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Official and author's review of PhD thesis titled

Application of a Digital Terrain Model; Increased safety of small and middle-size unmanned aerial vehicles; Development of its capabilities

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Introduction, scientific problem definition

Modern aircrafts (referred to as UAV[1]) are being used increasingly with an automatic pilot. The reason for the need of quick development is due to the advantages in comparison to the traditional aircrafts. The newer modern craft can carry out research activities and explorations in dangerous and difficult to negotiate areas. A mission can be directed from a safe distance without endangering the safety of human pilots and fellow researchers. Furthermore, the operation and maintenance of the UAV takes less time and is more cost efficient as is the training of the aircraft personnel. No health requirements are of concern. The UAV brings into consideration a perspective to the space requirements e.g. taking away that which is normally necessary for humans to carry on board. Space is better utilized for the research equipment and purposes.

It is also important to note the disadvantages associated with the UAV. Communications[2] from control towers must be finely tuned and stabilized to ensure safety.

A problem arises when there is an interruption in communication leaving the aircraft without control and consideration of possibilities for the aircraft to rebuild that communication. There needs to be the capacity to carry out the task independently.

Currently the majority of UAV aircrafts are not capable to fulfill tasks e.g. making orthophotos[3]. Due to their small size there is a limit to the loading capacity on the deck. This results in a lower altitude of flight stabilization and its ability to fly at an appropriate height.

During the discussion of my research I will go into detail on the flight safety of UAV aircrafts flying at a low to medium altitude[4]. As well, I explore possibilities of developmental improvement for the utilization of these aircraft.

Is there a possibility to increase the safety of the flight to avoid communication instabilities and events occurring due to the not-well planned route? An important question is posed - can it be done without increasing the quantity of the required freight?

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[1] Unmanned Aerial Vehicle

[2] A UAV can use several radio channels at the same time. (e.g. control channel, data channel) The range and stability of those limit their use.

[3] Near vertical axis, an aerial photo prepared by an optical camera, lacking in any perspective distortions which equals to a geographical projection.

[4] 10 – 500 (1,000) meters.

Can a solution be found for the perspective[5] digital air photos to be made in an optional position by UAV aircraft from a low to mid height, and then be transferred into an orthophoto image?

We should never give up safety of any flight. During a mission, UAV should by all means carry-out its given task and if it is not planned for a single application it must return. If this principle cannot be adhered to, in spite of all the advantages, the general use of UAV aircrafts could be hindered. Damages can be caused during an event. One of the instruments or collected data can get lost or get into the hands of incompetent persons. Furthermore, accidents may occur.

The UAV value could be increased – based on the current structure - if it were able to fulfill tasks that can be carried out only by special and very expensive systems. Due to the limited space, built–in instruments could be replaced with computer programs and data bases.

My research aim is to demonstrate solutions enabling UAV aircraft to carry out its tasks more safely, developing its capacities and possibilities to complete more functions.

This discussion concentrates on three points as follows:

- Analyzing propagation models for determining availability of a control tower
- On the basis of pre-planned co-ordinates[6], determining a safe route in relation to the height altitude and elaborating the mode of flight
- Making digital orthophotos, compensating deformations caused by the relief and the perspective digital aerial photos followed by the transferring of these to orthophoto maps.

During my research I determined the functions and tasks that can be integrated into the computer system of the control tower and/or of the UAV by making use of the possibilities offered by the Digital Relief Model[7] (referred as DRM) and the Digital Terrain Model[8] (referred as DTM).

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[5] If the projection plane and the object plane are not parallel, during projection the parallels won't be parallels. By affine transformation no connection can be established between the projection plane and the object plane.

[6] Series of coordinates which UAV has to fly above in sequence to complete its mission.

[7] Digital database containing the data of the terrain in systematic layers (e.g. terrain, hydrographic map, etc.) DTM could be a layer of DRM.

[8] Digital database containing the terrain's height data from which the height of any terrain location (with given coordinates) can be trapped.

This thesis has connections to other theses and relevant publications on the safety of UAV and therefore is supplemental to those.

Research aims

1. To examine the effect of stability in communication between the control tower and UAV – in case of different control models – on the successful fulfillment of the mission and on the safety of the flight. To analyze the applications of certain propagation models and to suggest how the coverage-diagrams and the shield-diagrams produced by applying the DTM can be integrated into the planning and fulfillment process of the UAV mission so that it will be more successful and the flight will be safer.
2. To demonstrate that during planning of and carrying out flights, the routes cannot be so exact and cautiously planned due to a three-dimensional place appearing in two dimensions on the map and on the monitor. To suggest how to plan flight routes with safe heights and to implement safe automatic terrain-following flights, the aircraft must avoid obstacles on the terrain. The flight route is described by three-dimensional coordinates originating from surface coordinates.
3. To prove that DTM and the program/s developed for its application are able to compensate the deformation caused by the relief and the perspective digital aerial photos can be produced by a relatively cost- effective and simple method.

Applied research methods

Besides collecting and systemizing information and data from the relevant literature, I carefully adapted and analyzed the results of the research. I tried to achieve the aims of my research by applying the methods of synthesis, induction, deduction, modeling and simulation of the UAV context.

I worked out algorithms and procedures based on my interpretation of the research literature. In testing these while observing their operation and analyzing the data, I created computer programs which can run in the Borland Pascal 7.0 computer application system.

On the basis of the results in having run these programs I could analyze the effects of the collected data changes and draw conclusions. I am going to demonstrate the uses of data bases and through the application of two models. These diverse models have different co-ordinate systems. The radio channel was introduced through a data base, ‘DTM-200’ (It is a

Digital Relief Model, Gauss-Kruger[9] projection system) the route planning was completed through the data base 'DDM-50' (It is a Digital Terrain Model, EOV[10] projection system).

The elaboration of the perspective digital photos (determination of the co-ordinates) was carried out through a generated DTM database.

Besides making research in the literature, I attended scientific conferences, symposiums, where these topics were discussed.

I consulted with prominent experts in this field who contributed to and helped with my work by giving information and advice, answering my questions and providing additional scientific resources.

Thesis structure

The first chapter entails descriptions of the basic modes of UAV. From them, I would like to emphasize the effect of the communication stability between a control tower and UAV on the safety of the flight.

In the event of the flight being in a low to medium height position, the calming effect of the terrain relief on the radio channel cannot be neglected. Using models with wave signal diffraction I will introduce the methods for estimating the over-reduction caused by the terrain relief.

Based on the estimated value of section reduction and the volume of the dominant ground obstructions the expansion models have been analyzed by considering the terrain heights data in software I developed. The height data filtering from DTM and terrain segment algorithm have been developed that became the input data of the expansion models. The conditions of the preparation of the coverage-diagram and the shield-diagram within the flight planning design of the UAV have been established by the combined use of the expansion models and DTM.

[9] Oblate spheroid's (Kraszovszkíj) tangent, angle-keeping cylindrical projection of transversal location. The Hungarian Army does not use this projection system any longer because of the map change made on 2004. Regarding that I started my research before that date when the above mentioned database was available; my research is based on this projection system.

[10] As a first step we project from the IUGG1967 ellipsoid to the Gauss-sphere with the ellipsoid's spherical projection, and then we project with a single slanting-axis cylindrical projection with two longitudinal auxiliary parallel circles and reduced distance-keeping cylindrical projection to the plane. This is called United National Projection (Egységes Országos Vetület).

In the second chapter I pointed out the dangers when modifying the flight routes. I demonstrated that the data processes which need to have a safe route plan are not simple when determining the minimum height of safe flight and when considering the technical possibilities of the UAV.

I worked out algorithms for setting flight routes by the application of DTM so that a route can be flown safely with the consideration of the abilities of UAV and the effects of the terrain. Therefore this mode of flight is able to follow the terrain.

In the third chapter, I discuss the causes of UAV inability to make orthophotos. These days, UAV can transport the smaller version of high standard devices for making photos and aerial videos. I go into details how the digital aerial photos made by UAV can be later processed with cost-effective means.

A mathematical apparatus has been created by the application of DTM through the implementation of a three-dimensional co-ordinate transformation (transferability between two two-dimensional co-ordinate systems); this tool helps to transfer the good quality digital perspective aerial photographs taken by the UAV into orthophotos; in a given co-ordinate system the different orthophotos could be united into an orthophoto map, which could be the base of the development of a new DRM layer.

With the help of computer programs developed by myself – on the basis of digital photos made on spots equipped in advance – I modeled the operation of algorithms and procedures built on mathematical apparatus. I analyzed the results as to the determination of co-ordinates at the strategic point and the conversion of digital perspective photos into digital orthophotos[11]. From this I worked out how to combine those two elements involving the photos.

The three directions and aims of this research found within these chapters serve to the development and capabilities of flight safety of the UAV. That which can be determined from this depends on the given construction as well as future construction possibilities within a certain type of UAV system.

[11] In fact orthophotos are prepared on the basis of a very strict specification. Digital cameras do not meet the requirements of the photogrammetry cameras, but the transformation of the photos made by central projection into photos of orthogonal projection results in an “orthophoto-like” picture.

Conclusions

The development of UAV and its scientific focus is no longer questioned by anyone. The research of this topic is multidisciplinary science and several engineering areas are united.

The topic concentrated on the flight safety of UAV aircraft flying at a low to medium altitude as well as on the possibilities of developmental improvement of its capabilities.

In order to increase the flight safety, I examined the possibilities of modelling the radio channel finding out those terrain route sectors where the communication between the control operators and aircraft may become uncertain.

Another point explored included ways to avoid the subjective human errors made during pre-planning routes by taking into consideration the dangers caused by the deformation of the terrain and the condition system worked out for the mode of flight associated with the given terrain. As to the viability of these results it is essential to make sure that the programs and databases can be implemented into the system of the available UAV aircraft or envisaged to be purchased. If not, the programs for route planning and for controlling the communication can be run only on a separate system. If an existing system or one under development is possible without restrictions, it can serve as a base to carry out algorithms or similar that are able to handle the emergency situations.

The possibilities of the UAV aircraft flying at a low to medium altitude are restricted because it cannot be loaded beyond certain extent. I examined how the aerial photos made by UAV can be transformed into orthophotos. This procedure is quicker in reaction, more cost-effective in comparison to previous operation costs in line with qualification of operators and provides a greater fulfillment of the task.

As an experiment during the research I made photos on a prepared area. I wrote and ran programs by applying terrain models generated by the computer. This was to find out whether my assumptions and algorithms could be applied.

I defined a number of processes and algorithms that could be built on and integrated with the existing architecture. These processes and algorithms could be built-in either within the computer of the ground control unit or within the board computer of UAV. During the flight planning, organization and operation they increase the safety of the flight and simplify the tasks of the flight planning and operation. They increase the potential use of UAV. At the same time the use of other, more expensive sources can be disregarded.

In summary, I have examined three separate scientific problems. Each is based on the potential use of the DTM. The result of this complex work points to a safer operation and expanded technical capabilities of UAV. These research areas are new nowadays with few samples of similar research, development of planning processes and photo processing procedures in the development and application of UAV flying at a low to medium altitude.

New scientific results of thesis

I regard the following as scientific results of my thesis:

- I found that the preparation of the Deygout-type of coverage-diagrams and shield-diagrams are necessary to increase the flight safety of UAV flying at a low to medium altitude. I came to this conclusion by examining the diffraction expansion model of the radio channel used for the operation control of the aircraft.
- I prepared the theory of the flight planning system of UAV and the software of a practical model; the latter allows the terrain-following operation of UAV by the application of DTM and reduces the operator’s human errors in flight planning.
- I prepared the theoretical foundation and demonstrated it with practical experiments how to transform terrain-distorted perspective photos made at low and medium altitude into an orthophoto by meeting certain requirements. Furthermore, an orthophoto map can be created by uniting the transformed photos, thus the potential use of UAV can be expanded.

References, practical use of thesis

In my thesis I identified the complexity of the mission planning of UAV flying at a low to medium altitude. Considering the continuity of communication and examining the radio channel it turned out that algorithms can be prepared for the expansion models investigated. With application of the expansion and terrain models the feasibility of the connection can be forecasted, however this is only theory. The behavior of each model is different. It is recommended to compare each expansion model with practical experiments on the terrain to prove that the Deygout diffraction model is the most suitable for the preparation of the coverage-diagram and the shield-diagram.

The application of those diagrams during flight planning and operation may contribute to the success of the mission. I strongly recommend including the preparation of those diagrams into the flight planning processes. The potential to create a flight path that contains terrain data reduces uncertainties for the planning personnel. However, it is advised to compare those results with traditional flight planning to ensure efficiency and safety.

I recommend testing the results by flight tests, which may identify any discrepancies between the aircraft's own system and mission requirements. Any errors made during modeling the perspective photos made by UAV flying at a low to medium altitude can be identified only by practical tests.

I call the attention of the researchers and engineers of UAV to consider that the software used by the aircraft and mission control can be modularly expanded. My thesis can be utilized in further research and technical education.

List of self publications

[1]. Ványa L. – Horváth Z.: Többfunkciós oktatástechnikai rendszer kialakítása a korszerűbb elektronikai hadviselési tisztképzésért. (Bolyai Szemle 1998. VII. évf. 2. szám p98. – 102. Budapest, 1998. ISSN 1416 1443 (társszerző 1/2);

[2]. A térinformatika katonai alkalmazása a digitális harcmezőn (Robothadviselés Nemzetközi Konferencia, ZMNE, Budapest, 2001. november, előadás és konferencia kiadvány);

[3]. A digitális domborzat modell alkalmazása az URH és mikrohullámú rádió-összeköttetés tervezése során I. rész (Bolyai Szemle, ZMNE, Budapest, 2002. XI./1. szám);

[4]. A Digitális Domborzat Modellek alkalmazása az elektronikai-harc szakos hallgatók szakképzésében (XII. Térinformatika az oktatásban Szimpózium, Budapest, 2003. október, előadás és konferencia kiadvány);

[5]. Pilóta nélküli repülőgépek útvonaltervezése digitális domborzat modell alkalmazásával (Gazdaságosság, Hatékonyság és Biztonság a repülésben Tudományos Konferencia, ZMNE RMI, Szolnok, 2004. április, előadás és konferencia kiadvány);

[6]. Objektumok koordinátáinak gyors meghatározása perspektivikus légifényképek alapján, digitális domborzat modell alkalmazásával („Kard és Toll" Doktorandusz Konferencia ZMNE, Budapest, 2004. május, előadás és konferencia kiadvány);

[7]. Raszteres állományú digitális terepmodell attribútum-adatok gyűjtésének támogatása, kisméretű pilótanélküli repülőeszközök által készített perspektivikus légifényképek posztprocesszálása útján (Robothadviselés 4 Nemzetközi Konferencia, ZMNE, Budapest, 2004. november, előadás és konferencia kiadvány);

[8]. A kis- és közepes méretű pilóta nélküli repülő eszközök, valamint a földi irányítópont közötti kommunikáció hatékonyságának növelési lehetősége, szabályos raszteres állományú Digitális Domborzat Modell alkalmazásával (Kommunikáció 2005 Nemzetközi Szakmai Tudományos Konferencia, ZMNE, Budapest, 2005. október, előadás és konferencia kiadvány);

[9]. Kis- és közepes méretű pilóta nélküli repülő eszközök autonóm feladat-végrehajtásának támogatása Digitális Domborzat Modell alkalmazásával (Robothadviselés 5 Nemzetközi Konferencia, ZMNE, Budapest, 2005. november, előadás és konferencia kiadvány ZMNE, Bolyai Szemle 2006. XV./1, Budapest);

[10]. Reconstructing of a given pixel's three-dimensional coordinates given by a perspective digital aerial photos by applying digital terrain model (kiadás alatt, várható megjelenés 2009. szeptember. Hadmérnök, Budapest, a Zrínyi Miklós Nemzetvédelmi Egyetem Bolyai János Katonai Műszaki Kar és Katonai Műszaki Doktori Iskola on-line tudományos lapja);

[11]. A terepdomborzat hatása a kis- és közepes magasságon feladatot végrehajtó pilóta nélküli repülőgép kommunikációs csatornájának stabilitására (kiadás alatt, várható megjelenés 2009. szeptember. Hadmérnök, Budapest, a Zrínyi Miklós Nemzetvédelmi Egyetem Bolyai János Katonai Műszaki Kar és Katonai Műszaki Doktori Iskola on-line tudományos lapja);

[12]. A kis- és közepes magasságon feladatot végrehajtó pilóta nélküli repülőgép repülési útvonal tervezése Digitális Domborzat Modell (DDM) alkalmazásával (kiadás alatt, várható megjelenés 2009. december. Hadmérnök, Budapest, a Zrínyi Miklós Nemzetvédelmi Egyetem Bolyai János Katonai Műszaki Kar és Katonai Műszaki Doktori Iskola on-line tudományos lapja).

Scientific Curriculum Vitae

I was born in Budapest, Hungary in 1964. I graduated from "Fürst Sándor" high school in 1981. I became a student at "Zalka Máté" Military Technical College in 1982. I became a Lieutenant at graduation in 1986. I graduated from the Radio Electronic Faculty as a Radio Technical Warfare Operator, as a Communicational Engineer.

My first appointment as an officer was at Radioelectronical Control Center, as a second in command of a mobile command control station, in Gödöllő, Hungary.

In September, 1987 I had the opportunity to join the Radio Electronic Faculty as a lecturer. I trained students for the following subjects: Systems; EHC Equipment and Operations; and Organizing Operations.

I contributed to other faculties by creating and implementing new training plans. I delivered the following subjects in officer training: Informatics; and Geoinformatics. I taught deputy officers and commanders in reserves.

Since 2005, I have organized, coordinated and taught intensive trainings of Information Security.

From 1989 and while remaining in the workforce I continued my studies at the Telecommunication Department of the Electrical Engineering Faculty of the Budapest Technical University. I graduated with a Masters in Electrical Engineering.

My Russian exam at the "Zalka Máté" Military Technical College certified my base knowledge of the language. In 2000 I completed a 10-month intensive English training. I passed "C" type middle level and "B" type high level exams. Following this, I spent 6 weeks in England practicing the language, where I passed the NATO STANAG 6001 3.3.3.2 exam.

My interest turned to the procession of digital terrain data during my university studies. I wrote my Master's thesis on this topic. I worked on the possible modeling of a radio channel and processing digital terrain data. Recognizing my programming skills I decided to pursue further research, hence I applied to the Doctoral School of 'Zrínyi Miklós' National Defense University where I completed Doctoral course-work in 2006.

I frequently published works in "Bolyai Szemle" bulletin, published and presented at several conferences including: Robotwarfare International Conferences, the 2004 "Sword and Pen" Conference, the Economics, Productivity and Safety in Flight Scientific Conference, the

2003 Geoinformatics in Education Symposium and the 2005 Communication International Scientific Conference. Altogether I have published 12 works.

Budapest, August 243, 2009

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