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Model of on-line control for the smart object by communication technologies

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Abstract. Based on analysis of opportunities of usage existing models, methods and techniques for on-line monitoring and control of unmanned dynamic objects, a mathematical model of remote estimation of distance to wire-controlled unmanned mobile object is proposed. The presence of model and techniques of remote estimation of distance to wire-controlled unmanned object increases the reliability of control for exclusion of critical situations in the strict radio counteraction conditions and powerful electromagnetic jamming setting during control.

1. Introduction

The development of capabilities of the element base and video equipment allows to implement new principles of construction of autonomous mobile transport [1–6], information and unmanned systems (US) [7–12] with more efficient algorithms for space review, detection, recognition, information processing, coordinate estimation for navigation and control in almost all environments of the Earth: air, water, ground and underground [13–19]. Mobile objects are generally considered to be objects moving at a relatively low speed (about tens of kilometers per hour or less) both on a two-dimensional plane, cross-country, and in three-dimensional space. Developers of unmanned vehicles are actively conducted research aimed at ensuring the autonomy of using US in the conditions of exclusion of the satellite navigation signal based on alternative data sources. These data include, first of all: synthesized image formed by phased antenna arrays of radars; video information taken by onboard photo and video cameras of optical and infrared ranges; digital lay of land data; space photos and aerial photographs, and "signals of natural influence": gravity vector, the Earth's magnetic field, stars position of the Universe [20–24].

Generally, applications of US are wide and varied.US as a universal platform for a wide range of application, among the tasks to be solved, except direct purpose, may include the solution of side tasks, such as automatically patrolling protected areas (for example, their perimeter) [25–30]. An applications of US allows he following: reduce the reaction time to an emergency situation and the number of false alarms; patrol the perimeter (including in the dark); eliminate the influence of the human factor; reduce the time of detection of violations; perform aerial photography and mapping of hard-to-reach areas, while the possibilities of obtaining information is much wider than using airplanes; search people at any time of the day; delivery of individual means of rescue or other small size of cargo in cases where the use of manned vehicles is impossible or impractical (for example, at a great distance from existing airports); it is also possible to use as a communication relay with ensuring restoration, reservation or rapid expansion of deployed networks (lines); high-speed communication with groups; link in hard-to-

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reach areas (including infected, mountainous, marshy, in wooded areas, etc.); communication at high rates of movement and much more [1–13,14–32].

The task of determining the coordinates of the location, range of distance and angular position of US occurs with each case of practical application system. Determination of the coordinates of US is advisable to calibrate at the start before using them, when the elements and units of US came to a steady state, characterized in that all transients from switch-on time are completed. Reliability of control of an Autonomous mobile object is based on a systematic approach, more fully considering all the factors acting in solving the problem – from the method of navigation and features of means ensuring security to the psychological perception of the actions of the system by the operator. The dynamics, mobility and speed of movement of unmanned vehicles, often controlled by man, increase requirements for accuracy of navigation and visualization of vehicle control for operator. Thus, studies aimed at improving the quality of control for navigation of a mobile object in difficult navigation and weather conditions are relevant. Determining coordinates of Autonomous US is an extremely important task, which is solved by using different navigation systems. The most popular navigation systems for determining coordinates of the locations of Autonomous US are [13–18] inertial navigation systems (INS), which are peculiar by characteristic features – increasing coordinate measurement errors as time passes, as well as a sufficiently significant mass and cost. These factors [1–19, 25, 29] determine the limits of their use by aviation and sea transport. For reduce these very significant errors, are used additional means ensuring correction and initial installation of INS. Satellite navigation systems (SNA) [1], which have a number of advantages, such as an unlimited area of application, small size and cost, high enough accuracy, are also widely used. However [2, 13], well-known fact, when hijacking American US RQ-170, carried out by Iranian militaries, through action of external signal formed false coordinates and ensuring landing, shows that development of new means of navigation is relevant. This and other similar facts suggest that increasing resistance to interference is one of the priorities in control of US. The greatest noise immunity to external influences hold principle of control of US by wired or cable line [1, 20], ensuring a solution to a wide range of problems in a localized area of action.

The purpose of article is to create model and method of operational on-line determination range of distance Autonomous mobile object controlled by wire line for improve accuracy of determining coordinates of its position in the conditions of possible interference in the local control area.

2. Method of research

The method used by authors can be attributed to the method of precise reference. This method provides high accuracy of determination absolute coordinates on range even at absence of inertial navigation systems, at zero range of visibility in terrestrial environments and at bad meteorological conditions of application of US. It also allows you to find the absolute position of US with camera even when its approximate coordinates are unknown. This is achieved by scanning entire database with images of the area and comparing them with current image. In addition, having "referenced" picture to range can be determine with high accuracy coordinates of ground objects had detected by optical and electronic video equipment [1,12–27]. The essence of considered method of estimation coordinates on range of distance of US as a method of precise reference of coordinates on range is based on application of model and algorithm of wave method of estimation of properties and parameters of control line of US as a line with dispensed parameters [28–34]. To do this [33–37], we accept in the model that geometric center of US coincides with remote end of control line, with possibility of providing a controlled short circuit (SC) of end of the line. In principle, the method of standing waves is suitable for determining location of control lines damage of US.

3. Equations

The essence the method of standing waves is [32–37] that a high frequency harmonic signal source is connected to disconnected control line of US. In area of high frequencies, the electric control line of US can be considered as electric long line with dispensed parameters. If frequency of the test signal generated by the source and f_0 being the own resonance frequency of electric long line will be coincided, the amplitude value of voltage (current) at the beginning of the control line of US will be maximum. With a sinusoidal test signal of frequency ω, the voltage at any point in the long control line of US can be represented as sum of two terms [33, 38]:

$$U = U_{+m}\exp(i\omega t) + U_{-m}\exp(i\omega t + \gamma x), \quad (1)$$

then U_{+m} is a complex amplitude of direct (+) wave of the test signal, V; U_{+m} is a complex amplitude of back (–) wave of the test signal, V; i is an imaginary number; γ is a propagation constant; x is a distance from beginning of control line to being measured location point of US, m.

The wave propagation in long electrical line is characterized by propagation constant, which generally has a complex form:

$$\gamma = \alpha + i\beta, \quad (2)$$

then α is an attenuation coefficient of wave in the control line of US, characterizes the change amplitude of wave per unit length of the line; β is a coefficient of phase change of an electrical signal in long control line of US [1, 33–35].

The point, in which value of phase of the test electric signal remains unchanged, moves in electric line with v is a phase velocity equal to:

$$v = 2\pi f/\beta\,, \quad (3)$$

then f=ω/2π is a linear frequency of test signal change in the control line. If we consider the initial time of test signal input into control line to be fixed (for example, t=0) and to consider the change of instantaneous value of test signal along control line depending on x being the coordinate of distance of US, then each of terms in (1) corresponds to harmonic wave. The wave described by the first term is a straight or falling wave. The wave represented by the second term is inverse or reflected [33].

If incident sinusoidal wave attenuates (decreases in amplitude) when moving from beginning of the control line of US, combined with the origin of coordinate system of the reference range to US, to end of the control line, combined with center of US, as well as reflected wave attenuates when moving from end of the control line, that is from center of US, to beginning of the control line, that is to origin of coordinate system of the reference range to US.

4. Results of research and discussion

For an example of the algorithm and method of application of the standing wave method [33–38] consider calculation algorithm for control line of US, parameters of which, generally, are given below. The length of the control line of US $l=l_k$, km; specific resistance of the line r_k, Ohms/km; specific inductance of line L_0, H/km; phase speed (wave propagation speed) v=297000 km/s. Suppose that at end of the control line of US (at point of location of US) occurred on single-phase short circuit to ground (the casing of US) [38]. Let determine f_t– frequency of the test signal, when standing waves effect occurs and estimate dispensing of voltage and current in the control line of US at a given frequency of the test signal. Considering this long control line of US as electric line without loss, let us determine f_0 as an own frequency of resonance such control line [33, 38]:

$$f_0 = v/4l_k, \quad (4)$$

Knowing the own resonance frequency of the electric control line of US, you can determine frequency of the test signal emitted into this line:

$$f_1 = 2f_0, \quad (5)$$

then the phase coefficient in the line will determine [33,38]:

$$\beta = \omega\sqrt{(L_0 C_0)} = \omega/v. \tag{6}$$

Figures 1 demonstrate the behavior of the amplitude damping coefficient α and the phase damping β, where α is an attenuation coefficient and β – coefficient of phase change; eq. 2 and 6); Figures 2 – dependence the phase velocity (v) on the distance (l_k) from measured location and f – linear frequency of test signal (eq. 3).

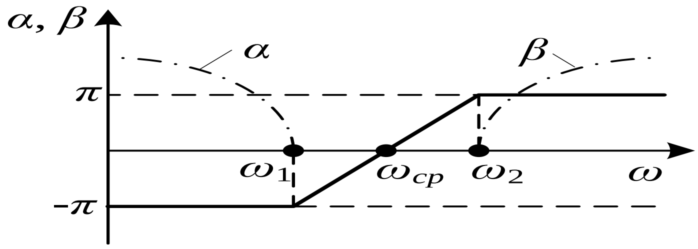

Figure 1. The structure damping (α –attenuation coefficient and β – coefficient of phase change) of the output signal in long electrical line is characterized by propagation constant: α – attenuation coefficient of wave in the control line of US, characterizes the change amplitude of wave per unit length of the line; β – coefficient of phase change of an electrical signal in long control line of U (eq. 2 and 6).

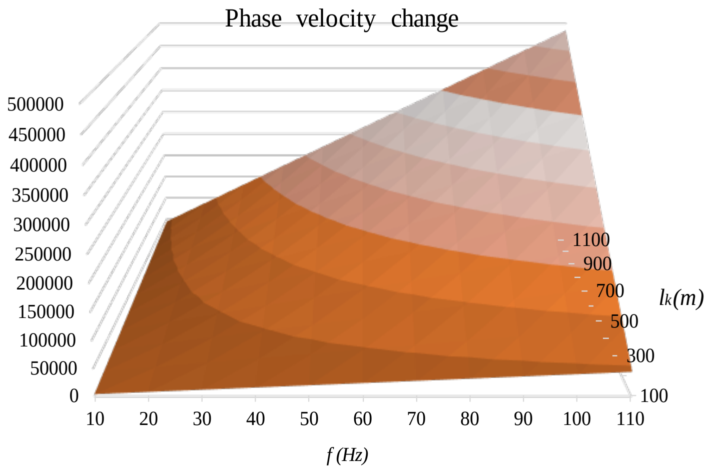

Figure 2. Dependence the phase velocity (v) on the distance (l_k) from measured location and linear frequency of test signal (f) (eq. 3).

The wave resistance of the control line of US will determine [33, 34]:

$$Z_0 = \sqrt{(L_0 C_0)}\ . \tag{7}$$

The length of the test signal wave in the control line of US will be equal to [33, 38]:

$$\lambda = 2\pi/\beta. \tag{8}$$

In accordance with (8), the length of the test signal propagation wave in the control line of US is proportional distance to damage site, in our case, to the geometric center of US. Note that the method of standing waves has been known for a long time, but it hasn't been widely used, because of the hardware complexity.

The modern level of development of electronics, radio, nanophotonics and microprocessor technology allows virtually and hardware with high speed to implement the on-line algorithm and the technique of high-precision remote determination of coordinates on range of distance of US by simply using the existing control line of US and elementary algorithm of the method for determining the location of line damage based on the effect of propagation of standing waves when short circuit in the line occurs [15–18, 21, 39].

The standing waves method supposes measuring total input resistance of damaged control line in a wide frequency range. The input impedance is most easily determined by measuring the current in line at a constant input voltage. Therefore, for determination distance as coordinate to the line closure point, that means to the center of the location of US by this method would requires a high-frequency sinusoidal signal generator, a meter of the input resistance of control line and microcontroller (MC), which in real time measures parameters of the electrical control line. The estimation technique is based on described above control model and distance to the site of damage determination algorithm or point of short circuit of the control line of US is combined with geometric center of US. When connecting to an undamaged line in MC by its definition, the length of this control line defined at the moment is automatically entered. Microcontroller is calculating initial frequency of measurement and forms remote monitoring algorithm and determining coordinate on range of distance of US. At the same time, the input impedance of the control line of US is determined by measuring the current when constant input voltage.

Changing the frequency of the test signal introduced into the control line, the MC finds, at maximum current, resonance frequency of undamaged line [33,34]. Subsequent connection to other lines associated with investigated US, their resonance frequencies are calculated [38]. By the ratio of frequencies of resonance at the length of the control line, MC is calculating distance to US, which corresponds to the point of given short circuit or damage of the control line of US [1, 33, 34]. Their coincidence with geometric center of US corresponds to coordinate on range of distance of US; non coincidence indicates problem with this control line.

The simulation results, numerical results and analytical description [35–38] statistically with a satisfactory accuracy of ~10% of the linear size of US coincide with data obtained on above mathematical model [35–41].

5. Summary

The method of determining coordinates of the location of US, controlled at the communication line, by remote on-line estimation on range of distance of US with knowledge of the angular position are similar to the methods used by man for orientation in three-dimensional space. The application of the above method in the management of deep-sea US during study of the sea depths, as well as US designed to work in hard-to-reach, man-made dangerous or closed earth and water spaces: dungeons, catacombs, caves and labyrinths of any type of environments is especially efficiently. Computer simulation of algorithm for remote on-line estimation of US's removal in closed earth space proved principal possibility of achieving position coordinates estimation of US by the wave method with an error not exceeding 0.01% of resonance frequency of US's used control line. When using the remote method for estimating on range of distance of US together with video navigation, which ensure provides an image of the terrain by camera, with subsequent analysis of this image by a special processor or computer, an exhaustive complete set of coordinates can be obtained for ensure Autonomous orientation of US. Based on the summary, the following conclusion can be drawn. The considered model, algorithm of estimation and technique of realization of the remote method for determining on range of distance of US by the wave method based on standing waves effect used for monitoring the state of electric lines and determining places of damage or short circuit in the lines is highly effective for remote monitoring of US state in critical and life-threatening situations, in hard-to-reach and rough terrain.

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