Perspectives for Development of an Autonomous & Intelligent WIG-Craft and its Peculiar Control Problems

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Abstract: In the paper a scientific and technological analysis has been presented for the viability, advantages and highly successful prospects for the realization of an Autonomous and Intelligent Wing-In-Ground Effect Vehicle mainly for Coastal Patrolling and Search & Rescue Operations. The necessary Autopilots and Automatic Control Systems have been proposed and described especially considering such vehicles for their various modes of motion**.** Also has been described the special Phase-Radioaltimeter created in IIAAT for such purposes and missions. Some alternate sources of power and energy for such systems for round the clock sea surveillance have also been suggested for such highly promising and highly advanced next generation intellectual amphibious vehicles**.**

Keywords: Intelligent vehicles, automatic control, integrated navigation systems, data fusion.

1. INTRODUCTION

Thousands of years ago humans strived hard so that they allow the human civilization to sail and navigate and constructed ships. A century ago, the Wright brothers helped fulfill the great dream of letting humans fly. But now it is ironical to note that we currently strive hard to get humans out of such vehicles and let man-made systems sail and fly without humans but as per his desires as these are the demands of the future.

Autonomy is commonly described as the ability to make decisions without human intervention. Thus, the main aim of autonomy is to teach machines to be “smart” and act more like human beings. One may pay attention to the fact that the development of autonomous vehicle is closely associated with the development in the field of artificial intelligence, expert systems, neural networks, machine learning, natural language processing, and vision.

However a great part of the contribution to the field of autonomy may also be attributed to Control Sciences, and not just Computer Science. In the near future, the two fields will merge to a much greater degree, and specialists, practitioners and researchers from both disciplines will work together to bolster rapid technological development in the area.

Because Unmanned Vehicles are not burdened with the physiological limitations of human pilots, they can be designed for maximized on-station situation times. The maximum flight duration of unmanned aerial vehicles varies widely. Internal combustion engine vehicle endurance depends strongly on the percentage of fuel burned as a fraction of total weight and so is largely independent of vehicle size. Of course a few types of conventional UAVs (Unmanned Aerial Vehicles) are able to perform very low-altitude flight close to the sea surface. But the stabilization and control at extremely low altitude is a very complex task.

As for WIGs, they are specially designed for performing such low-altitude motion and if apprpriately designed, stability is highly supported by the Dynamic Air-Cushion itself besides having many other important advantages, the most important being the ability to integrate many properties, characteristics and functions of both a marine vessel and an aircraft only in one transport vehicle (Fig. 1).

A significant amount of development has already taken place in the field of Unmanned Aerial Vehicles (UAVs) and Unmanned Surface Vessels (USVs).

Such continuous developments have now paved the path for developing Unmanned WIGs which are aimed to integrate many properties, characteristics and functions of both the UAVs and the USVs. The task is in many cases simpler and more advantageous than Unmanned Aerial Vehicles.

Fig 1. Prototype of the Autonomous WIG being developed in IIAAT

2. UTILITIES & ADVANTAGES

2.1 Prospective Utilities

1. The main area for the use of such vehicles is for Coastal and Maritime Surveillance. Round the clock patrolling is a major issue for any coastal region.

2. Anti-Pirate, Anti-Smuggling and Anti-Illegal Immigration Tasks. Generally the Navy and Air Surveillance, AWACS and Surface Monitoring Satellites work together to monitor such activities in many developed parts of the world. Unmanned WIGs provide the opportunity to contribute to these joint tasks. In many regions however such Autonomous, Intelligent and Smart Unmanned Ekranoplanes may be sufficient and self-dependent to solve such problems.

3. In places where ships, hydrofoil vehicles and helicopters are too slow and aircrafts are not able to carry out very low altitude tasks.

4. Anti-Terrorist and Peace-Keeping Operations. May be equipped with ammunitions for critical situations. No human pilot's or sailor's life to be risked. Another feature of Ekranoplanes is that they have very low radio and infrared signature and are difficult to be detected on the submarine SONAR.

5. They may be deployed either singularly for surveillance of different regions, or else a number of such vehicles may be used for Joint and Combined Autonomous Operations. Some special algorithms have to be developed when a group of such vehicles have to work together.

6. Many other features include reconnaissance, sea-loitering and air-loitering.

7. They are less prone to mine-threats while engaged in Patrolling. Thus may be used for purposes where human life cannot be threatened and ships and hydrofoils may not be risked.

8. Further another utility may be the usage of such crafts for the launch of Micro-Aerial Vehicles to broaden the efforts during Search & Rescue operations.

9. Ecological Monitoring may be another important task for such vehicles. They may be extensively used where ships, boats and hydrofoils are too slow and aircrafts find it difficult to carry out extremely low flight.

10. For the purpose of Marine Surveys and Geological Monitoring.

11. Servicing and Maintenance of Oil Rigs;

12. Some large sized variants may be used also for urgent transportation of goods. This may be considered merely as a secondary option. Commercialization in rough weather conditions where the life of the pilot or the sailor cannot be endangered.

13. Search and Rescue Operations. A few of such vehicles may be deployed in different regions for round the clock SAR Missions.

14. In regions which are more prone to natural calamities such as tsunami, volcanic eruptions or earthquakes near an island. Once again the main idea is to minimize human life threat by using unmanned and uninhabited vehicles. They may also be used to monitor such regions. It can go into "the dull, the dirty and the dangerous" situations and areas, the main advantage being, it is unmanned thus executing potentially dangerous environmental monitoring.

15. Type B or C Ekranoplanes are able to execute their pre-programmed mission tasks not only from extreme low altitudes, but also from high and in some cases comparable to aviation altitudes.

16. Such vehicles may be used to carry out extensive R&D Activities and study the complexities of Ground Effect. Such vehicles will not carry either passengers or crew, thus providing a broader and safer opportunity to experiment and research even on very large sized variants.

2.2 Important Advantages of the Autonomous & Intelligent WIG-craft:

Besides the many important advantages of Ekranoplanes like absence of the necessity for runway and possibility to perform special operations using amphibian property, they can take-off or land from the surface of land, water or ice, there are many other specific advantages which can be fulfilled by Unmanned Ekranoplanes. These include:

- Cost of construction, maintenance and exploitation below piloted or manned Ekranoplanes;
- Exploitation is also cheaper as compared to manned Ekranoplanes, also the thrust needed for propulsion is lesser than manned Ekranoplanes of comparable size as there are no life-supporting systems, also there are no necessities to pay wages to pilots;
- In the case of an emergency pilot-less ekranoplane may simply alight on the sea surface and increase their survivability. They may be equipped with special systems for transmitting "Distress Signals" using GLONASS or GPS SNS up to the next few days so that the unmanned WIG vehicle may later be recovered, repaired and then again be re-used;
- Reduced requirements towards engines reliability and, therefore, possibility of their fuller use of service life as compared to manned WIG;
- Reduction of the quality and complexity of other type of patrolling vehicles (patrol boats, ships, hydro-acoustic helicopters and hydrofoils) as many of their tasks for a particular region may be solved by such Autonomous WIG crafts.

- Reduction of the requirements of commissioning large number of officers for naval surveillance. Many of these tasks may be solved by the Autonomous, 'Smart' and Intelligent Unmanned Ekranoplanes.

3. SPECIFIC CRITERIA

3.1 Autonomy technology that will become important to development of Intellectual WIG

- Sensor Systems Development: Combining information from different sensors for use on board the vehicle.
- Communications: Handling communication and coordination between multiple agents in the presence of incomplete and imperfect information.
- Motion planning (also called Path planning): Determining an optimal path for vehicle to go while meeting certain constraints, such as obstacles.
- Trajectory Generation: Determining an optimal control maneuver to take to follow a given path or to go from one location to another.
- Task Allocation and Scheduling: Determining the optimal distribution of tasks amongst a group of agents, with time and equipment constraints.
- Cooperative Tactics: Formulating an optimal sequence and spatial distribution of activities between agents in order to maximize chance of success in any given mission scenario.

3.2 Usage As a Launch Platform for Micro Aerial Vehicles in the Coastal Region

The term **micro air vehicle** (**MAV**) refers to a new breed of remotely controlled aircraft (UAV) that are significantly smaller than similar craft obtainable with the current state of the art. The target dimension for MAVs today is approximately six inches (15 centimeters) and development of insect-size aircraft is reportedly expected in the near future. Potential coastal surveillance, patrolling and serach and rescue operations may be the driving factors to broaden and deepen the missions.

Three types of MAVs are under investigation. Airplane-like fixed wing model, bird- or insect- like ornithopter (flapping wing) model, and helicopter-like rotating wing model.

3.3 Embedded Software for Autonomous, Intellectual WIG:

The first requirement for physical autonomy is the ability for an unmanned vehicle to take care of itself without causing a threat to its environment while still trying to maximize its mission's success rates. As per the study carried out in IIAAT, the folllowing tasks may form an important part to be implemented by the Embedded Software for Unmanned Ekranoplane.

- Embedded Power PC real time solution;
- Advanced System: Configurable to Wing-In-Ground Effect mode and also during Free Flight mode;
- Waypoint Navigation (GLONASS, GPS, D-GPS, INS);
- Special Fail Safe Navigation Mode;
- Dynamic real time gains, limits etc. adjustments;
- Dual extended Kalman Filtering for precision navigation;
- Compressed digital image transferring;
- Autonomous Launch or Autonomous Take-Off from land, water or ice surface, Autonomous Flight in different modes as well as floating on the sea surface, Autonomous Landing;
- Return Home Mode for communication loss, GLONASS/GPS signal loss, etc.;
- Communication Relay Mode;
- Customizable software filters for noise reduction in sensors
- Auto target coordinate detection through INS support;
- Fault tolerance embedded software;
- Special Programs for supporting the joint operations of many such unmanned Ekranoplanes working together.

3.4 Computational Intelligence:

- Neural Networks;
- Fuzzy Systems;
- Evolutionary Computation;
- Hybrid Intelligent Systems;

4. SPECIAL REQUIREMENTS

In order to fulfil its operations and missions successfully, the following points must be given proper attention, also allocation for such systems, algorithms and programs must be carefully developed taking into consideration the necessities for its various modes of motion:

- Robust and Optimal Control Methods & Algorithms;
- Special Automatic Control Systems and Flight Parameters Monitoring System;
- Artificial Intelligence;
- Pre-Programmed Flight Control;
- Usage of GLONASS and GPS SNS for Navigation;
- Limited Ground Station Control for special modes and missions;
- Decision Making;
- Intelligent Systems;
- Real Time Operations;
- Asynchronous Learning Environments;
- Network Centric and Networking Operational Effectiveness
- Team Effectiveness;
- Robust acquisition of Re-locatable Targets using MMW Sensors;
- Smart Antennas;
- Antenna Arrays;
- Auto-calibration;
- Beam Forming;
- Conformal Structures;
- Imaging Arrays;
- Integrated Systems;
- Space Time Adaptive Processing;
- Tracking Arrays;

- C3ISR;
- Situational Awareness.

5. PECULIARITIES OF MOTION CONTROL

WIG-effect is an interesting physical phenomenon with multilateral characteristics, having positive and negative influence for providing the flight at extremely low altitudes. For motion of WIG-craft near the surface it is necessary to take into account a series of specific physical characteristics, related with the influence of the WIG-effect on aerodynamic forces and moments.

It is well-known that for the essential action of WIG-effect the altitude of ekranoplane flight has to be less than a half of the wing chord. The size of ekranoplanes should allow maintaining an optimal altitude at cruise mode and not be too limited by the height of sea waves.

Unfortunately, an ekranoplane has the essential instability of motion in the longitudinal plane and perfect automatic control system is necessary first of all for providing the flight stability. For heavy machines the automatic control systems are required definitely. For smaller ekranoplanes many attempts to exclude any automation of motion control are known, but only the grim necessity to lower the cost of commercial vehicles causes such attempts that certainly degrade the safety of motion.

Trouble-free motion close to the disturbed sea surface may be guaranteed by the application of special methods and means of navigation and control, which have the capability to solve the following specific problems:

- The precise control of the altitude of motion with the error not above 3-10 cm;
- Restricting the angles of airframe inclination for prevention of undesirable tangency of water by the extreme points of body or wing;
- Ensuring of the vehicle stability in the circumstances of the action of flake non-linear aerodynamic effects near the surface;
- Non-contact measurement, tracking and prediction of ordinates and biases of the field of sea waves for the rising of motion control effectiveness.

Certainly, the automated control for WIG-craft is a necessity to prevent accidents and the automation of motion control has to be callable for all ekranoplanes.

6. SOURCES OF ENERGY AND POWER

The primary source for power and energy definitely has to be the engines installed on the vehicle. Apart from them another important alternate source of power may be solar energy. Solar Electric Cells may be installed on the vehicle thus helping in solving long-term energy problems and also increasing the range and endurance. When multiple unmanned WIGs are together being used for joint operations, a new method to execute in-flight re-fuelling from one autonomous vehicle to another may be an interesting topic for research in the future.

Some contemporary research activities in the world have also proposed the idea of nuclear energy as a source of energy, but for such autonomous vehicles, the use of nuclear energy is rather very risky and hazardous. In principle it is simpler to construct unmanned vehicles running on nuclear fuel as compared to manned vehicles. Even the latest current level of cutting-edge technology does not ensure safe methods for such an implementation.

7. CONTROL LAW SYNTHESIS FOR THE AUTONOUMOUS AND INTELLECTUAL WIG

It is possible to execute the altitude control under the change of wing lift force in:
a) Trailing-edge flap deflection;
b) Elevator deflection (thus a pitch varies);
c) Change of speed of flight at the expense of engines thrust control.

As at pitch angle variation, the drag and, therefore, the flight speed changes, the version *b)* demands the presence of velocity stabilization system. Thus all channels of the control complex substantially participate in the maintenance of the ekranoplane demanded motion in the longitudinal plane. The synthesis of control laws can be fulfilled under the several criteria, but their general structure appears to be almost similar in the majority of cases. The estimations of the vehicle stabilization errors, linear and angular rates and also wave disturbances, being filtered accurately, have to be used at the formation of control signals. Now the main problem of a good accuracy and measurement instruments for WIG crafts has been solved with the development in IIAAT of the Phase Radio Altimeters (RA) specially designed for low fly altitudes (Fig. 2).

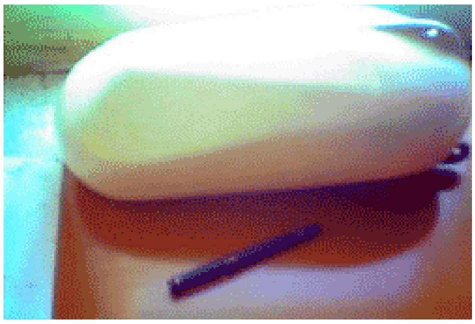

Fig. 2. Precise Phase Radio Altimeter (RA)

The flight parameters measuring system was designed for an experimental WIG-craft. It is intended for control and record of flight parameters:
- Altitude of flight up to 5 m with accuracy 5 cm;
- Speed up to 180 m/s with accuracy 0.1-0.2 m/s;
- Roll and pitch angles with accuracy 0.1-0.2 deg;
- Vertical overloads up to 3g with accuracy 0.06g;
- Considerable sea waves height up to 1.5 m with accuracy 5 cm.

Primary sensors were: 3 special radioaltimeters, vertical reference system, multi-antennas DGPS receiver, etc. They were integrated with the aim of improving the accuracy and providing the fault-tolerance properties.

The characteristics of RA are:

- Altitude (or distance) measured - 0-10m;
- Error - not more than 5 cm under sea state number 0-5;
- Measured parameter frequency range - 0-50 Hz;
- The operating RF - from X-range (9000 MHz);
- Radiated power - 20 mW;
- Power consumption - 2 W;
- Output signal - digital and analog;
- Mass - 1.2 kg;

8. DEVELOPMENT OF CONTROL SYSTEMS FOR INTELLECTUAL WIG

Structure of algorithm of a complex filtration of measurements of RA and vertical accelerometer on the channel of height will be installed for the measurement of height, pitching angle and banking.

The algorithm of complex filtration of measurements of RA and vertical accelerometer (Fig. 3) includes:

- The block of recalculation of measurements RA on a point of installation Inertial Unit (IU);
- The block of recalculation of an estimation of altitude from a point of installation IU on CG ;
- The filter of altitude (Filter 1);
- The filter of vertical acceleration (Filter 2).

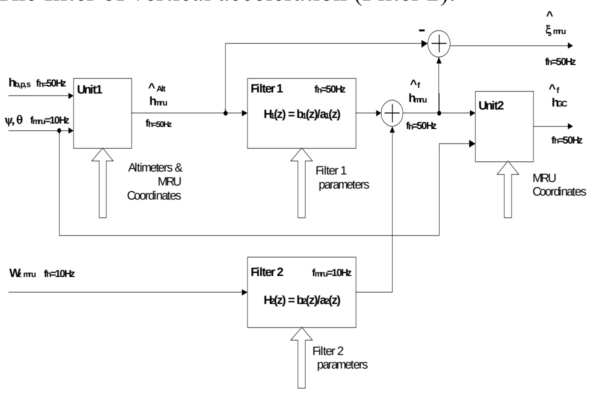

Fig. 3. The block diagram of algorithm

With the use of three described radioaltimeters, the integrated system for measurement of parameters of motion close to a sea surface can be built, the compact INS is also included in the system. This INS involves three angular-rate sensors, three linear accelerometers, calculator and temperature transmitter for compensation of temperature drift of angular-rate sensors and accelerometers.

The structure of integration algorithm for altimeters and vertical accelerometer output signals involves:

- The unit of recalculation of altimeters outputs to a point of IU installation (Unit 1);
- The unit of recalculation of the altitude estimations to the point of centre of gravity CG and to the points of altimeters installation (Unit 2);
- The filter of an altitude (Filter 1);
- The filter of a vertical acceleration (Filter 2).

The recalculation of altimeters outputs to CG is executed under the formula

$$h_{GC\_K} = h_k - x_k\psi + z_k\theta - y_k,$$

where the index $k=n,l,r$ (n - nose altimeter, l - left side altimeter, and r- right side altimeter). For recalculation of altitudes from a point of CG to a point of INS installation the relation

$$\hat{h}_{INS}^{Ail} = \underset{k}{med}(h_{GC\_k} + x_{INS}\,\psi - z_{INS}\,\theta + y_{INS})$$

is used, where med (.) is the operation of median definition. The formula for recalculation of the filtered value of an altitude from a point of the IU installation

to CG (Unit 2) looks like:

$$\hat{h}_{GC}^{f} = \hat{h}_{INS}^{f} - x_{INS}\,\psi + z_{INS}\,\theta - y_{INS}\ .$$

The filters of an altitude and vertical acceleration have the transfer functions:

$$H_1(s) = \frac{\tau^2 s^2 + 2\tau k_3 s + k_3}{s^3 + \tau^2 k_3 s^2 + 2\tau k_3 s + k_3}$$

where

$$k_3 = 0.035\ c^{-3} \qquad \tau = \frac{1.32}{\sqrt[3]{k_3}} = 4.035s$$

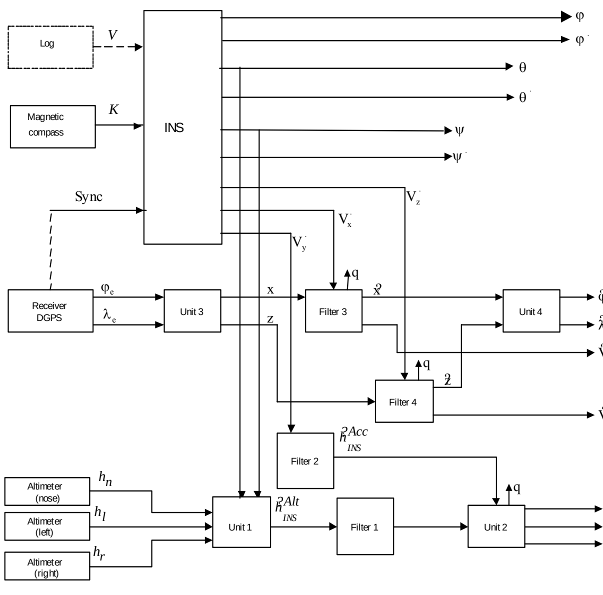

Fig. 4. Block-diagram of the integrated measuring system

In discrete time the structure of filters is described by the formulas:

$$H_1(z) = \frac{b_2^1 z^2 + b_1^1 z + b_0^1}{z^3 + a_2^1 z^2 + a_1^1 z + a_0^1} \qquad H_2(z) = \frac{b_2^2 z^2 + b_1^2 z + b_0^2}{z^3 + a_2^2 z^2 + a_1^2 z + a_0^2}$$

The measuring system allows tracking the profiles of sea waves ξ_n, ξ_l, ξ_r in three points (Fig.4), corresponding to the points of radioaltimeters installation at a nose and both sides of the vehicle, with the accuracy 10 cm at seaway number 4. Separately, that is important for optimization of a mode of landing approach and splashdown. Separately the problem of automatic estimation the general direction of sea waves spread was solved, that important for the optimization of landing on water. The problem of automatic estimation of the general direction of sea waves propagation with the use of three radioaltimeters outputs will be lighted.

9. CLASSIFICATION - IMO or ICAO

It remains an important question to be solved whether the classification of such vehicles will fall under the authority of IMO or else ICAO. Type A WIGs are completely under the guidelines and authority of IMO.Type B are partially IMO and partially ICAO and Type C WIGs are mainly under the authority of ICAO. However special guidelines have to be laid down for the probable realization of such autonomous vehicles in the future.

10. FUTURE PROSPECTS

- The applications of such autonomous, intelligent and unmanned vehicles may be broadened to more extensive fields upon the successful and reliable development of the maritime surveillance vehicle.
- Future Autonomous and Unmanned Ekranoplane may include very large sized cargo transport vehicles up to the size of ships or even larger using the Ground Effect principle and the dynamic air cushion and their advantages but moving at a speed ten times faster than that of a cargo vessel.
- As compared with UAVs of the same size, unmanned ekranoplanes are generally cheaper to construct, maintain and operate. Thus commercialization of such vehicles may be an interesting idea in the future for multi-utilities.
- Another future development may be in the field of modifiable aero-hydrodynamic structures and the possibility to make a temporary dive under the sea surface (for example, may be during a storm or other externally critical environmental situations) and then coming out and continuing in its conventional mode of motion.

11. CONCLUSION

A significant amount of development has already taken place in the field of Unmanned Aerial Vehicles (UAVs) and Unmanned Surface Vessels (USVs). Such continuous developments have now paved the path for developing Unmanned WIGs which are aimed to integrate many properties, characteristics and functions of both the UAVs and the USVs. The Autonomous, Intelligent and Unmanned WIG Effect provide a very important and useful method to solve the problems of Maritime Surveillance, Coastal Patrolling and also extensive Search & Rescue Operations.

It remains a significant question whether future developments of autonomy technology, the perception of this technology and most importantly the political environment surrounding the application of such technology will limit the development and utility of autonomy for the applications in UAVs, USVs or Unmanned Amphibious Wing-In-Ground Effect Vehicles.

Compared to the manufacturing of Unmanned Vehicle hardware for both UAVs and USVs, the market for autonomy technology is fairly immature and undeveloped. Because of this, autonomy and intelligent systems have been and may continue to be important bases for future unmanned vehicle developments, and the overall value and rate of expansion of the future unmanned vehicle’s market could be largely driven by advances to be made in the field of autonomy and intelligence.

The future research will concentrate on making such Unmanned Ekranoplanes more intelligent by providing important and appropriate Artificial Intelligence-Conventional AI and Computational AI.

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