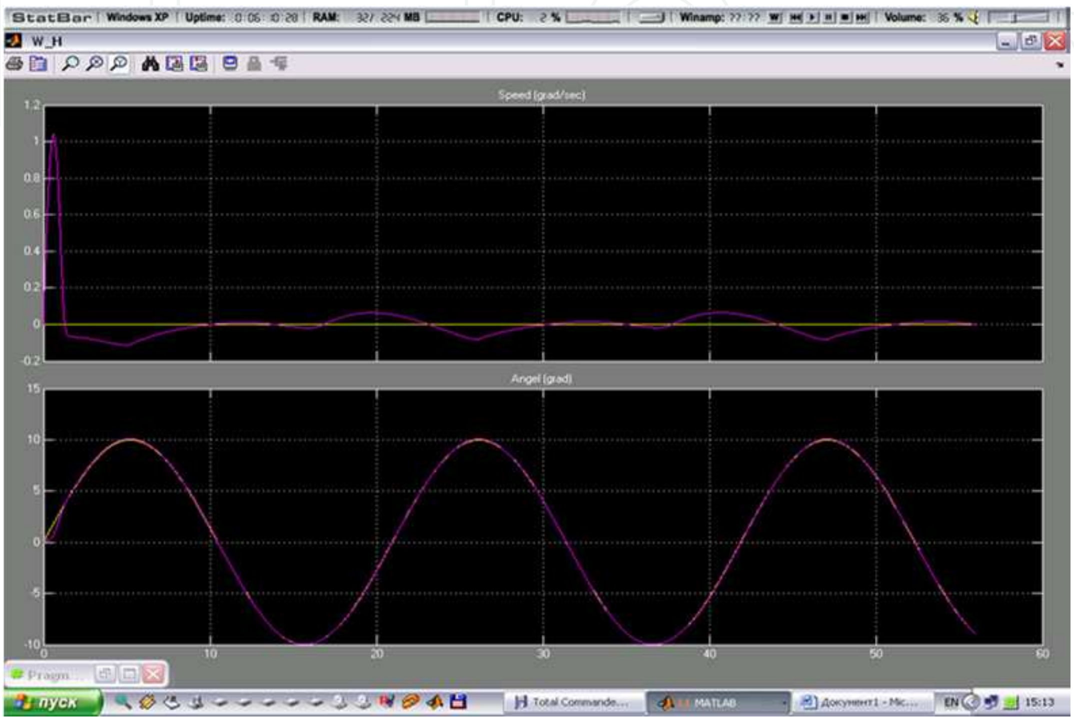


Fig. 23. The modelling of deviation errors for AS tracking along the sinusoidal GT.

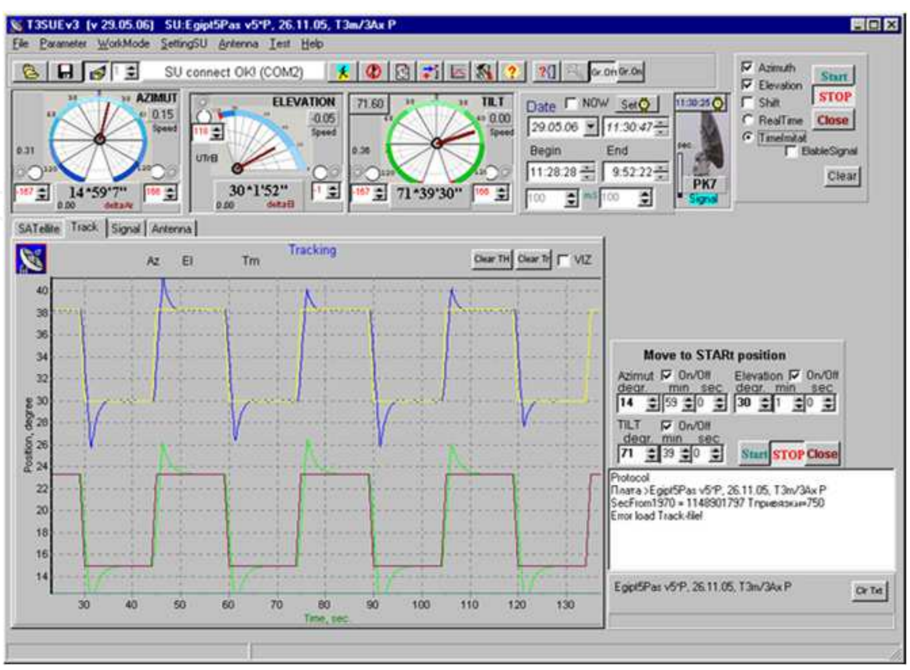


Fig. 24. Adjustments of the rate regulation of the impulse functions on 2 axes ($\alpha 1$, $\alpha 2 = 8°$).

The results of control PID-coefficient adjustment were tested on the 3-axes AS "EgyptSat-1" with the perfecting of various test orbits, and especially generated impulse functions (Fig.24, Fig.26), sinusoidal functions (Fig.25), special "high-speed" tables of target designations (Fig.27) and real satellite orbits.

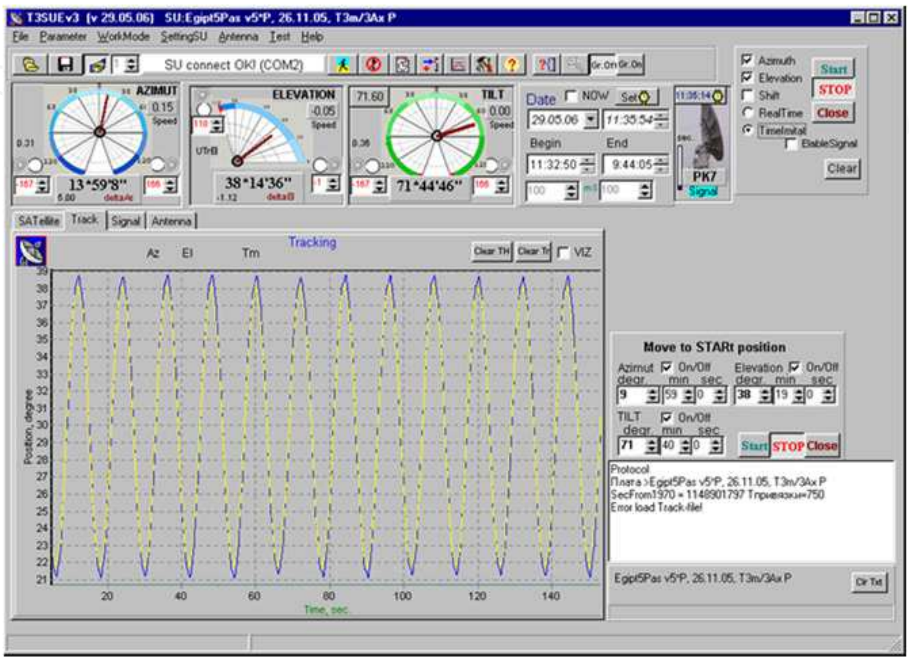


Fig. 25. Adjustments of the rate regulation on sinusoidal functions (α2 = 60°).

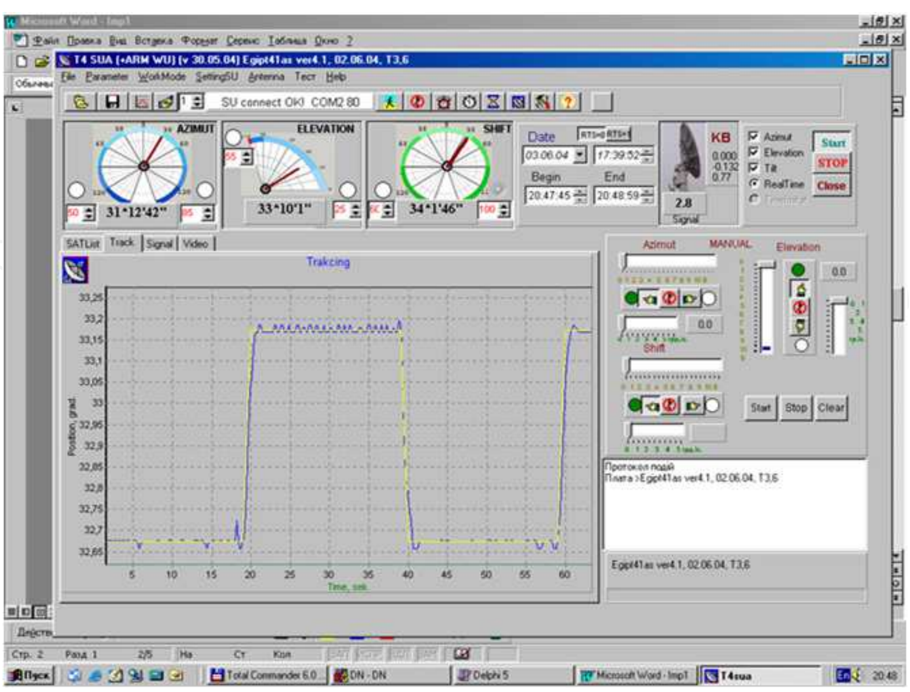


Fig. 26. Diagram of the impulse AS orbit perfection along the β axis.

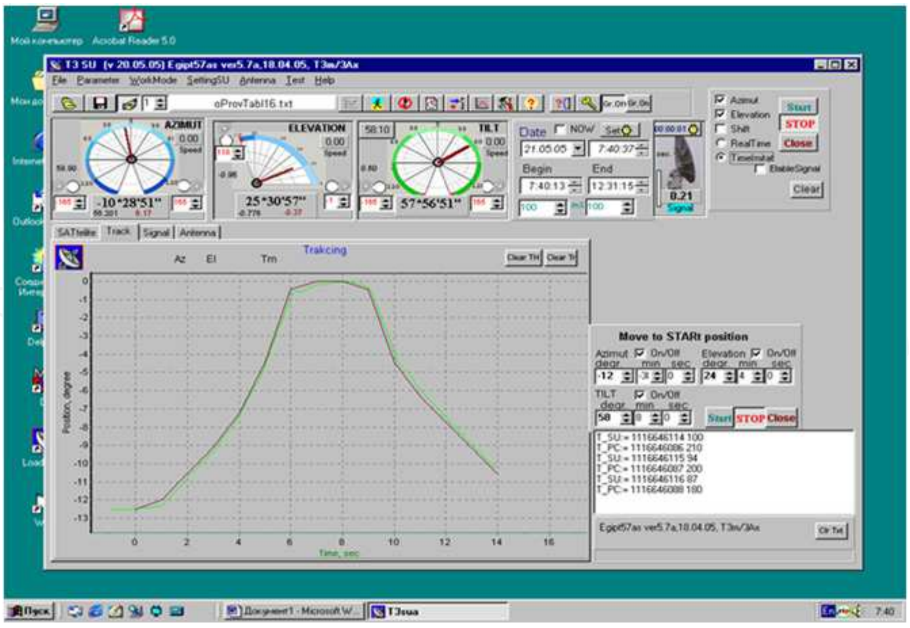


Fig. 27. Test orbit with a maximum tracking speed of 5 degree/sec.

4.3 Neural network use in the contour of aerial axes control

Another structure of neural AS control like dynamic object is offered. In this structure neural network and common PID-controller are used at the same time (Fig.28).

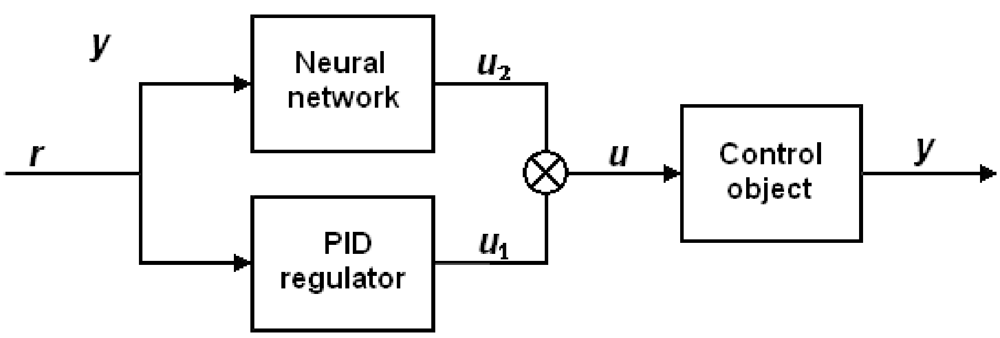


Fig. 28. Parallel scheme of a neuro-controller.

A typical two-layer perceptron with 10 neurons in an intermediate layer was chosen for the contour of the AS's axes control. Synthesis was carried out with the NNTOOL utility and MATLAB MEDIUM. A functional model of the system with a PID and neuro-controller was created with the Simulink program (Fig.29). The neuro-controller emulates the operation of the PID-controller. Neuron network teaching was executed via the method of reverse error extension. For this purpose, a set of teaching pairs - "input vector"/"right output" - were generated. In such a case, the input vector enters the network entrance and the state of all the intermediate neurons is calculated in series, while the output vector is compared with the right one and formed at the exit. Deviation provides errors which extend in the reverse direction along the network connection; afterwards, weighting factors are corrected to rectify it. After repeating this procedure a thousand times, we managed to teach the neuron network.

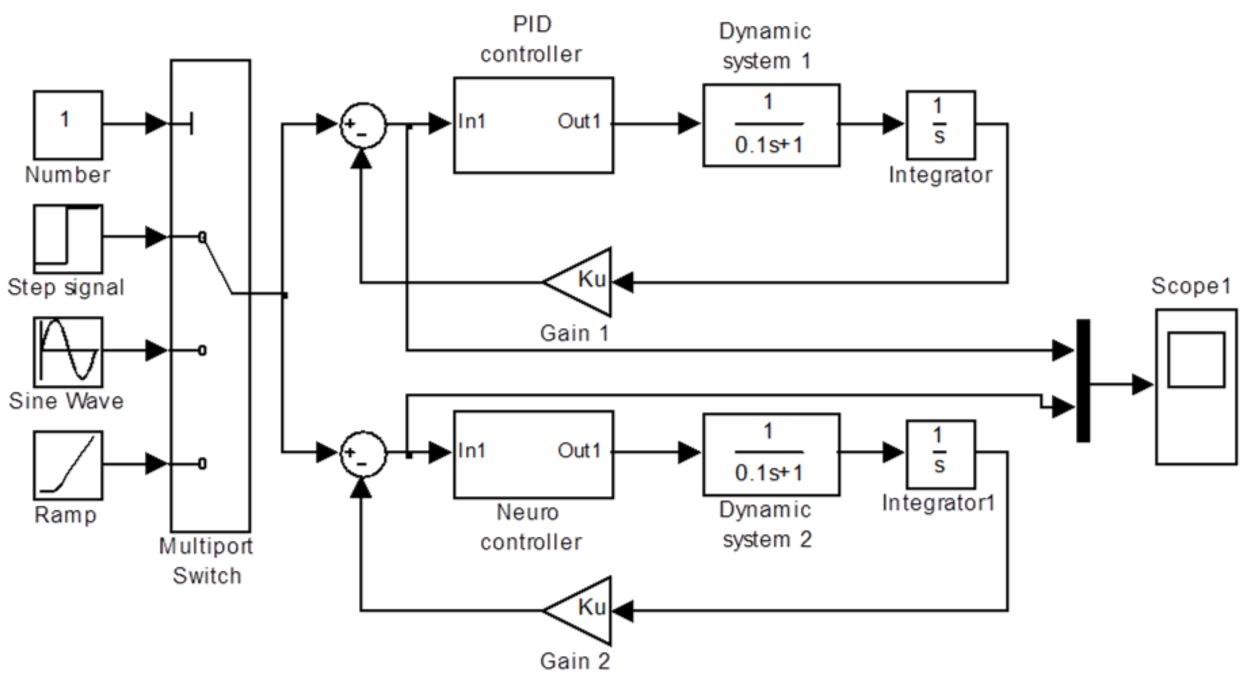


Fig. 29. Functional comparison model of systems with a PDF and a neuro-controller.

Fig.30 depicts the results following the neuron network's operation. Evidently, a simple multilayer perceptron (red colour graphics) had worse results in comparison with the PIF-control. The application of a recurrent perceptron distinguishing from the previous one by presence of delay lines on entries has better results (Fig.31). However, insufficient teaching stability marks its disadvantage. Imitative modelling shows that during the optimal selection of neuron network topology and the teaching of algorithms, it is possible to use it for the effective control of complex dynamic objects, such as large-sized aerial complexes.

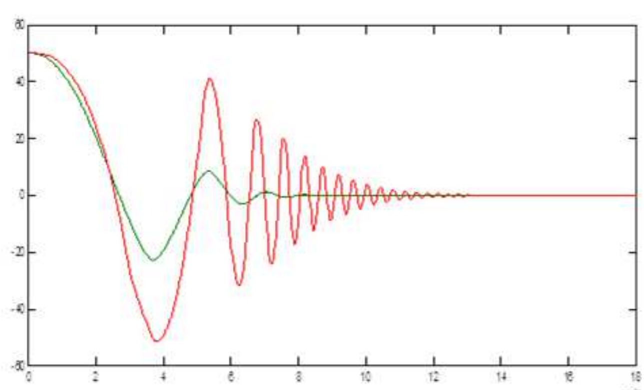


Fig. 30. Comparison of the PIF-controller's operation with a multilayer perceptron.

By introducing the neuron network into the control scheme, it can be used for the more effective operative adjustment of control parameters by means of its teaching of various test orbits. The strategy of neuron control with self-adjustment can be used for different types of AS drives with various dynamic characteristics.

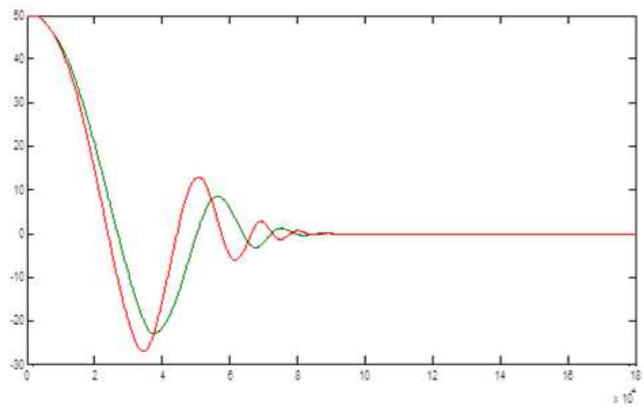


Fig. 31. Comparison of the PDF-controller's operation with a recurrent perceptron.

5. Conclusion

The investigation and search for optimal structures for mounting-traversing devices and control systems for the construction of aerial stations for remote sensing data reception have been carried out in this work. The models and results of the operation of two types of mounting-traversing AS devices have numerous advantages when compared with classical models and can be used for the creation of personal aerial stations for remote sensing data reception, as shown. The application of neuron networks in the control systems of ASs for remote sensing data reception can provide for the more accurate operation of control systems for satellite guidance and their tracking along the orbit in spite of the faults relating to constructional and dynamic AS parameters. The use of a neuron network in a control circuit also provides considerable advantages over traditional control systems due to the fact that for their realisation there is no need for accurate mathematical models of control objects.

6. References

Afonin V.L., and Krainov A.F., Kovalev V.E., Lyakhov D.M., Sleptsov V., Processing equipment of new generation. - Design concept Moscow: Mashinostroenie, 2001, 256 p.

Belyanstyi P.V., Sergeev B.G. Control of terrestrial antennas and radio telescopes. – M.: Sov. Radio, 1980. – 280 c.

Callan R., The basic concept of neural networks. - Moscow: Publishing House "Williams", 2001. - 288.

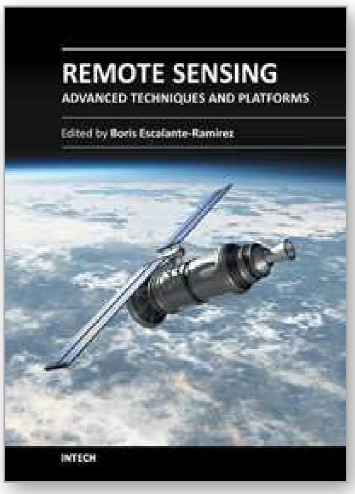
Fichter E.F., A Stewart platform – based manipulator , general theory and practical construction. - International Journal of Robotics Research. 1986. Vol. 5, No. 2, pp. 157 – 182.

Garbuk S.V., Gershenson V.E. Space remote sensing. – M.: publishing house A and B, 1997. – 296 c.

Golovko V.A., Neural networks: training, organization and application. - M.: IPRZHR, 2001. - 256.

Hnatyshyn A.M., Shparyk Y.S., Position and tasks of remote sensing (RS) according to the requirements of Derzhheolkarty. - 200

Kolovsky M.Z., Evgrafov A.N., Semenov Yu.A., Slousch A.V., Advanced Theory of Mechanisms and Machines. - Springer – Verlag, 2000, 394 p.
Kuncevych V.M. Adaptive control to indeterminate dynamic objects // Adaptive control to dynamic objects. - Kiev: Science thought, 1982.
Miroshnik I.V., Fpadkov A.L., Nikiforov V.O., Nonlinear and adaptive control of complex dynamic systems. - St. Petersburg.: Nauka, 2000. - S.653.
Nair R., Maddocks J.H., On the forward kinematics of the parallel manipulators. - The International Journal of Robotics Research, Vol. 13, No. 2, April 1994, pp. 171 – 188.
Omata S., Khalid M., Rubiya Y., Neuro-control and its applications. - M: Radio, 2000. 272.
Reshetnev M.F. and others. Control and navigation satellites in circular orbits. – M.: Engineering, 1988
Sich-2 Space System: Tasks and Application Areas – K.: SSAU, 2011, - 48 p. – Ukr. and Eng.
Shikin E., Boreskov A. Computer Graphics. Dynamic, realistic images. - M.: “Dialog MIFI”, 1995- 288p.
Stewart D., A Platform with Six Degrees of Freedom. - UK Institution of Mechanical Engineers Proceedings 1965-66, Vol 180, Pt 1, No 15.
Zaichenko Y.P., Fundamentals of intelligent systems. - K.: Publishing House "Word", 2004. - 352



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This dual conception of remote sensing brought us to the idea of preparing two different books; in addition to the first book which displays recent advances in remote sensing applications, this book is devoted to new techniques for data processing, sensors and platforms. We do not intend this book to cover all aspects of remote sensing techniques and platforms, since it would be an impossible task for a single volume. Instead, we have collected a number of high-quality, original and representative contributions in those areas.