Real Time Tracking of Aerobots

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Abstract: In pursuance of tracking aerobots there are several tasks to implement to get valid informations from sensors mounted on the airplane and to display current position, flight-route precisely on digital maps. Flight parameters must be displayed real-time without signal noises on the user interface. The most complex problem is to implement mapping since there are many sort of maps capable for tracking with different properties. Depending on the aim of missions, different kind of maps are used for tracking. A tracking application is really flexible only in case of supporting large variety of maps and sensors.

Conditions of Monitoring, Infrastructure [1]

One of the most important requirements of monitoring is getting the accurate position of the aerobot. Accuracy depends on the applied coordinate system, coordinate format, and the type of navigation system, technolgy being used.

In the course of monitoring positions standard geographic coordinates are processed, provided by GPS receivers. These coordinates are represented in DM format thus degree component is followed only by the minute part of the coordinates. The advantage of this fomat is that the second component doesn't need to be stored and rounding errors are negligible, the second component of the DMS system can be computed easily. In contrast with these formats applying DD format provides very poor accuracy if the number of decimal places is too less because this format stores only the degree component thus minute and second components are expressed by the decimals after the decimal point.

The accurate position of the UAV is provided by the Global Positionong System, which can be freely used in civilian sphere since 1995. Accuracy is around 3 meters but can be decimeter accurete using DGPS corrections.

During missions the aerobot transmits flight parameters and navigation data from the onboard GPS receiver using wireless technolgy. This method can cause noisy signals and accidental errors in the datastream. Error detection can be implemented by checksum functions and noise reduction algorithms can be applied to remove unusable values from the received datastream. Checked and filtered values can securely be displayed on the user interface.

Tipically the position of the aerobot and its track are displayed on the screen during the tracking process. If there is no map for the current area then the UAV and its track can be displayed on a blind map using the start position as reference point. This method is appropriate for basic navigation purposes. Direction, route length, scale is visible for the user but it is not capable for accurate navigation, map of the concrete area is neccessary. Accuracy of maps depends on their scaling factor, projection model and validity of the objects displayed on their surface. Different projection models satisfy different criterias and there is no most accurate projection because the Earth is ellipsoidal. In most cases it is not possible to choose from different projection models because the number of them with showing the current territory is very limited. Scale is an important factor if small movements have to be displayed. Using large scale makes this possible however in case of small scale maps these movements can not be detected or they will be visible at a later time.

Display Options

Digital maps are using many sort of models representing areas of the World by different methods. There are 3 dimensional models showing the surface of the Earth with height maps and bitmap based traditional map textures. Another modeling method is to store the original maps in digital bitmaps and combine them into a large logical bitmap. In this case geographical positions are represented on a plane using one of the projection models and the defined calibration points make it possible to perform the projection with minimal distortions caused by the ellipsoidal surface.

Different kind of maps portray the same territory. General purpose maps are not always suitable to complete the objectives of missions thus displaying satellite maps and height maps could be neccessary. Tracking is really effective if switching between different map views and displaying layered maps are implemented.

Blind Maps

The current position and track can be displayed on blind maps although it is hard to place geographical positions for the observer without a real map. Showing position, track and heading is possible with this method so blind maps are suitable for basic navigation purposes if the surrounding objects are not important for the aims of the mission.

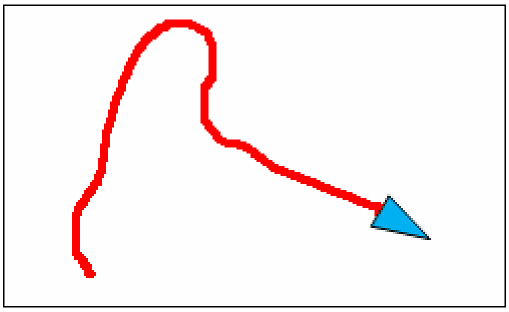

Figure 1
A simple blind map

Digital blind maps store meta-data for display functions. Meta-data fields provide reference points for drawing tracks, placeing current position and they contain scale informations. Displaying the current position is implemented by reference points and scale. Choosing the appropriate degree-pixel rate depends on the size of the area. The less degrees covers a pixel the bigger the displayed area and track can be. Because usually a degree covers a large territory it is advisable to apply minute-pixel rate.

Since observers can easily define geographical positions only if there are reference objects on the map thus disadvantage of blind maps is the lack of real objects. That's why their effectiveness is poor but it can be improved by simple techniques.

Placeing orientation points decreases the lack of objects. These points can be placed by their geographical positions the same way as the current position. Orientation points can represent houses, squares, small settlements, any object that is important in the mission. The great thing is that there are geographical objects placed on the blind map to help the observer in navigation so the monitored vehicle won't just „run in space".

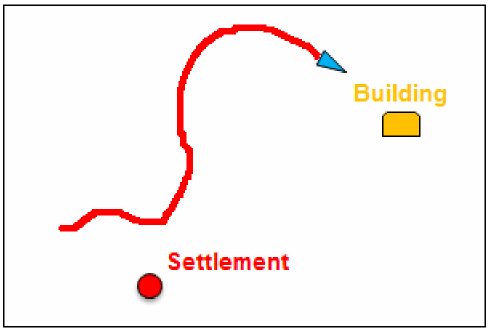

Figure 2
Blind map with orientation objects

Effectiveness can also be improved by gappy filling of the digital map if it is possible. In this case we have some pieces of maps showing parts of the territory and the objects placed on these parts can be used as orientation points. The advantage of this method is that observers can follow the object on the map even if they do not have a whole map of the area.

The latter methods can be combined. On gappy areas orientation points and on the filled parts map pieces assist in navigation thus highly increasing the effectiveness of blind maps.

It is hard to measure the accuracy because of the lack of the objects but it is very important that there is large distortion on longer routes if the specialities of the Earth surface is left out of consideration. Using map projection models is also essential in case of blind maps because positions are projected on a plane surface. On shorter routes distortions can not be noticed but on longer routes imprecision cumulates and more than hundred meters of distortion arises worsening effectivenes.

When using blind maps choosing the appropriate scale and projection model highly affects effectiveness. Accuracy mainly depends on the projection model beeing used and efficiency is based on the chosen orientation points. Choices have to be made by the aims of the mission.

Main benefit of blind maps is fast displaying. Many legacy GPS receivers used this technique because of memory limitations and processing bottle neck. It wasn't possible to make better and faster alternatives on mobile devices.

Commercial Maps [2]

Many commercial maps are suitable only for general purpose navigation because of their scale, distortion. These maps aren't accurate enough for effective navigation but their advantages are that they are cheap and they can be used for testing purposes and for simple navigation.

There are two main group of maps.

General maps illustrate line of the land, relief, hydrogeology and objects of the territores. Within this group there are further classifications:

- Huge scale (1:500-1:5000)
- Large scale (1:5000-1:00000)
- Medium scale (1:100000-1:500000)

- Small scale (1:500000-1:20000000)

Thematic maps represent quantitative and qualitative phenomena of nature and sociality. Usually simplified versions of general maps provide a skeleton for these maps. Economical, civil service, and historical maps are rated in this group. Important flavor of these maps is that they always contain information for a given profession and they represent important objects for these subjects.

In most cases commercial maps are not produced in larger scale than large scale so precise measurements can not be performed. Many of them are thematic thus they mainly illustrate areas for a profession so they can opress the details and objects needed by another profession. Simplified maps used as sekeltons for these maps may have a large distortion so they do not provide high accuracy and we have to count with false information.

High Accuracy Military Maps [3]

Unlike commercial maps high accuracy military maps can be applied not just for general purpose navigation. There are two groups of military maps:

- topographic military maps
- thematic military maps

Particular theme of topographic maps is to portray terrain with small margin of error depending on different scales. Scale of these maps is between 1:5000 and 1:1000000. They provide large-scale detail and quantitative representation of relief, because of their geodesical and scale accuracy they are capable for geographic planning or large-scale architecture in contrast to chorographic maps that are using simplistic terrain models and their scaling is above 1:1000000.

Thematic military maps do not focus on terrain, they are designed to serve special military purposes. Their content can be more or less but always appears something special compared to topographic maps. They focus on legibility and tractability because a topographic military map usually doesn't fulfill these criterias.

Depending on scale and resolution of digitally stored bitmaps fairly accurate digital maps can be constructed of military purpose maps thus for tracking these maps are the most suitable materials if calibration is done precisely.

Chosing military map with the appropriate phenomena is carried out by the main goal of the mission and the importance of detailed relief. Custom demands of users may dictate to use thematic maps because sometimes displaying detailed relief is not so important. Thematic maps are more suitable for these purposes due to their specialities.

Since military purpose maps are fairly accurate and they may portray secret objects, private data and it is very hard to get them, creation of these maps is impossible for the civilian sphere.

Satellite Maps

Satellite maps are produced since 1959. At first stallite images was available only for military purposes, nowadays they are freely available for the public in high quality. There is huge variety of satellite images: metheorological, military purpose, economical and educational purpose imageries. Images are produced in visible colours and in other spectra, or height maps made by radars.

Images are created with high technology cameras. There are two different types of resolution: radiometric, and geometric. Previous refers to the effective bit-depth of the sensor and is typically expressed as 8, 11, 12 or 16bit. The latter refers to the satellite sensor's ability to effectively image a portion of the Earth's surface in a single pixel and is typically expressed in terms of Ground Sapmle Distance (GSD). For example the GSD of Landsat satellite is 30m x 30m which means the smallest unit that maps to a single pixel within an image is 30m x 30m. The most modern satellite GeoEye 1 have a 41cm GSD but effectively this is only 50cm because of government control. In the civil sphere it is forbidden to create better quality images.

Scale is defined by the GSD value: the smaller area a pixel represents the better is the detail of movements and the accuracy of the current position. When drawing tracks on bitmaps accuracy depends on the appropriate projection of coordinates because different map projections are used for mergeing the pieces of the imageries to project them on a plane (e.g Google Earth uses Plate Carree). This is the main reason why corrections must be made when drawing tracks on the satellite maps.

The resolution of images measured in pixel determines the size of the portrayed area. High GSD imageries usually need huge amount of storage space if the portrayed area of the images is large so it is advised to use compressed image formats (JPG, PNG, etc.).

In contrast to general purpose maps objects can be recognised easily on satellite maps since they are very similar to photos. This method has many benefits. One of them is more efficient tracking or reconassiance for example when searching for a building or an object. The other benefits are easier and more accurate manual calibration due to better recognition of objects.

Satellite images are available from commercial markets since 1991 for personal usage. They portray the surface in a very detailed way thus provide a good alternative for tracking and reconassiance. The disadvantage of these maps is the high cost, even for a small area high resolution variants are very expensive. Aerial imagery is a similar way to create realistic maps but it is much more expensive than satellite imagery.

Three Dimensional Maps

Maps are really realistic if they protray terrain in three dimensions. The model representing the airplane lifts as high above the terrain model as the real flight altitude. With detailed, low distortion model and appropriate scale the effectiveness of tracking can be the best and user experience is much better.

Three dimensional maps are based on elevation maps. These maps represent the height values of given territories at certain resolutions. Resolution defines the detail of the terrain model. Every piece of a 50m x 50m resolution height map represents the (usually mean sea level) height of the associated area. The smaller the associated area the detailed the model we get.

The created model demonstrates just a homogenous surface of the terrain, lack of orientation points and difficulty of navigation make it hard to use these maps. Orientation points and map pieces can be placed on these maps similary like on blind maps but pieces are used as textures and orientations point will represent 3d objects. In fact terrain models are generally layers in 3d maps and depending on the aim of the mission there are several map and object layers placed on it.

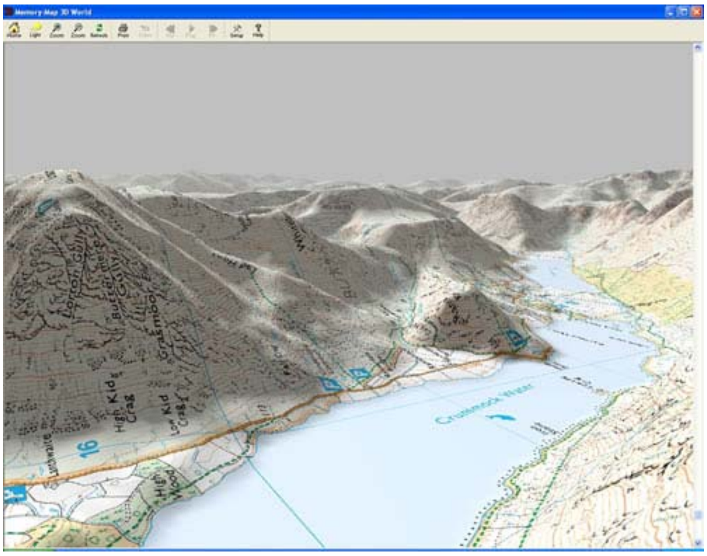

Figure 3
Memory map application – 3D view

Implementing layered display is not an easy task because different layers might use different map projections, scaling and the start and end points of the maps differ from each other and from the height map in almost every case. Models need to be textured with two dimensional maps and fitting is accomplished by the calibration data of the different maps. It may happen that some textures can not be associated with height maps, if so a plain area is displayed with the map texture. On the other hand if there is no texture for the model a homogenous model represents the terrain without any texture.

Nowadays 3d modeling and portraying „virtual worlds" have very elaborated techniques. Rendering of 3d models can be achived easily and at high speed thanks to 3d accelerated hardware and different 3d multimedia APIs. Due to popularity of 3d modeling numerous controls, accessories make it possible to naviagate and roam in these worlds.

Universal Display Controls for Monitoring UAVs

After selecting and calibrating the apropriate maps visual tracking of UAVs becomes available. Besides navigation informations (position, heading, etc.) several flight parameters need to be displayed on the user interface to achieve effective tracking.

When monitoring UAVs tipically air speed, roll, pitch, fuel level or accumulator voltage of the airplane is displayed. Since one of the main goals of tracking is reconing the environment cameras are essential accessories of aerobots. Depending on the objectives of the mission thermal cameras can be used for night reconnassiance. With different kind of sensors like radiometers people are able to operate aerobots in dangerous situations and monitor unapproachable territories. Mounting a pollen-sensor provides information about degree of air pollution above cities. Aerial photographics is also a popular scope of using aerobots with professional, precise video cameras.

It is practical to develop tracking applications to support customizable user interfaces to handle different kind of aerobots with different number of various sensors. The main concept is to dynamically create the user interface by the number and kind of the sensors. In case of maps it is important to allow changeing between different sort of maps and to display them in a layered structure. When using 3d maps it is neccessary to get the best resolution textures for the terrain model and apply them without reference of their map projections.

Calibration and Correctional Calculations [4]

Maps stored in digital bitmaps are unusable for mapping softwares without calibration data. They do not contain any information about the portrayed area, scale, projection model for the applications. Through the calibration process bitmaps gain additional information to make them capable for navigation softwares to display geographical coordinates. So result of calibration is a digital map that defines the range of displayable geographic coordinates and their pixel positions on bitmaps. After this process tracks, positions, pixel-meter rates, distances can be associated to digital maps.

Basic problem in case of two dimensional maps is to display areas of the Earth which is three dimensional and ellipsoidal thus a projection is neccessary to represent them on a plane. There are numeruous techniques to solve this problem but none of them are free of distortions, that’s why map projections are used. All projection models have their own advantages, disadvantages and limitations. Some projections are only capable for portray small areas while others are better for larger territories. Respectively other map projections provide better accuracy near the polar circles and others will suffer great distortions above a given latitude.

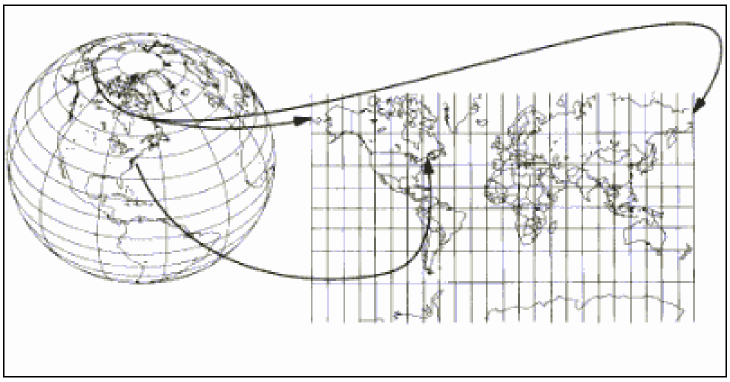

Figure 4
Map projection

Strictly speaking the earth is not a perfect ellipsoid that's why many ellipsoid models (datum) has been defined. Different models represent the ellipsoidal models by major (equatorial) axe, minor (polar) axe and flattening. Different map projections may use diferent datums. GPS receivers use the WGS84 datum which is the base of UTM projection in many countries.

When calculating distance or heading, map projections have to be considered. Both Spherical and ellipsoidal models are suitable. In case of calculating distance ellipsoidal or spherical formulas must be applied in calculations to get accurate results. Ellipsoidal models provide more precise results but calculation time is longer due to the complex trigonometric functions used.

Through the calibration process selected objects are placed on the raw map. In case of bitmaps the calibration points are pixel coordinates associated with the geographical coordinates. The more calibration points are placed the more accurate the projection can be. The best case would be if all of the pixels on the map were associated to its corresponding geographical coordinate but associating manually is a very long process. That's why missing pixel calibration data have to be calculated by the existing ones to let the application perform projections. Since raw map determines the projection model, its attributes need to be considered when calibrations are performed.

When choosing calibration points on raw maps we have to make sure about validity of coordinates by matching the position on the map and in the reality. If there are many calibration points far from each other, calibration can be fair accurate to a given latitude independently from the applied map projection. In case of small sized maps not portraying the polar circles, this technique might be adequate but with larger maps the number of errors can increase because of the personal elements, and the calibration process can take a long time. Artificial calibration points can be generated the other points to solve this problem. When implementing these algorithms we have to consider the specialities of map projection models beeing used by raw maps, otherwise distortion will increase extremely.

Experiences and Results

Effectiveness of tracking was determined by scale of maps, projection model, resolution of bitmaps and calibration data. Several maps with different scale and resolutions were used in tests. Scale determined the detail of tracking. With larger scale (1 pixel=1,5 meter) the tracked object was closer to the line of original track while with small scale (1 pixel=12 meter) short movements (<10 meter) could not be detected at all. Smaller bitmaps were generated with resizing the images.

All segments of map were calibrated manually in case of many points-manual calibration. One segment covered about a 25km x 25km area. With this method the line of the generated track went off the original line only above 100km routes. These errors could be generated by map distortions or by re-engineered roads. The largest distortion on a 7 meter/pixel map was 3 pixel namely 21 meter. With less calibration points there were 10-15 pixel errors 30km far from a calibration point that means errors above 100m.

Figure 5
Distortions due to weak calibration

Distance calculation formulas are also important to be mentioned as it would be impossible to calculate precise distances without them. Euclidean distance formula gave improper results between to points even at short (20km) distances. Haversine formula was a more accurate alternative moreover there are ellipsoid based models which gave more precise results but their run-time were much longer because of the complex trigonometric functions.
Incoming data integrity was checked by standard NMEA checksums placed at the end of the sentences. Altered sentences were not processed. Although nowadays

many GPS receiver uses Kalman-filter some sentences contained noisy fields. Noise reduction was implemented by median and prediction filters so invalid data fileds were not displayed thus enabling use of older receivers. With use of different filter algorithms sensor signals could be filtered successfully thus noise free, continuous data were displayed on the user interface.

References

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