Deutscher Luft- und Raumfahrtkongress 2010
DocumentID: 161183

OVERVIEW OF PATH PLANNING FOR HELICOPTERS WITH RESPECT TO PILOT ASSISTANCE SYSTEMS

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OVERVIEW

This contribution presents an overview of the design concept for algorithms used within an assistance system for manned helicopters. Therein the main focus is on a dedicated trajectory generation helping the pilot in pre-flight planning and therefore reducing the navigational workload. The trajectory planning is subdivided into three parts, according to different flight situations: takeoff, en-route and approach. For every part special algorithms are designed to generate optimal trajectories with respect to particular requirements. To identify and to meet some of these requirements within the trajectory planning, a multipart survey is conducted. The results are examined statistically to classify the pilot behaviour. The achieved parameters are used as basis for the trajectory planning and are preferred, as long as performance limits, regulations or flight manual limitations are not exceeded. The calculated trajectory will be adapted to the pilot to meet his requirements and to ensure a sophisticated flight path generation.

1. INTRODUCTION

Helicopter usage today is often limited due to adverse meteorological conditions or simple nightfall. These conditions force pilots and operators to fly under IFR rules or to quit flying completely. In any case this leads to more or less prolonged periods in which the operation of helicopters is not possible or only limited (in airspace and time). To circumvent this, DLR develops a pilot assistance system allowing the operation of the helicopter even under adverse meteorological conditions. This system will encompass all aspects from environment measurements by sensors to the display of all relevant information via different human-machine interfaces. The sensor collected data will be fusioned [1] to generate a 3D earth surface model of the helicopter's surroundings. This model will be the input for the trajectory planning. Upper mode control laws and auto pilot functions will enable the pilot to stay on the planned trajectories even in adverse weather conditions. By usage of different human-machine interfaces like displays, helmet mounted displays or active control sticks an information overflow of the pilot should be omitted and safe guidance should be possible.

The path/trajectory planning is an important part of an assistance system allowing 24h all weather operations. If the pilot has poor to no vision it is hard or even impossible for him to navigate without aids. Since pure stabilisation of a helicopter under DVE (degraded visual environment) conditions is much harder and needs more pilot action then that of a pilot in a comparable airplane situation, the pilot’s mental resources for helicopter navigation are very limited. Thus it is important to support the pilot in planning his route and especially in replanning during a running mission so as to free mental resources for achieving the intended mission goals.

A lot of work has already been done in the field of trajectory planning. Especially in the field of robotics and unmanned air vehicles, path planning is a crucial part of the systems since the UAVs are designed to work independent of human operators. In [2] an overview on different methods and their usage in UAV path planning is given.

In [3] a system concept is described allowing unmanned vehicles to fly among obstacles by combining sensors and a two step approach for path planning. In the first step a global planner roughly computes the total path, the second part refines short pieces of the trajectories avoiding obstacles but still keeping close to the initial global path. A two step approach for path planning is also used in [4] too. Here a rapidly exploring random tree is used to find a path from start to goal and then a Dijkstra algorithm is applied that optimises the predefined path. Adolf et al. [5] propose the usage of probabilistic roadmaps for UAV 3D path planning. The approach has the advantage of less computational effort needed in comparison to optimal solutions and supports multi agent planning. Another approach used in [6] applies an incremental heuristic path planner to plan and replan the trajectory in a regularly updated environment. In [7] an algorithm is developed that enables fast replanning during missions in case the environment changes. The developed algorithm is named D* Lite and is said to be easier to handle and faster then pure D* algorithms.

All the systems and algorithms mentioned were designed for unmanned vehicles which allow the operation close to performance limits without considering pilot trust or passenger comfort. A helicopter path planning system designed for the usage in manned systems and for passenger transport additionally has to take these issues into account.

Some work has been done since the late 80's regarding pilot assistance focusing on trajectory generation especially for NOE (nap of earth) military flight. Here, environmental information as well as performance limits and mission relevant boundaries (e.g. available fuel) are taken into account in the path planning process [8], [9]. In [10] the aim was to enable NOE flight particularly in bad weather conditions. The trajectory is planned by respecting the performance limits, such as: achievable rate of climb, torque and rotor speed limits.

Some work has also been done in path planning for helicopter medical services. In [11], [12], [13] a system allowing the planning of trajectories for en-route flight with respect to obstacles and weather conditions is described. The system is capable of taking the actual meteorological forecasts into account and will replan the trajectory if the conditions change. Thus, the pilot can leave the observation of weather phenomena, like clouds or thunderstorms, to the system and concentrate on his mission. The system uses clothoids and straight lines to create a trajectory between the pilot's waypoints. The avoidance is done by adding waypoints around the back side of the phenomenon and recreating the trajectory.

Additionally, the present paper regards the flight path planning on dependence on pilot dependent requirements and will give an overview of the system’s capability. To further enhance the quality of the planned trajectories, a survey is conducted that should reveal patterns of pilot behaviour. These patterns will be used to define sets of constraints for the path planning algorithms thus allowing each pilot's individual style of flying to influence the trajectory planning. By means of the survey, at least a subset of the overall pilot requirements can be regarded. Therefore, the main focus of this paper is on the concept, namely on the integration of the pilot requirements to the flight path planning. First simulation studies show that the integration of the regarded pilot requirements to flight path planning can be performed.

In chapter 2 an overview of the system architecture is given. Therein the integration of the flight path planning within the whole helicopter system is shown. Chapter 3 clarifies the evaluation of pilot dependent constraints, which are examined by a helicopter survey. This chapter mainly focuses on a general overview of the survey and the concept to apply the results to the ongoing flight path planning. Chapter 4 till 6 demonstrate the application of pilot dependent requirements for takeoff, en-route and approach. Based on a general point of view, these chapters mainly characterise the regarded constraints and the methods used to find an appropriate flight path. Finally, a summary and outlook are given.

2. HIERARCHICAL SYSTEM OVERVIEW

The software architecture is subdivided into several modules according to predefined tasks. Figure 1 shows a hierarchical overview of the system’s software architecture. The inner control loop mainly focuses on the body-fixed control regarding pitch, roll, yaw or heave dynamics. The navigation and upper control modes realise the earth referenced control concerning e.g. trajectory-following or position hold. The local flight path planning generates trajectories that avoid obstacles in the actual flight path. Within this planning mode, only a short time-horizon is analysed, enabling high flexibility and fast response times for computing the replanned path. In contrast to this approach, the global flight path planning regards the mission dependent flight path which is independent from any restrictions in space or time and yields a pilot dependent trajectory.

The global flight path planning is subdivided into takeoff, en-route and approach. Figure 2 illustrates this graphically and further shows a so called control unit which is situated on top of each flight phase. This control unit ensures a holistic trajectory generation and coordinates the execution of each underlying module. The appropriate transition points from takeoff to en-route and furthermore from en-route to approach are defined according to the mission task by means of the takeoff and approach module respectively. Furthermore, the control unit provides environment data from a database which generates a topographic map based on the sensor data fusion [1].

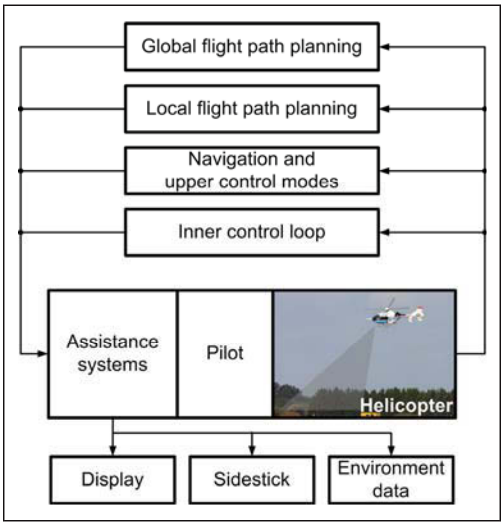

FIG 1. Hierarchical overview

By means of this database the 4D trajectory is planned for each flight phase concerning static obstacles like buildings, dynamic obstacles like other aerial vehicles or specific topographic conditions. Hence, the global path planning system is used to calculate unobstructed trajectories within an uncontrolled airspace for all weather conditions. The actual approach is based on solving single shortest path problems. The predefined mission characterises a more general problem which is not regarded in the overall complexity. But in a certain way the mission can be subdivided by the pilot into several mission elements (such as hover or fly over) together with an appropriate sequence number. This finally allows the definition of several shortest path problems. The calculated trajectories are displayed by means of a tunnel in the sky display and therefore the system permits either an automatic flight or a manual flight controlled by the pilot.

However, within each flight phase pilot-dependent requirements are taken into account yielding a flight path which is specifically adapted to the pilot. The regarded pilot requirements are described in the following chapters. Together with the limitations given by the flight manual, and with the dynamic constraints concerning the upper control modes, the trajectory is close to a realistic flight path. This is summarised in figure 2 showing a functional schematic of the global path planning.

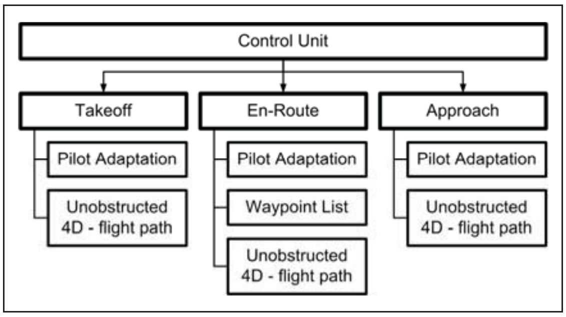

FIG 2. Functional schematic of the global path-planning

3. HELICOPTER SURVEY

The survey is conducted to detect different behaviour patterns of helicopter pilots. Therein the behaviour patterns mainly reference to constraints, procedures and processes which are regarded or executed by helicopter pilots within takeoff, en-route and approach. Pilots with different backgrounds (e.g. Military, Police and helicopter emergency medical services (HEMS)) are invited to take part achieving a broad data base.

To conduct this kind of survey, in automobile research usually simulator or drive test investigations are carried out [14], [15]. Due to lower availability of pilots compared to car drivers the survey described here could not rely on simulator or flight test data. Thus, a different approach had to be used. In [16] the behaviour of pilots in wind shears is analysed. Therein neural networks are used to face different behaviour patterns. In this work fuzzy systems and cluster analysis are used to identify the pilot behaviour.

The survey is divided into two parts, the first one is devoted to personal interviews with special emphasis to ensure that every pilot interprets the questions in the same way. Misunderstandings and resulting outliers can thus be minimised. Actually, this survey is in process. So far, 18 helicopter pilots have taken part whereat the aim is to interview up to thirty pilots. Several helicopter pilots, who have different background (civil, military together with mission scenarios) and fly different helicopter types, have taken part. The averaged flying experience equals 21 years.

The first part of the survey is used to derive classifications for different types of pilots and will be discussed in section 3.1. Each class or group is defined by a specific set of constraints which is used within the trajectory planning. Furthermore, the aircraft performance is also taken into account. This guarantees that no limits like maximum continuous torque are exceeded. The classification will be done by automatic algorithms described in more detail in section 3.2. After classifying, a variance analysis identifies unreliable data points. In these points the available data base is not sufficient and hence more data are needed. In future work, the necessary data are to be collected by the second part of the survey which will be designed as an internet survey. The biggest advantage of this kind of survey is the relative large number of participants. Thus, a big data base can be produced to verify the unreliable data collected by the first part. The resulting adaptation of the path planning to the identified pilot behaviour will be described in section 3.3.

3.1. Design of the interview survey

The survey encompasses a lot of questions and partly open discussions. That way a lot of additional information can be gathered based on the pilot's experience. Each interview takes up to 1.5 hours and thus the number of participants has to be limited. The interview survey itself is subdivided into three parts. The first deals with the takeoff procedure. The second deals with the en-route flight and the third with general obstacle avoidance. For all three parts the flight mechanical characteristics like maximum and minimum rate of climb or forward speeds are enquired. These characteristics are used in the path planning as limitations additional to the flight handbook values. If the limits for a flight mechanical characteristic defined by the survey differs from that given in the handbook the more restricting will be used.

Besides the flight mechanical characteristics, all relevant path planning information such as minimum clearances or preferred trajectories over or around different obstacles are gathered as well as special information which may be only important in the corresponding phase of flight i.e. states at the takeoff decision point or rate of climb during climbout. Because only a subset of the regarded pilot requirements are regarded, the general intention of pilot dependent flight path planning is not to calculate high performance flight paths which are needed in NOE (nap of the earth) flights but is applicable to generate safe flight paths.

One example of these special data is the maximum accepted cross wind for the takeoff procedure. Here again, values defined in the flight manuals are taken to decide which of the values is less and thus is used as the valid boundary for the trajectory planning. By means of these boundaries pilot and passenger comfort can be included in the trajectory planning.

3.2. Classification of pilot behaviour

Due to the large quantity of data (ten questions for takeoff and twelve questions for enroute) gathered, in the following the general idea of introducing a pilot classification is presented by means of exemplary results. Although the survey is not completed the actual database is adequate to examine several methods.

Basically, univariate statistical analyses can be used to determine the mean value or the standard deviation. In general, a large amount of data is needed to perform such analyses. These assumptions don’t hold for the pilot requirements identified by the survey and needed within takeoff and enroute. To demonstrate this, a basic and exemplary data analysis is shown on top of figure 3. Therein the maximal accepted crosswind data as histogram is shown. For this example which is one of the most significant results of the whole survey, the significance determined by the Shapiro-Wilk test equals S= 0.5. The hypothesis of normal distributed data is accepted, if S= 1.

The mean and the standard deviation equal x_{mean}= 21.4kn and s_{std}= 11.3kn, respectively.

In order to perform a classification for several data such as obstacle clearances, rate of climb, crosswind and further data simultaneously, multivariate statistics is used. This ensures that on dependence on several characteristics single clusters can be defined. First results of a classification are presented at the bottom of figure 3 which shows the maximum acceptable cross wind during the takeoff procedure.

The first box plot encompasses all pilots. It has a large standard deviation. The median is at approximately 20kn cross wind. The classification shown in the preceding box plot is obtained by means of a k-means algorithm building disjunctive clusters. This leads to two groups which both show much smaller standard deviations (group 1: s_{STD}= 8kn and group 2: s_{STD}= 6kn). The first group has its median at a maximum cross wind of about 30kn, the second one at 18kn. The classification also lead to the exclusion of the outlier accepting 50kn cross wind.

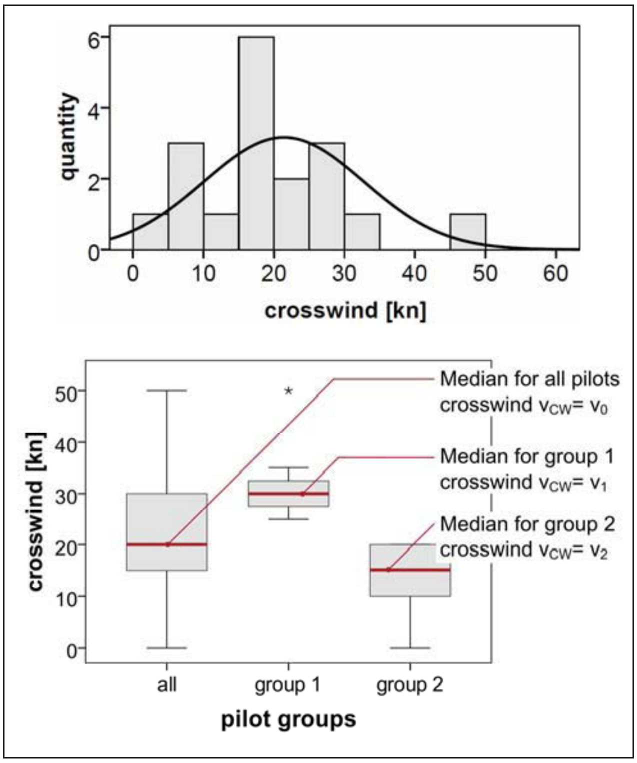

FIG 3. Maximum acceptable cross wind for takeoff

Further analysis of the data shows that both automatically clustered groups correspond to helicopters with masses below 5to (group2) and helicopters with masses above this value (group1). The outlier in the first group is an example for a high performance aircraft which has exceptional flight performance and thus can not be forced in a group with the other data points.

Furthermore it can be seen, that the deviation in group 2 is bigger than in group 1 which shows a stronger effect of pilot behaviour on the data. Since the underlying personnel in group 2 has a more spread background this is a more inhomogeneous group. The usage of these data in the trajectory planning can be seen in section 4.

An example of the en-route part of the survey is shown in figures 4 and 5. As can be seen in figure 4, four different routes from start into the east direction are given. The pilots could choose from the paths which one they would like to fly. The conditions of flight were given as no wind, good visibility and no mission specialities like NOE flight. The hills are considerable higher than the initial height.

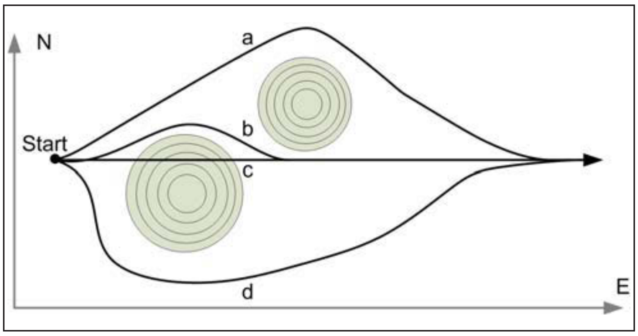

FIG 4. Possible trajectories around a series of hills

As can be seen in figure 5, most of the pilots decided to fly path c. The direct route is therefore the preferred one under these conditions. Second to it path b is likely to be chosen. Only a few pilots would fly around the hills avoiding the area completely. Reasons for this behaviour were mainly a better visibility of other air traffic and obstacles on the way around the hills.

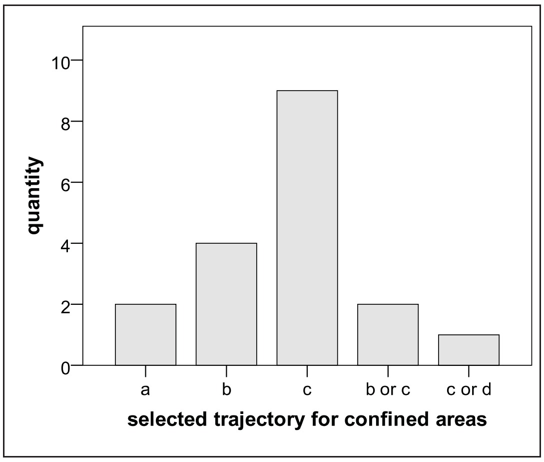

FIG 5. Pilot chosen trajectories around hills

The reasons for flying the straight route (flight path “c” in figure 4) were a shorter flight time and less changes of the heading. Based on figure 5, it can be seen that for this example several types of pilot behaviour can be identified. The possible influence of the survey's result on the en-route path planning is shown in section 5.

Based on a couple of such classifiable results of the survey an overall classification will be performed. This classification reflects the parameters and constraints which are regarded within each flight phase. In general, multivariate statistical analyses have to be used to represent the pilot’s behaviour. Thus, the results are clustered automatically according to each flight phase. The cluster analysis is based on fuzzy clustering ensuring that each pilot is represented by a degree of belonging to a specific cluster. This ensures that the regarded constraints can vary in a smooth way avoiding discontinuities and therefore allowing a more sensitive characterisation. Further analysis will attach a linguistic notion to each cluster such that the pilot can easily select an appropriate pilot class which defines a set of constraints regarded within the actual flight phase. Thus the path planning is based on pilot behaviour to a certain extent.

3.3. Pilot adaptation

Pilot adaptation is the basic idea to enable pilot dependent path planning. In a hierarchical point of view this module is situated within each path-planning module (takeoff, en-route and approach) and is executed simultaneously within each flight phase (figure 2). By means of a knowledge base the characteristics of several pilots can be reflected. This knowledge base is initialised with the results of the survey and will be continuously updated by flight tests. In figure 6 the conceptual design to adapt the pilot's behaviour is shown. One important part is the representation of the pilot behaviour and the other one is the identification of the actual pilot class. By means of representation, a pilot dependent flight path can be generated. As mentioned before, the pilot can define an appropriate class which yields specific constraints regarded by trajectory generation. This process is depicted schematically on the left side of the flow chart in figure 6.

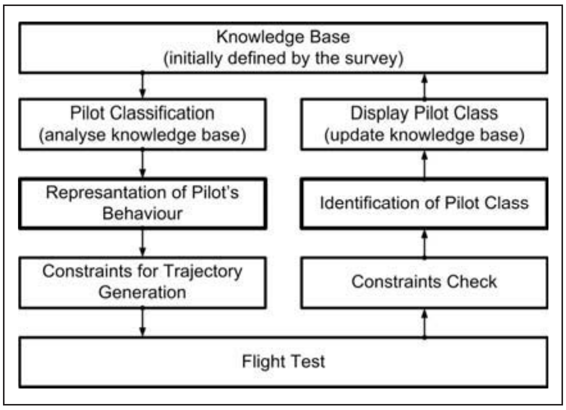

FIG 6. Schematic describing the pilot classification

During any flight of the helicopter, flight data are recorded which are used to identify a pilot class. The identified class will be displayed to the pilot, so he can choose to accept the system's recommendation and thus update the knowledge base. This is sketched on the right in figure 6. Hence, the actual concept will enable a half automatic adaptation on dependence on the pilot who is part of this loop. Actually, possible algorithms such as fuzzy or neural networks are compared in order to identify an appropriate methodology.

4. TAKEOFF

In general, modern helicopters are often certified by CAT-A to allow HEMS operations. Consequently, one objective is to calculate a takeoff profile on dependence on the CAT-A procedures including surface level takeoff and standard type takeoff. Further takeoff procedures like normal takeoff, running or rolling takeoff, vertical takeoff or maximum performance takeoff are also taken into account. Each takeoff procedure is subdivided into three modules, the characterisation of the takeoff profile, the calculation of the initial takeoff flight path and the determination of an unobstructed flight path for climb. To plan realistic flight paths, several constraints are considered. They are defined by the mission task, environmental data, pilot requirements, results of the pilot adaptation, the limitations given in the flight manual and further regulations defined by flight mechanics. This ensures that the generated flight path is comprehensible to the pilot and close to his own usual flight path selection. In figure 7 the conceptual design of the takeoff is shown schematically.

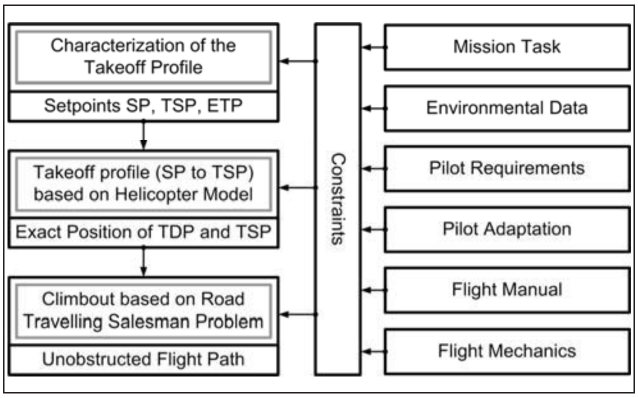

FIG 7. Schematic of path planning within takeoff

Independent of the takeoff procedure selected, the takeoff profile is described by a set of reference points which consist of the

– start point (SP),
– takeoff decision point (TDP),
– takeoff safety point (TSP), and
– en-route transition point (ETP).

The start point is defined by the position of the helicopter on ground. The takeoff decision point is primarily characterised by the flight manual. The position at which the takeoff safety speed (v_{TOSS}) is obtained defines the takeoff safety point (TSP). The en-route transition point is described by stationary states mainly focusing on ground speed, rate of climb and heading. Hence, a smooth transition to the en-route point can be achieved.

4.1. Characterisation of the takeoff profile by means of reference points

To distinguish between each takeoff procedure, a characterisation by the mentioned reference points is required. The takeoff procedure is determined automatically in accordance to the mission task either by the pilot or by the system. The automatic selection of the appropriate takeoff procedure depends on safe landing sites, obstacles, mission task and the pilot himself. Each takeoff procedure is characterised by the same qualitative reference points but not necessarily by the same quantitative definitions. The takeoff procedure chosen is displayed to the pilot, so that further results of the path planning can be checked easily by him. In general, the reference points describe height above ground, the desired true air speed and rate of climb. Thus, the specific takeoff profile can be computed as follows.

4.2. Initial takeoff profile

By means of the SP and TDP an initial takeoff profile is calculated based on a longitudinal model of the FHS (Flying Helicopter Simulator) regarding power settings and state constraints. The initial takeoff profile is proofed not to clash with any obstacle, but there is no planning algorithm used which avoids obstacles. The output variables of this model have to meet the required states at the TDP (height above ground and true air speed) and at the TSP (true air speed and rate of climb). To solve this problem a control loop is established. The reference variables, namely height above ground, rate of climb and true air speed, are pre-defined based on flight tests. The control loop minimises the error of the position and of the velocity in dependence on wind or other disturbances, in addition to pilot dependent power settings and state constraints. Solving this problem yields the required radial position of the TDP and TSP together with the according unobstructed flight-path. Both points are calculated for a set of takeoff directions which yields an elliptical curve containing possible takeoff decision and safety points. This concept is emphasised in figure 8.

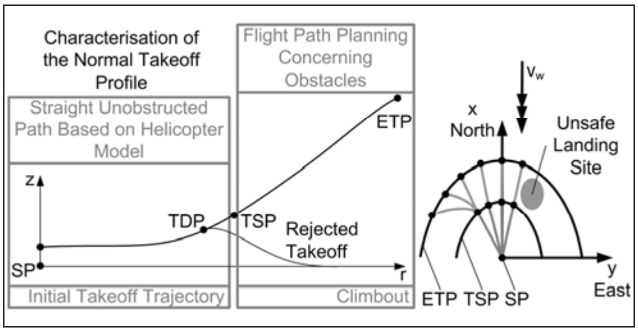

FIG 8. Characterisation of the normal takeoff as one example of a possible takeoff procedure

On the left the principle of a flight path for a normal takeoff is shown. The initial takeoff profile is sketched within the left box. Due to the position of the TDP and the specifications from the flight manual, the maximal distance for a rejected takeoff is calculated. With respect to possible emergency landing sites only safe takeoff directions are accepted. By means of the topographic map appropriate landing sites are identified using a roughness criterion. The illustration on the right of figure 8 demonstrates this schematically. The resulting states (position and velocity) of possible safety points depending on the heading are the bases to plan an unobstructed trajectory to the ETP. The latter is defined by the height above ground, the desired velocity and rate of climb so that its geodetic position has to be determined within the climbout.

4.3. Trajectory planning for climbout

By means of the TSP and the ETP a three dimensional surface with respect to state constraints and pilot requirements is generated. Therein maximal accelerations and velocities for the radial and vertical direction are taken into account. The three dimensional surface is mapped on the topographic map which is generated using either the sensor fusion or an existing database. This defines an obstacle space which is determined based on a point helicopter representation. The set of start points (TSP) and the set of goal points (ETP) are linked to each other so that a so called "road travelling salesman problem" is defined. There are several methods known to solve this problem [1]. The method used here is based on the A* algorithm which utilizes a graph represented by possible fly-by or fly-through points on the surface. By means of the A* algorithm an optimal flight path in accordance to the heuristic is chosen. The selected flight path concerns pilot requirements e.g. obstacle clearances, maximal angle of bank, desired true air speed and rate of climb. Additionally, limitations given in the flight manual are also considered e.g. "the dead man curve", maximal rate of climb. This methodology yields a highly adaptable trajectory generation to meet the natural flight path.

This trajectory depends on the pilot requirements which were analysed by means of the survey. Within takeoff high priority is devoted to

- cross wind and tailwind
- vertical and horizontal clearance distances to obstacles,
- rate of climb and
- true air speed at TDP and ETP.

These pilot requirements are utilized as constraints within the A* algorithm. The pilot classification, which is based on the survey, allows the pilot to define a desired pre-defined constraint set. After each takeoff an algorithm evaluates the constraints and identifies the appropriate pilot classification which is displayed to the pilot so that the pilot can choose to accept the system's recommendation for the next takeoff (see figure 6 for details). This ensures a continuous adaptation to the actual pilot even if the same pilot changes his behaviour e.g. after novel flight experiences.

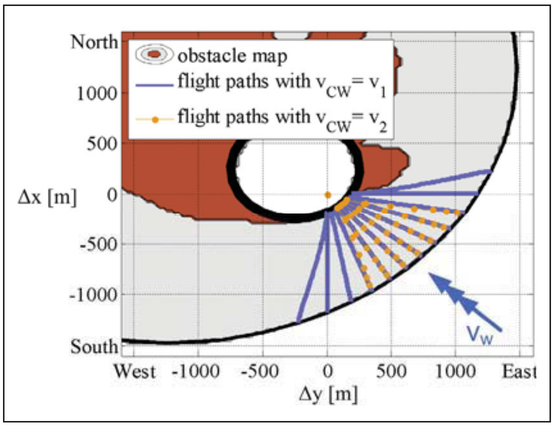

FIG 9. Takeoff trajectories on dependence on the cross wind settings v_1= 30kn and v_2= 18kn

Figure 9 emphasises the basic idea of pilot dependent path planning. Based on figure 3, the clustered results concerning the maximal allowed cross winds are evaluated within the flight path planning. Allowing the higher cross wind v_{CW} = v_1 yields a couple of possible flight paths. For the other pilot group, which accept the smaller cross wind setting defined by $v_{CW} = v_2$, fewer takeoff trajectories are calculated. The former are illustrated in figure 9 as blue lines and compared to the flight paths of the latter case which are indicated as orange dotted lines.

Independent of the actual pilot who controls the system, one takeoff trajectory is selected. The selection is primarily characterised by the mission task. In figure 10 the selected flight path based on the cross wind setting $v_{CW} = v_1$ is shown. Additionaly, the three dimensional surface is illustrated which is defined by the start point (SP), the takeoff safety point (TSP) and the en-route transition point (ETP). The topographic map of figure 10 shows a section of the SRTM-data used here [17].

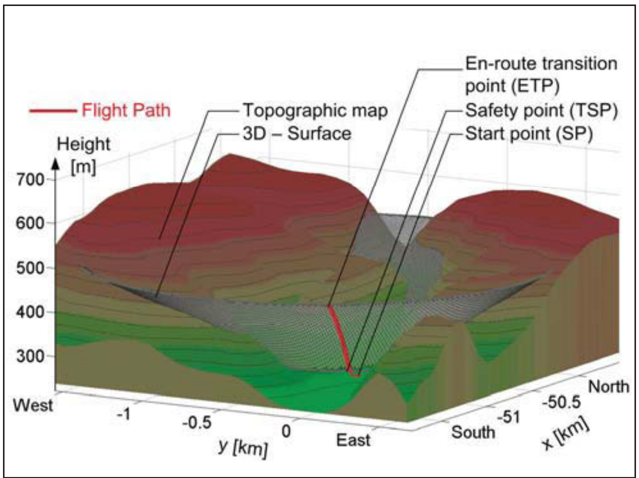

FIG 10. Selected takeoff trajectory

5. EN-ROUTE

The en-route trajectory generation is divided into two parts. At first a long term planning is done in this a path from the end of the takeoff trajectory to the beginning of the approach trajectory is planned. This part has a rough resolution in space and thus can be computed with low computational force. The second part is the short distance planning algorithm which calculates an optimal trajectory with a high resolution in space. Thus small obstacles can be taken into account and a more precise trajectory can be generated. This algorithm will be used for subsequent parts of the whole trajectory thus creating a high resolution trajectory for the whole route.

A second difference in the two planning modes is the different usage of constraints. In the rough planning only the most important constraints will be used (ROC or absolute height) ensuring an overall flyable trajectory. The high resolution planning will use all constraints from the flight manual of the helicopter and the pilot's demands. This trajectory is much more sophisticated and uses the results from the pilot survey. The resulting trajectory is not only flyable in a physics way but is although adapted to the pilot and his flying capabilities.

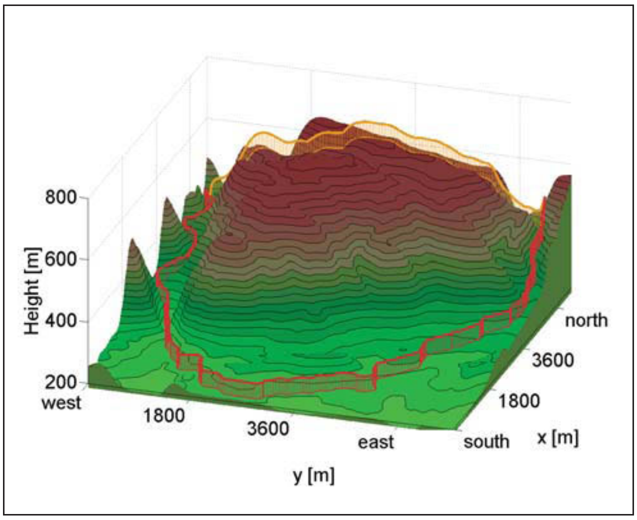

FIG 11. En-route trajectories for different cost functions

In figure 11 an example for the en-route path planning is shown. The figure shows two planned en-route trajectories from the en-route transition point (ETP) to the landing site. The two paths shown correspond to the two main groups of pilots discussed in section 3. One path leads over the hill and the other one around it. This can be realised by the usage of simple cost functions and heuristic path planning algorithms. It can clearly be seen, that the path around the hill avoids rises in the terrain and thus reduces climb and sink phases. This leads to a path with many heading changes which are caused by the definition of the cost function. In order to develop a practical en-route flight path an additional smoothing of the path has to be performed. The path over the hill just avoids the top peaks of the hill. Otherwise the path is as short as possible and thus resembles more a straight line without heading changes. For future adaptability more complex cost functions will be used and different path planning methods will be tested.

6. APPROACH AND LANDING

Similar to takeoff, several procedures like CAT-A, single angle (constant slope for the whole approach) or double angle (approach is subdivided into two parts, each with constant slope) can be regarded. In the following the main focus is on the single angle approach which is subdivided into the following phases of flight:

– Identification of an appropriate landing point
– Level flight at constant altitude
– Approach with constant slope
– Landing

First of all the landing point is checked. Therein a ground surface referenced roughness criterion is used to ensure a smooth and flat landing site. The level flight at constant altitude, together with a single angle approach, specifies a three dimensional surface similar to the takeoff profile. This is graphically depicted in figure 12.

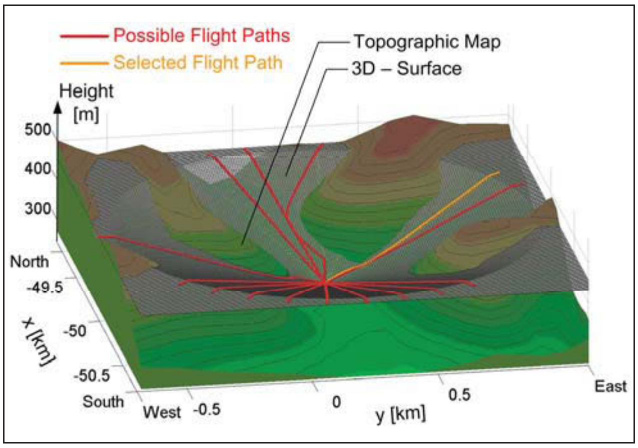

FIG 12. Approach with constant slope

Unlike to takeoff, the slope is constant for the whole approach trajectory from level flight to hover. The “road travelling salesman problem” is solved by an adapted A* algorithm concerning wind, pilot requirements and the “dead man curve”. The possible flight paths, together with the selected one, are shown in figure 12. All the trajectories displayed depend on pilot definitions which are characterised by a maximal angle of bank, a continuously decreasing true air speed and a permanent visibility of the landing site. With respect to these constraints a pilot adaptation is possible. If the pilot allows an adequate angle of bank, namely 30 degrees, the planned trajectories are as smooth as plotted in figure 12.

To select one of the calculated possible flight paths a dedicated characterisation of each approach trajectory is executed. The selected unobstructed trajectory depends on the position of the helicopter, together with the actual heading, and on the pilot’s acceptance for a curved approach. These characteristics can be adjusted by means of specific weights. This enables a distinction of all possible flight paths and allows the selection of the appropriate flight path. Furthermore, the system’s capability will be enhanced to identify these weights automatically. Hence, the selection of an appropriate trajectory is delegated to a software algorithm enabling the pilot to monitor the landing site or other important information.

7. SUMMARY & OUTLOOK

This paper summarises the conceptual design of a pilot assistance system which is developed within the frame of the ALLFlight project (Assisted Low Level Flight and Landing on Unprepared Landing Sites). The description mainly focuses on the development of software algorithms for trajectory generation. These algorithms are developed for a global path planning which analyses the whole space to determine an unobstructed flight path. The latter depends on the pilot behaviour and on the capability of the helicopter. To meet some of the pilot dependent requirements, a survey of helicopter pilots is conducted which is used to identify the main influencing variables. These characteristics are analysed to determine an adequate pilot classification which is used to reproduce the characteristics and the associated constraint set. The pilot dependent constraints, together with the limitations given by the flight manual and by flight mechanics, define a pilot dependent unobstructed path. This path is determined for takeoff, en route and approach, such that for each flight phase optimal trajectories can be generated. Actually, basic algorithms for path planning and pilot classification are available.

In order to evaluate the system’s capabilities, flight tests are needed. By means of such experimental studies the reliability of the overall system can be analysed. Up to now, only simulation studies on a standard PC can be performed to check the general functionality. Consequently, in future work, these algorithms will be integrated into a holistic software architecture and will be prepared for flight testing. Additionally, further pilots will be interviewed to gather more data and to refine the classification.

ACKNOWLEDGEMENTS

The authors thank Stefan Suck for his assistance in analysing the survey, to Thorsten Strohmaier, who developed the approach and landing planning during his diploma thesis. Our special thanks go to all the pilots of the different organisations who took part in the survey so far and will in the future. Without their support, the work could not have been performed.

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