Opportunities and Challenges of Terrain Aided Navigation Systems for Aerial Surveillance by Unmanned Aerial Vehicles

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Abstract Unmanned Aerial Vehicle (UAV) technology has become a promising means both for military and civilian surveillance issues that UAVs may provide more accurate, inexpensive and durable information than ground surveillance systems. The information can be obtained from various sensors which are equipped on a UAV. Most of the current UAVs depend on satellite based navigation systems such as Global Positioning System (GPS). However, GPS signals are easily jammed especially in military fields which necessitate a Terrain Aided Navigation (TAN) system. TAN systems aim to provide position estimates relative to known terrains. Such systems collect the height values from the surface with the help of active range sensors which are then matched within a terrain Digital Elevation Map (DEM). In this chapter, we have developed a preliminary TAN system as a testbed, in order to emphasize and address the opportunities and challenges of designing an autonomous navigation system. In addition, we have determined and summarized some of the design objectives for UAV based surveillance posts.

Keywords UAV surveillance · Terrain aided navigation · Simulated annealing

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1 Introduction

A UAV is defined as an aerial vehicle that does not carry a human, uses aerodynamic force to provide lift, can fly autonomously or be piloted remotely and may carry lethal or nonlethal payloads [1]. Thanks to their versatility, flexibility, easily installation and relatively small expenses, usage of UAVs promise new ways for both military and civilian reconnaissance and surveillance applications. For the last two decades, in military areas, UAVs are being used for real-time surveillance, reconnaissance, intelligence and warfare operations. On the other hand, for civilian areas, UAVs are well suited for situations that are too harsh or dangerous for direct human monitoring.

One crucial advantage of UAVs is that they assist surveillance by improving coverage throughout the remote and unreachable sections of terrains. Hence UAVs can be defined as "eyes on the sky". As an example, for the last decade, UAVs are being used for Homeland Border Security [2]. Equipped with various electro-optical sensors (such as cameras) UAVs provide precise and real-time imagery to the border security ground control operators, who then successfully deploy border patrol agents to the exact location of the border. While the range of UAVs is wider compared to stationary surveillance equipment, UAVs would have a greater chance of tracking a border violator with thermal detection sensors than the stationary video equipment.

UAVs can also provide precious assessments after catastrophic natural events such as earthquakes, tsunamis, floods, hurricanes etc. As the ground surveillance systems can be destroyed or limited, as it happened during Japan earthquake in 2011, UAVs may provide autonomous, accurate and robust information for the search and rescue efforts. This information can vary from photos, video or radar images which will help to find survivors. If dispatching of ground rescue teams into the disaster area to examine the damage and find survivors is extremely dangerous or impossible, UAVs can play a crucial role for saving lives. For example, one significant rescue service is developed and successfully operated in UAVTech lab which presents an emergency UAV mission scenario [3]. It involves search and rescue for injured people by utilizing UAVs. The mission study is divided into two steps. In the first step; UAVs scan designated areas and try to identify injured civilians. In the second step, an attempt is made to deliver medical and other supplies to identified victims.

UAVs are also used to examine environmental and scientific facts. Surveillance of animal swarms, vegetation, volcanic mountains, forests etc. are such examples. As an example of a scientific study, which is totally based on deploying UAVs, is developed in Australian Center for Field Robotics (ACFR). In AFCR, a UAV based surveillance system is used to detect aquatic weeds in inaccessible habitats of Australia. Fixed-wing and rotary-wing UAV pairs are successfully deployed for large scale mapping and precision classification of woody/aquatic weed infestations [4].

Another example of UAV surveillance can be seen in forensic examinations where forensic events vary from car accidents to public security situations etc. Although there are many other sources of intelligence that provide information from a scene with manned helicopters, they cannot fly in close proximity to the sites like UAVs can do. Also in order to safely monitor a situation before personnel are sent into a dangerous environment, UAVs can provide lifesaving information to the authorities. An example of UAV usage in forensic scenes can be the DraganFly Heli-UAV which provides high definition motion video for security, reconnaissance, inspection, damage assessment, research, real estate promotion, or advertising etc. [5]. Equipped with IEEE 802.11n based radio equipment, DraganFly UAVs have been successfully used in various surveillance scenarios. Another example is the FIU-301 Unmanned Aerial System (UAS) of the Ontario Provincial Police department of North America [6]. The system was developed to obtain high quality digital aerial images of major case scenes in a timely and efficient manner while operating within a secure police environment.

Different versions of UAVs are also being developed to be used for the upcoming lunar and planetary posts [7, 8]. As, the world has recently turned its attention back to the moon, it has recently turned out to be a competition to land humans to the lunar surface [9]. Thus, various techniques must be developed or reinvented to place humans and cargo safely and precisely. Because there is no satellite navigation (such as GPS) data available on lunar surface, TAN systems can be extended to assist a lunar landing spacecraft with precise and safe landing. The required landing precision for the upcoming lunar missions is much stricter than Apollo 11 where the landing ellipsoid was 18.8 km along-track by 4.8 km across-track [7]. Although Apollo missions were able to achieve reasonably precise landings, the accuracy is not sufficient to meet the new objective, particularly for the unmanned missions that will not have benefit of astronaut-assisted navigation. To improve navigation precision, TAN is required, since inertial sensors alone cannot achieve the necessary performance.

It can be seen in the aforementioned examples that UAVs have a crucial potential to provide valuable surveillance assessments both for civilian, scientific and military applications. However, the autonomous and unmanned nature of the UAV necessitates accurate navigation capabilities. In aeronautics, consistent, incessant and exact location information is vitally important. Hence, most of the UAV systems are equipped with satellite navigation systems such as GPS, GLONASS and GALILEO. These systems are widely used with Inertial Navigation Systems (INS) in order to provide an air vehicle with continuous navigation information [10, 11]. Although satellite navigation systems provide about 10 m location accuracy, they are highly vulnerable to jamming and cannot be used in lunar and underwater missions [12]. In addition, if a navigation instrument such as a GPS receiver defects, an auxiliary system has to be assigned to estimate the location of a UAV. Thereby, there has always been a need for a satellite-navigation-free TAN system for UAVs.

Development of TAN systems started in 1970s and they were successfully used for Tomahawk cruise missile navigation [13]. Nowadays, TAN technology has

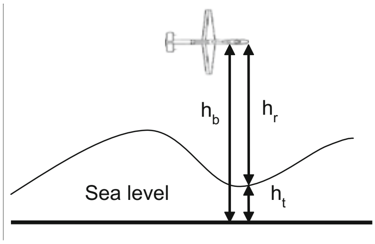

Fig. 1 Calculation of the height of the terrain from a UAV

reached to be used in underwater, planetary or ground vehicles [14]. However, it hasn't been successfully adapted to any UAV systems yet.

The basic idea behind a TAN system is to match the height values collected from a radar altimeter with the terrain heightmap data of an area of Interest (AOI) which is loaded into the flight computer in advance of a flight. While a UAV flies along its journey, the height of the terrain below the air vehicle is estimated with the help of a radio altimeter and a barometric altimeter as shown in Fig. 1. The height of the terrain h_t is calculated by subtracting the radar altimeter height h_r from barometric altimeter height h_b which is shown in (1). Measurements are taken periodically and when sufficient height values are collected, they are searched within the AOI which the UAV is currently flying over.

$$h_t = h_b - h_r \tag{1}$$

Although TAN systems provide various advantages for UAV navigation, there are some inherited disadvantages. Four of the major ones can be summarized as follows:

(i) TAN systems need undulating or rough terrains to operate [9],
(ii) The search and solution spaces of a TAN system is so huge that with a deterministic algorithm, providing a UAV with exact location information in a feasible amount of time is nearly impossible [8],
(iii) The active range sensors produce errors on high altitudes,
(iv) The miss probability of the matching the height values (that a UAV takes along its journey) with the DEM data is high because of the resolution gaps on the DEM data.

These problems necessitate the usage of a metaheuristic TAN approach for determining the location of a UAV. In this chapter, we address the issue of autonomous navigation, that is, the ability for a navigation system to provide information about the states of a vehicle without the need for a priori infrastructure such as GPS data. In this study, we have developed an exemplary TAN system in order to intensify and address the opportunities and challenges of designing an autonomous navigation system. The consequences of our research revealed that metaheuristic algorithms (such as SA) can be a good alternative for the determination of a vehicle's location. Thus, we have developed a TAN system which is based on SA approach and conducted our work on a real 3D DEM heightmap of northern part of Turkey which is nearly 100 × 100 km wide with 30 m resolution.

We expanded our work both on respectively flat and rough zones on the terrain. Our studies revealed that although average position estimation error rates on flat terrains are higher compared to rough terrains, a UAV can autonomously determine its location with mitigated drifts even on relatively flat zones. To our knowledge this is the first study which explores the TAN design objectives and with metaheuristics. We hope that our study will reveal and enlighten many of the controversial issues in the literature.

The related work, overview of TAN systems, SA algorithm, our exemplary TAN method and the conclusion with design objectives are described in following subsections.

2 Related Work

The term "*navigation*" originates from the Latin word "*navigare*" which means "*sailing ships*". For more than a century, the term is also used in aviation terminology to indicate determining the geographical position and velocity of air vehicles. In early days of aviation, pilots used to determine their location by matching particular land forms with the topographical printed maps while flying. Today, the range of airborne navigation systems and their capabilities are greater now than at any other time in aviation history.

Mainly, airborne navigation systems are divided into two main categories: *INS navigation* and *reference based navigation* [8]. An INS system utilizes an inertial measurement (which is basically a compass) device to determine an air vehicle's position, velocity, and attitude at high data rates. These data has a vital role for the guidance and control of an air vehicle. However, the INS equipment continually produces position estimation errors which necessitate *absolute sensors* to constrain the drift. Absolute sensors are categorized into two groups: *satellite based* and *terrain based*. Generally, satellite based navigation systems utilize GPS sensors. Fusion of INS with GPS systems has been widely studied in the literature [15, 16]. On the other hand, terrain based systems diminish the need for GPS devices with deploying a radar (or sometimes laser) altimeter and loading the terrain height map database on to an air vehicle. Although satellite navigation systems are well suited to UAV navigation, if the mission is within a GPS denied environment, such as a military zone where the signal is interfered, for underwater or lunar systems where no GPS signal is available, etc., implementation of a TAN system becomes the only alternative [17, 18].

TAN approaches can be split into two categories based on the type of sensor supplying the terrain data: *passive imaging* or *active range sensing*. Passive imaging has the advantage that the sensors (cameras) are mature and easy to accommodate on a UAV. Some of the passive imaging approaches can provide navigation measurements from any altitude. However, passive imagers have the distinct disadvantage that they are ineffective in poor illumination and weather conditions which casts challenging constraints on mission planning. The active range sensors (such as radar altimeters) have the advantage that they operate under any illumination condition. However, active range sensors are less mature than passive imagers and they have limited maximum operating ranges which limit the altitude at which TAN measurements can be made available [8].

The TAN approach can also be classified based on the structure of the algorithm used to compare surface measurements to the map, *correlation approaches* and *pattern matching approaches* [18, 19]. In correlation approaches, a contiguous patch of the surface is acquired using the onboard sensor. If a passive imager is used, then the patch is essentially a subset of the image; for a range sensor, the patch is elevation map or contour. This patch is then correlated, in the image processing sense, with the onboard map. Correlation algorithms place the patch at every location in the map and then measure the similarity between the patch and the map values (this process can be visualized as raster scanning the patch across the map). If the values are similar, then the location is given a high score; if they are not, then the location is given a low score. The location in the map with the highest score is chosen as the best match location for the patch in the map. Interpolation of the correlation scores is used to obtain a sub-pixel estimate of the match position. The orientation (and altitude for imagers) is then used to compute the position of the UAV in the map coordinate system [8]. Some famous correlation TAN methods are: Image to Map Correlation for Position Estimation (e.g. DSMAC) [20] and Altimeter to DEM Correlation (e.g. TERCOM) [21].

Besides these, the main drawback of the TAN systems is that they cannot work on a flat area or over the sea. In order to find a position match, the system needs an undulating terrain or some specific terrain features like well-known craters, hills, rivers etc. When the height values which are determined from the altimeter are constant, the slope values will remain constant too. In order to attain a terrain that is rough enough to navigate on, there is a need for an automated terrain analysis system like the one described in [22] where the flight path can be automatically determined by examining the results of the smoothness-based segmentation which shows the areas in the image that surpass a degree of smoothness.

Pattern matching approaches use landmark matching instead of patch correlation. Landmarks are specific terrain locations that can be extracted from the map and also have distinct characteristics that make them amenable to comparison to other landmarks. For example, hills, rivers, craters are often used as landmarks because they can be easily extracted reliably from image data over a broad range of image scales and illumination, e.g. the diameter of the crater is an identifier that can be used for matching. The relative distances and angles between landmarks are also used during the matching procedure. Some famous pattern matching TAN methods are: Scale Invariant Feature Transform (SIFT) [23], Shape Signature Pattern Matching, Onboard Image Reconstruction for Optical Navigation (OBIRON) [24].

A range of different techniques have been developed to obtain position fixes from the comparisons of measured and database terrain heights. The TERCOM system has been successfully applied in cruise missile systems, which combines onboard radar-altimeter readings with a preloaded Digitized Terrain Elevation (DTE) map to estimate the INS errors as well as guiding the low-flying missile at a fixed height above the ground. The TERrainPROfile Matching TERPROM system correlates passive sensor data with a terrain database. It can provide terrain proximity and avoidance information as well as INS aiding capability and it has been widely adapted as a navigation system within various aircrafts [25]. TERCOM and TERPROM are such examples in which, the difference between the radar altimeter generated and database indicated terrain height is input as a measurement to Extended Kalman Filter (EKF). The principal advantage of the EKF approach is relative simplicity and comparatively low processor load. However, it relies on accurate knowledge of the terrain gradient below the aircraft, which is an over-demanding requirement. Moreover, utilization of TERCOM or TERPROM on UAVs is still an open and challenging issue.

In this study, we have developed a preliminary TAN system for UAVs, which neither necessitate an onboard passive imagery sensor and/or GPS receiver nor an accurate knowledge of the AOI terrain gradient data. Our studies show that TAN systems can easily be deployed on UAVs to be an effective auxiliary navigation system. In the following subsection the main attributes of the exemplary method is explained in detail.

3 The Exemplary TAN Algorithm

Metaheuristics are used for combinatorial optimization problems. In such problems, whether it is a minimization or maximization problem, an optimal solution is sought in a discrete search space. As most of the design problems in engineering suffer from the vast dimensionality, it is infeasible to use exhaustive search or analytical methods. Metaheuristics are also used for problems over real-valued search-spaces. Their advantage is that the function to be optimized need not be continuous or differentiable and it can also have constraints [26].

The search-space of a TAN system is also so huge that with a deterministic algorithm, providing a UAV with exact location information in a feasible amount of time is nearly impossible [9]. In addition, the miss probability of the matching the height values (that a UAV takes along its journey) with the DEM data is high because of the resolution gaps on the DEM data. These problems necessitate the usage of metaheuristic approaches for TAN systems. In this study, a metaheuristic TAN algorithm which is based on SA algorithm has been developed. The SA algorithm and the proposed technique are described briefly in following subsections:

3.1 Simulated Annealing Algorithm

SA algorithm is a commonly used metaheuristic. The main advantage of SA algorithm among other metaheuristic approaches is that it works relatively fast with avoiding to local optima [26]. It is named as ‘simulated annealing’ because conceptually this method is similar to a physical process known as annealing. In an annealing process, a material is heated into a liquid state then cooled back into a recrystallized solid state. Similarly, an SA algorithm starts with an initial complete feasible solution and iteratively generates additional solutions as it is annealed. Also it can exactly or approximately evaluate candidate solutions and maintain a record of the best solution obtained so far. While SA is essentially *memoryless* and a probabilistic device is used to escape from local optimum, it can be regarded as a fast and thus powerful technique.

The algorithm works as follows: at any iteration k, we have a current solution x_c and a candidate solution x from the neighborhood $N(x_c)$. As the localization of the UAV is a maximization problem, if $f(x) > f(x_c)$, then x becomes the new x_c on the next iteration. If $f(x) < f(x_c)$, then there is still a chance that x replaces x_c. The associated annealing probability can be described as follows:

$$P(x \rightarrow x_c) = exp\left[\frac{f(x) - f(x_c)}{T_k}\right] \tag{2}$$

where T_k is the annealed temperature parameter. The probability of accepting the inferior solution x is seen to decrease as the performance gap between x_c and x increases or as the temperature becomes smaller. The sequence of temperatures usually satisfies $T_1 \geq T_2 \geq \cdots$, that is, the temperature is gradually decreased. In our simulations, we have used different temperature values ranging from 100,000 to 100 and halved the temperature value at each iteration. Decreasing the T means that in the early iterations, diversification is more likely and in the later stages intensification is achieved. When the search is terminated, a local search is made in order to ensure that the final solution is at a local optimum.

3.2 Proposed Algorithm

As in our previous work of [9], the algorithm takes as input a heightmap. We assume that in advance of a flight this heightmap is preloaded into the vehicle's memory. As one of the main objectives of this study is to relieve a UAV from utilizing beacon based navigation sensors, our algorithm does not depend on any information coming from GPS, cameras etc.

On a flight, the active ranging sensor of a UAV, such as a radar altimeter, collects elevation data between two sampling intervals as shown in Fig. 2. A sampling interval is chosen to be 3–5 s for rough terrains and 5–15 s for undulating terrains. For example, if a UAV has a velocity of 40 m/s, and the frequency of the radar altimeter is 10 Hz, then within 5 s our UAV will displace 200 m and collect 50 height values which form an array of height values as illustrated in Fig. 3. We named each array of height values as a *profile*. When sufficient number of height values is collected, these values are fitted into a line with the help of minimum square roots method. The result of minimum square roots is the well-known line formula as

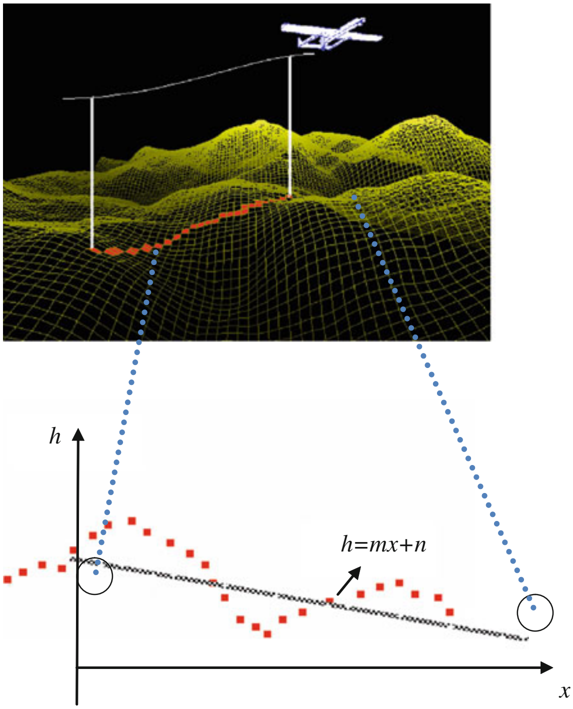

Fig. 2 Collected height values form a line which has a slope value of α

shown in (3). The slope of the profile is calculated by (4) which bear critical information about a terrain profile. Such as, a negative α value means a descending hillside and a positive value corresponds to an ascending terrain. The bigger the absolute value of α, the steeper the terrain gets.

$$h = mx + n \tag{3}$$

$$\alpha = ArcTan(m) \tag{4}$$

Afterwards, the estimated slope value is searched within the DEM file. As illustrated in Fig. 3, the projection of altimeter swaths resembles a virtual line on the map. The pseudo code of the algorithm is shown in Algorithm 1. As stated earlier, it is assumed that the UAV makes its journey on a predefined terrain so the proposed algorithm starts with loading the $n \times n$ sized DEM file into memory. The sampling number, *Sn* which corresponds to the number of the sampling points that the UAV is on and the initial heat, T, values are initialized.

Fig. 3 The UAV's flight path is virtual line on the map

25	23	36	7	0	8	9	17	19	0	36
14	45	48	36	25	33	38	20	8	25	48
5	33	5	25	14	7	14	14	25	14	5
7	14	7	48	5	25	5	5	28	5	7
36	38	36	8	7	28	7	7	35	7	36
25	49	25	49	36	35	36	36	49	36	25
38	20	8	14	17	49	36	19	14	17	8
5	34	13	23	19	5	25	12	5	19	13
7	17	14	45	48	36	25	5	7	48	14

Algorithm 1 SA based TAN system on lunar surfaces

1. **Load** *DEM(nxn);*
2. **Initialize** *M*, *Best*, *T*, *eps*;
3. $Sn = 0$;
4. **Repeat**
5. *Sn* ++;
6. *Get(x);* //get displacement from UAV;
7. *Get* (x_{slope}); //get the actual lidar slope from UAV
8. **For** jj = *size(M-Best)* **to** *k* **do**

   Select a random p_1, $p_1 \subset E$;//start pixel from entrance area
   Select a random β,$-45 \le \beta \le 45$;
   $(slope, p_2) =$ Bresenham(p_1,α,x);
   update *M*;

9. **end for;**
10. **For** kk = 1 **to** *size(M)* **do**

    if ($|slope - x_{slope}| \le eps$) & ($rand[0,1] < 1/\exp(|slope - x_{slope}|/T)$)

    update *Best*;
    update *T*;

    end if;

11. **end for;**
12. update *M with Best*;
13. **Until** satisfaction OR end of sampling;
14. **Display** Best;

The *T* values are set to be different values ranging from 10^2, 10^3, 10^4 to 10^5 in order to determine the best initial heat. At the very start of the algorithm the displacement, *x*, and the evaluated slope, x_{slope}, on the corresponding *Sn* is taken from the UAV with the *Get*() function. *x* indicates the amount of pixels that the UAV flied over and x_{slope} indicates the calculated slope in that *Sn*. While the aim of the algorithm is to find a best location match for the UAV the x_{slope} value is searched stochastically within the DEM. This search is achieved by taking a random initial pixel, *p1*, and a random flight angle, β, from the entrance area, *E*. The β values are restricted with -45 and 45 degrees in order to maintain a direct flight from west to east and enabling unrealistic flight paths. Afterwards, the swath and the slope of the selected positions are calculated with utilizing Bresenham line drawing algorithm [27]. Initially, this procedure is iterated *k* times and all the evaluated values $(p_1, p2, x, \alpha)$ are written into memory, *M*. *M* comprises the solution space of the evaluation. By controlling all the solutions with the actual slope x_{slope} and the evaluated slope which reside within an amount epsilon of errors, *Eps*, and the annealing heat, *T*, the best results are derived with the following control:

$$\left(\left|slope - x_{slope}\right| \leq eps\right) \wedge \left(rand[0,1] \leq e^{-\frac{slope - x_{slope}}{T}}\right) \tag{5}$$

The best results are collected into a matrix, *Best*, which is then placed into the *M* matrix. This adaptation gives rise to escape from the local optima while keeping more adequate solutions in the solution set. After looping for a specific number of iterations, in the case that the UAV is out of the map or a satisfactory location solution is estimated within two consecutive iterations, the algorithm terminates.

4 Results and Discussion

In this study, we have utilized two types of terrain structures which are named as rough terrain and undulating terrain. These terrains are derived from a 3D DEM data of north-western part of Turkey which has 30 m resolution. By utilizing these maps, a latitude/longitude information is achieved where the values of all (x,y) coordinates correspond to the actual height of the terrain. An example of the terrain types that we used for this study is given in Fig. 4.

As stated earlier, this study aims to search for the best location for a UAV throughout its journey. When the size of the DEM grows, the possible routes and slope calculations grow up exponentially that exhaustive search algorithms will be in adequate to search for a possible position within a reasonable time. Hence, SA algorithm fits well for a UAV TAN system. In addition, exact algorithms will fail to provide location information when the estimated elevation values do not reside in the memory. It is a well-known fact that representing every height values of a terrain on a heightmap is impossible. Hence, interpolation and extrapolations techniques are used to fill the height value gaps between adjacent two pixels of a terrain. In real world situations, it will be a misleading assumption to expect a height value to exactly reside in the heightmap.

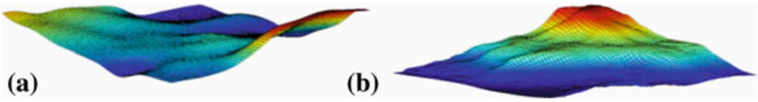

Fig. 4 Examples of terrain types used in this study **a** Undulating terrain, **b** Rough terrain

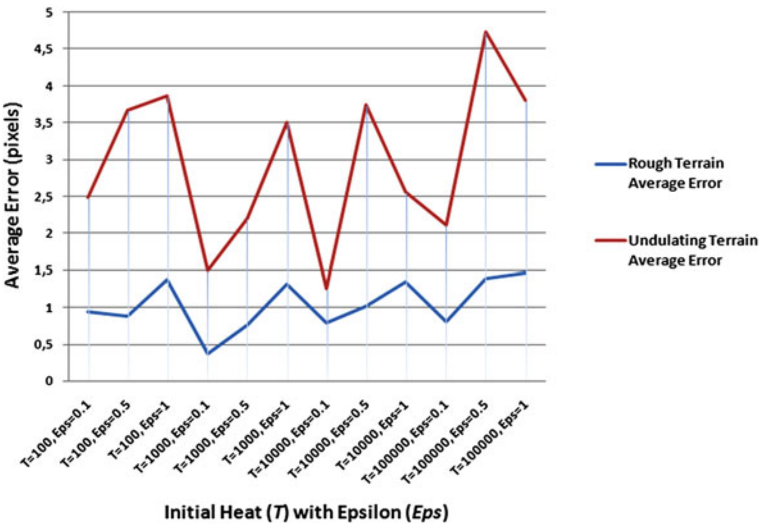

Fig. 5 Simulation results

4.1 Results of the Exemplary TAN Approach

The method followed in this study bases on SA algorithm which starts with an initial complete feasible solution and iteratively generates additional solutions. The escape from local optima is achieved by the heating parameter *T*. The *T* value is halved in each iteration and the performance evaluation of the proposed method is conducted by various initial heat values ranging from 10^2, 10^3, 10^4 to 10^5. Also the average measurement error in pixels which is expressed as *Eps* indicates the robustness of the altimeter. If *Eps* is high, the height estimation errors are also high. Throughout simulations, *Eps* is set to 0.1, 0.5 and 1.0 pixels respectively. Because the resolution of the map is 30 m, when $Eps = 0.1$ there is a ±3 m fault range. When $Eps = 0.5$ the fault range is ±15 m etc.

The results of the numerous simulation runs are illustrated in Fig. 5, where the vertical axes corresponds to the average location estimation error of the UAV in pixels. For example, with an initial heat of $T = 100$ and a measurement error of $Eps = 0.1$, the proposed algorithm will find a location with drifts of 0.9 and 2.5 pixels from the actual UAV position on a rough terrain and on an undulating terrain consecutively. While the map resolution is set to 30 m, 0.9 pixel drift will cause a 27 m drift from the actual position. On the other hand, a 2.5 m drift will cause a 75 m drift on an undulating terrain.

It can be inferred from Fig. 5 that the average position estimation error rates on undulating terrains are higher than the rough terrain results. This is because; the TAN methods exploit the terrain elevation structure to differentiate position estimation solutions. This phenomena result in that, TAN algorithms will fail on flat terrains and will be more successful on rough terrains.

It can also be seen from the figure that the errors decrease with decreasing *Eps* values. This is because; the correctness of the altimeter plays a crucial role on height estimations. Hence, well calibrated radar altimeters have to be chosen for TAN systems. On both terrain types, when T is set to 100 and *Eps* is set to 0.1, the minimum error rates are achieved.

4.2 Discussion and Design Objectives

In this study we have explored and experimented many of the challenges of TAN systems and proposed some design objectives which are summarized as follows:

(i) TAN systems can easily be used as an auxiliary navigation system both for military and civilian UAV missions,
(ii) In order to implement a TAN system on a UAV, barometric and radar altimeter devices have to be deployed on the UAV. The measurement sensitivity of these devices is vitally important that when the fault grows, the miss probability also grows proportionally,
(iii) The altimeters play the vital role on a TAN system. The maximum altitudes that the altimeter works properly has to be determined and fine-tuned in advance of the flight,
(iv) The AOI terrain which a UAV is flying over has to be installed on the flight computer in advance of the flight. The resolution of these maps plays an important role in finding the exact location of a UAV. With high resolution maps (which are bigger than 30 m), the miss probability also grows. In addition, the time that a UAV collects height swaths also grows which leads to delayed location estimation,
(v) With exact algorithms it is impossible to provide a UAV with location information in a feasible amount of time. On the other hand, metaheuristic algorithms (such as SA) give rise to more timely and effective solutions,
(vi) Although TAN systems are good alternatives for GPS based navigation, TAN systems cannot be operated over a totally flat terrain, lake, sea etc. hence techniques to route UAVsto more rough terrains have to be reinvented,

5 Conclusion

UAVs are effective and robust means for wide area surveillance posts. Nowadays they are regarded as "eyes on the air", in the sense that they provide wider and more powerful imagery techniques. However, they have challenging demands over autonomous navigation issues. Today, most of the UAVs are equipped with satellite based navigation instruments such as GPS. It is a well-known fact that GPS signal are prone to jamming and also they cannot be used in underwater or planetary environments. Hence, there is a need for a GPS-free navigation system which is based on the terrain information which a UAV flies over. However, development of a TAN system is a non-trivial task that development of a robust TAN system addresses many challenging issues.

In this chapter, we have examined the opportunities and challenges of TAN systems. Moreover, by developing an exemplary metaheuristic algorithm which is based on SA, we have issued some TAN system design objectives to provide a UAV with precise location information. We have shown that TAN systems can be a good alternative for traditional GPS based position estimation for UAV based surveillance missions by deploying various types of real world elevation maps. We hope that our study will reveal and enlighten many of the controversial issues in the literature, guide and encourage enthusiastic researches, and appreciated as an initial but important step on the subject.

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