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SUPERVISORY MULTI-SWITCHING CONTROL FOR AUTOMATIC TAKEOFF AND LANDING OF UNMANNED HELICOPTER

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Abstract. *This paper proposes one innovative control strategy – multi-switching control with supervised learning for unmanned helicopter's automatic takeoff and landing process. More specifically, firstly before showing our proposed control strategy, the detailed description and analysis on automatic takeoff and landing of unmanned helicopter are given, respectively, meaning they are all divided into many subprocesses, so the controller design problem is turned to devise each subcontroller for each subprocess. Secondly, to better understand the control principles for automatic takeoff and landing process, three different points are analyzed from constraint analysis, automatic takeoff control and landing control, bringing the idea of model predictive control to consider these different constraints. Thirdly, based on our above detailed analysis about automatic takeoff and landing process, i.e., both entire processes can be separated into many subprocesses, we combine multi-switching control and supervised learning together to be supervisory multi-switching control. After separating the total time interval for automatic takeoff and landing process into five subintervals, corresponding to five subprocesses, five subcontrollers are designed for each subprocess, while introducing one supervisor mechanism to achieve that switching function. Finally, one practical platform is constructed, and some simulation results are given to prove our theoretical results.*

Keywords: Unmanned helicopter, Automatic takeoff and landing, Multi-switching control, Supervisory control, Flight control

1. **Introduction.** Unmanned helicopter is one of the greatest innovations made by human beings in almost all sectors, like e-commerce, defense, agriculture, surveillance, traffic management system, communication in remote areas, human organ transportation, chemical or drug delivery, entertainment sector, and wildlife monitoring. In addition, unmanned helicopter supports disaster management during earthquakes, massive floods, forest fires, and nuclear-chemical accidents. For example, unmanned helicopter can be used in three steps of disaster management. In the pre-disaster state, unmanned helicopter is used for surveillance, prevention and early detection. During a disaster, it might be used for food packet-medicine delivery, monitoring the situation to support critical decision making and prevent or reduce losses. Finally, after the disaster, unmanned helicopter is used to monitor the situation, assess quickly and estimate loss. As unmanned helicopter has a

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wide range of applications and its usage is mostly in hazardous environments, a fundamental aspect of a controller design is obtaining the dynamics of unmanned helicopter that permits us to examine the system performance. The design of control strategy for unmanned helicopter is important, just like a biplane quadrotor for trajectory tracking, payload delivery-pick up and slung load with partial rotor failure despite wind gusts, and a total rotor failed condition. The cost of unmanned helicopter is high and has a very high risk of damage, and even a small oscillation could lead unmanned helicopter to crash, so to prevent this, the controller needs to be functional experimentally once some simulations have been tested so as to tune the controller parameters. To control unmanned helicopter well, there are different control algorithms at hand, like linear quadratic regulator, proportional integral derivative, gain scheduling control, fuzzy control, backstepping control, and sliding mode control.

Due to its high nonlinearity of unmanned helicopter, a large number of nonlinear control strategies appear in control field during these recent years. Among them, backstepping control is a common nonlinear control algorithm, which mainly constructs a suited Lyapunov function and combines it with other control strategies, so as to make the combined control system stable. For example, backstepping control was applied to designing both position and attitude controller for unmanned helicopter, and also introducing the extended state observer into the control loop to show a good suppression function against wind through simulations. Furthermore, based on the dynamic, linear and nonlinear controllers are designed. [1] presented a nonlinear model predictive controller while [2] established gain scheduled proportional integral derivative control for fixed wing unmanned helicopter and validated the effectiveness experimentally. A mathematical modeling technique for unmanned helicopter based on its robust controller design procedure is proposed in [3]. The rotary wing unmanned helicopter is widely applied in urban areas for traffic monitoring, surveillance, payload delivery, etc. There are also some linear and nonlinear controllers developed for rotary wing unmanned helicopter, like proportional integral derivative, model predictive control, self tuning fuzzy control, H control, incremental nonlinear dynamic inversion and neural network based control. Some special properties exist for unmanned helicopter, such as underactuated, highly nonlinearity and coupling, thus meaning less control inputs and more outputs. For example, a biplane quadrotor tail sitter has four control inputs and six output states. The role of the control engineer is to design the control law or controller such that the hardware meets the control requirement. In addition, there are numerous built in sensors like ultrasonic sensors, cameras, pressure sensors and inertial measurement unit, which contains an accelerometer and three-axis gyroscope to measure acceleration and angular rate. For the purpose of illustration about controlling unmanned helicopter, the example of nonlinear control strategy for tracking autonomous trajectories is explained as follows. During the payload delivery-pick up, the system's overall mass changes, so different adaptive control architectures are developed. In the real world, external disturbances like wind gusts act on unmanned helicopter during the mission, requiring a nonlinear disturbance observer and a nonlinear controller with completer stability analysis.

To the best of our knowledge, although linear control strategy and nonlinear control strategy exist for unmanned helicopter flight control system, control engineers always like to use linear control strategy due to its simplicity. It means after modeling unmanned helicopter flight system to yield one corresponding nonlinear system or nonlinear state space equation, then control engineer often linearizes it to one reduced linear system or linear state space equation, so the matured linear control strategy is applied directly. However, the simplified linear system is an idea case and one approximated form for the original nonlinear system, leading to more computational complexity for latter design process, such as controller design, observer construction, and state estimation. As a consequence, more control engineers started to study nonlinear system or nonlinear control directly without linearization process, bringing our contribution in this paper. [4] revisted the interconnection based notion of moment by introducing an output based signal generator, named generalized signal generator. [5] extended the geometric relation between the controllable subspace of a linear system and the unobservable subspace of its dual to the realm of nonlinear systems on smooth manifolds. The notion of virtual nonlinear nonholonomic constraints is introduced in a geometric framework, which is a controlled invariant submanifold and show the existence and uniqueness of a control law preserving this submanifold [6]. [7] addressed the problem of tracking control for an unknown nonlinear system with time varying bounded disturbance subject to prescribed performance and output constraints. The detailed nonlinear control theory is seen in [8]. Generally, as the real unmanned helicopter is a nonlinear system, nonlinear control strategy is more suited for nonlinear controller design than linear control strategy, and the linearization process is neglected, thus reducing some computations.

During these recent years, our team also study this interesting problem on controlling unmanned helicopter from different aspects. Roughly speaking, [9] proposed one nonlinear direct data driven control from theoretical analysis and practical engineering, i.e., formation flight system. Then iteration and learning strategy are extended into data driven control to form iterative learning data driven strategy for aircraft control system, while applying adaptation, optimization and learning idea to getting one optimal data driven control [10]. [11] proposed direct data driven safety control for aircraft flight system to achieve the dual missions about perfect tracking and safety property, corresponding to a new notion about safe controller. As aircraft flight control structure is a three-closed loop system, resulting in three unknown controllers, we study synthesis cascade estimation through prediction error identification to design these three unknown controllers sequently [12], where this three-closed loop structure corresponds to one network system, and then parametric and nonparametric controllers are all given within the statistical environment. The reason about why we only concentrate on data driven identification and data driven control for some practical plant is that all useful information about both unknown plant unknown control is included in data samples, so our only mission is to extract the useful information from the collected data.

Based on our previous contributions about aircraft flight controller design and our studies about different control strategies, for example, safe control, adaptive control, direct data driven control, learning control, nonlinear control, nonlinear adaptive control, and differential geometry control, this new paper extends above topics into unmanned helicopter's automatic takeoff and landing control, thus extending our existing research about controlling unmanned helicopter or other aircrafts in level or back flight. To the best of our knowledge, research on automatic takeoff and landing control is very few. To be more precise to show our work, firstly automatic takeoff and landing of unmanned helicopter is described in detail to explain the whole flight process, automatic takeoff process and automatic landing process, respectively. As the whole flight process is divided into some subprocesses, different controllers are needed to design during each subprocess, thus corresponding to our named multi-controllers. Secondly, before to devise these multi-controllers in each subprocess, some preliminary analyses about automatic takeoff and landing are explained from constraint condition, automatic takeoff control strategy and automatic landing control strategy respectively in detail. Thirdly, from our detailed analysis and description on unmanned helicopter's automatic takeoff and landing, we propose one innovative control strategy, i.e., supervisory multi-switching control, to design each subcontroller for each subprocess, while combining data driven idea, switching mechanism, optimization and other interesting ideas. Roughly, lots of control strategies exist for unmanned helicopter flight control, for example, classical PID control, linear Gaussian or optimal control, predictive control, adaptive control, sliding control, nonlinear control, fuzzy control and intelligent control, being applied during the whole flight process. However, the external environment always changes with time varies, so only one kind of control strategy cannot guarantee unmanned helicopter fly perfectly, thus requiring that controller changes with the varying environment. Our considered multi-switching control appears to make the controller switch during different time intervals or varying environment.

Generally, the main contributions in this new paper are formulated as follows.

1) The detailed automatic takeoff and landing process of unmanned helicopter is described in our own sentences, and three different flight envelopes are also shown.

2) Automatic takeoff and landing control are analyzed around constraint analysis, automatic takeoff control analysis and automatic landing control analysis.

3) Supervisory multi-switching control strategy is proposed to control automatic takeoff and landing process, and the detailed analysis is also given to explain or complete our contributions.

The paper is organized as follows. In Section 2, automatic takeoff and landing of unmanned helicopter are described, and three kinds of descriptions about the whole flight process, automatic takeoff process and automatic landing process are explained. For latter controller design purpose, Section 3 proposes the different control missions for both automatic takeoff control and automatic landing control, respectively, and furthermore some detailed control steps are given from the point of control missions. Then our main work is in proposing supervisory multi-switching control strategy, given in Section 4. Recall that each automatic takeoff process and each automatic landing process are divided into many different subprocesses, so multi-switching control strategy is benefitial to achieve multi-controllers design, while combining learning data, data driven idea and adaptation. Section 5 shows some simulation results to prove our proposed theoretical analysis. Finally, Section 6 formulates our main conclusions and points out our future work about automatic takeoff and landing control in more depth.

2. Automatic Takeoff and Landing Description.

Automatic takeoff and landing processes are two important bases of unmanned helicopter automatic flight as the efficiency and safety of automatic takeoff and landing directly affect the performance and level of engineering applications. During these automatic takeoff and landing phases, it is very complicated to control due to the complex aerodynamic characteristics and its susceptibility to external perturbations.

The entire flight process of unmanned helicopter is described as follows.

1) Unmanned helicopter flies from the ground up to the altitude of obstacles.

2) Unmanned helicopter lands at a specified target point or zone after completing the predesigned mission, plotted in Figure 1.

Specifically, from Figure 1, we see the complete autonomous flight process includes the following six subprocesses, i.e., automatic takeoff, fixed point hovering, mission execution, slipping down to target point, fixed point hovering, and automatic landing, corresponding to the named vertical takeoff and landing.

2.1. Automatic takeoff description.

Automatic takeoff process of unmanned helicopter can be divided into the following five processes, i.e., stay-on-ground process, near ground flight process, stabilized climb process, fixed point hovering process, and hovering forward flight process, also given in Figure 2.

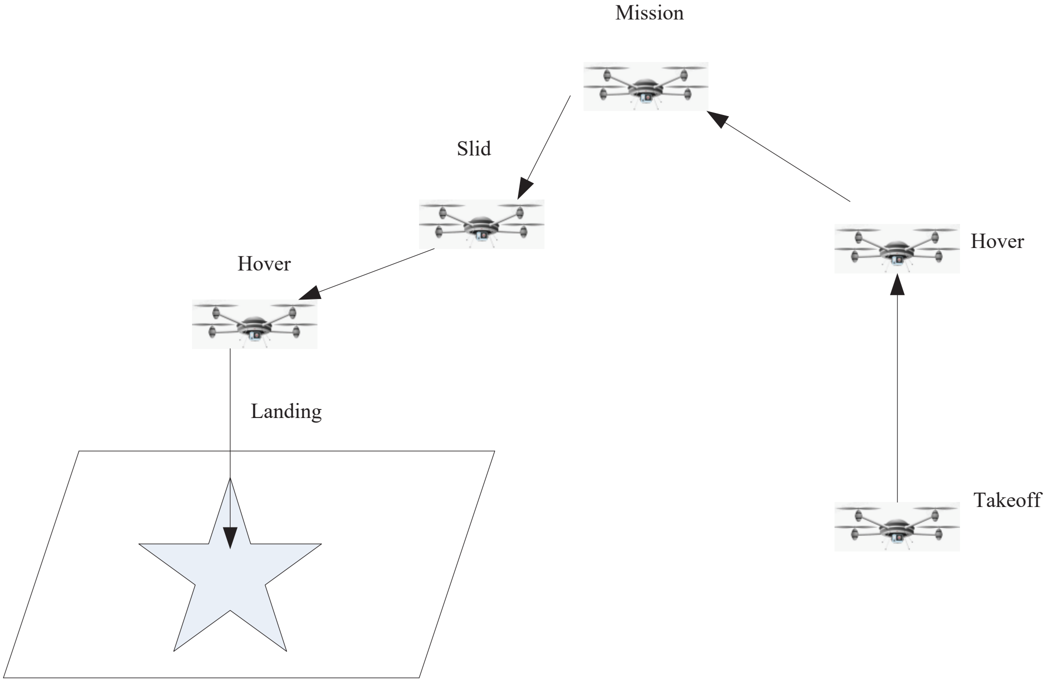


Figure 1. Entire flight process

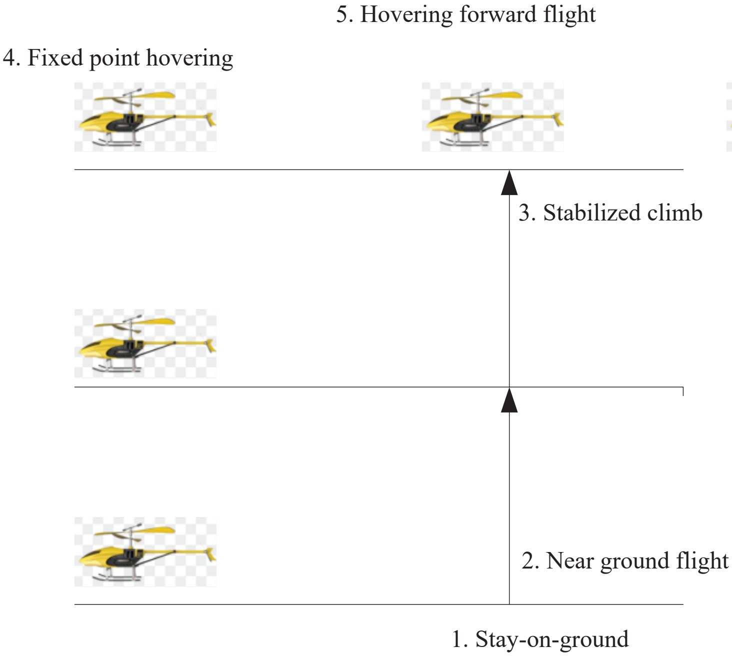


Figure 2. Automatic takeoff process

From Figure 2, after unmanned helicopter is fired on ground, then the motor gradually reaches its standard velocity, and unmanned helicopter's lift is increased through gently increasing the total distance. Unmanned helicopter will leave the ground and climb to a safe altitude while maintaining a stable attitude, so it hovers in the air and waits for the next instruction.

2.2. **Automatic landing description.** Figure 3 shows the complex six processes of automatic landing, i.e., return process, adjustment position process, fixed point hovering process, stabilized descent process, floating process and touch down ground process.

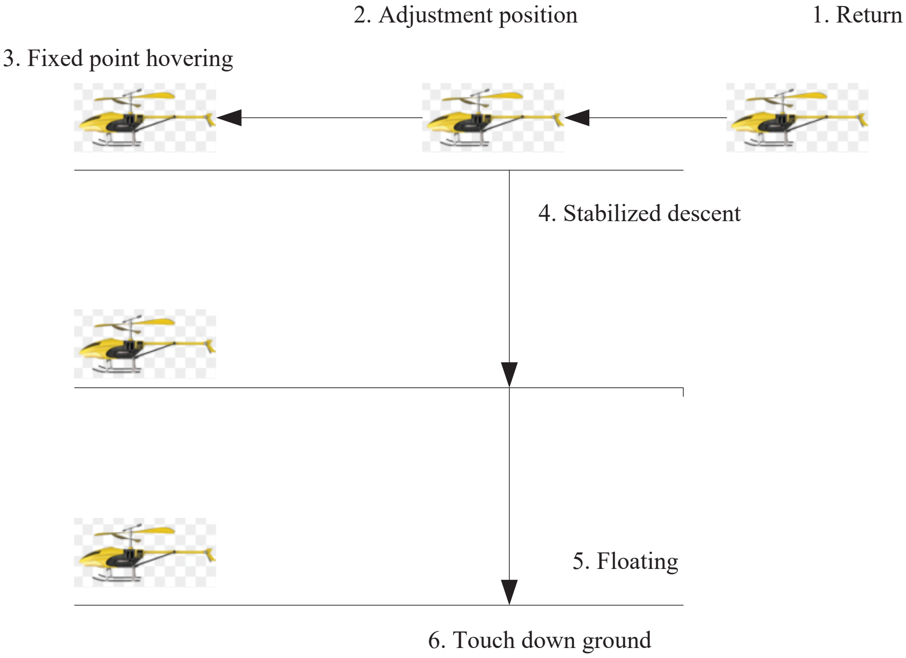


Figure 3. Automatic landing process

In addition, after unmanned helicopter performs its mission, it flies precisely fight above the predesigned target point and keeps the hovering state for some seconds. In case of receiving the order from ground station, its body descents smoothly and touches the ground, and then finally engine is shut down.

3. **Automatic Takeoff and Landing Control Analysis.** Automatic takeoff and landing are two important flight modes in the flight process, i.e., flight envelope. Unmanned helicopter with automatic takeoff and landing control needs to have some functions, such as automatic trim, precise fixed point hovering, and low altitude control, where command keys can be used to complete automatic takeoff and landing control. By the way, automatic takeoff control includes ground automatic trim control, near ground hovering and altitude control, etc. Automatic landing control has precise fixed point hovering control, near-ground hovering and anti-slip control, etc.

3.1. **Near ground constraint analysis.** Our considered unmanned helicopter adopts a ducted fan structure, and its landing gear is composed of 4 legs, which are symmetrical in longitudinal transverse left and right, so the constraints of the transverse channel and longitudinal channel are the same as those of longitudinal and transverse channel due to its symmetrical structure. The instantaneous height of unmanned helicopter from ground is very small, and one constraint exists on the pitch angle of ground surface, being a function of ground clearance and weaker with the height increases. Above near ground constraint analysis is shown in Figure 4, where O is the center of unmanned helicopter, and d is one distance relative to the undercarriage surface of the landing gear from point O. b denotes length from point O to end of landing gear leg, and h is the flight height of point O relative to the ground.

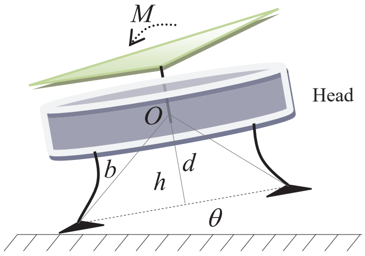


Figure 4. Pitch angle constraint

Making use of the symmetrical structure in the vertical and horizontal directions, above Figure 4 tells us that when $h \in [d, b]$, constraints on pitch angle and roll angle from ground are expressed as follows:

$$\theta(h) \in [-\alpha(h), \alpha(h)];\ \ \pi(h) \in [-\alpha(h), \alpha(h)];\ \ \alpha(h) = \arcsin(h/b) - \arcsin(d/b) \qquad (1)$$

where θ and α are pitch angle and roll angle, respectively. Equation (1) shows unmanned helicopter with severe near ground attitude constraints. As $b = 1$ and $d = 1.1$ m, the maximum pitch angle and roll angle are only just 4°, when the actual landing gear is 0.1 m above ground. Specifically, the attitude angle during the whole automatic takeoff and landing process is guaranteed to be in the constraint range. Moreover, if this constraint range does exceed, unmanned helicopter may touch the ground and crash.

3.2. **Automatic takeoff control.** According to above analysis, automatic takeoff requires zero instantaneous attitude from ground, and no movement trend in the longitudinal and horizontal directions. When unmanned helicopter takes off automatically, the vertical-horizonal and altitude channels are required to satisfy the following constraints under the premise of heading maintenance.

1) At the instant of vertical departure from ground, the pitching moment and roll moment are all in balanced states; thus, the pitch angle and roll angle must be within the constraint range.

2) Vertical and horizonal slip velocities from ground are less than 0.5 m/s, and the slip distance from takeoff point is less than 3 metre.

3) Lifting velocity is less than 0.5 m/s within the range of off-ground to constrain altitude.

4) Maximum pitch angle rate and maximum roll angel rate must be less than 4°/s.

Roughly, above constraints 1) and 2) essentially require the longitudinal force and pitching moment are balanced during takeoff process, and then the lateral force and roll moment are also balanced. On the other hand, before leaving the ground, the rotor pull force is not enough to pull up unmanned helicopter, and the excess gravity component is unloaded to ground through four feet of landing gear. Ground restraint force, gravity and rotor pull force maintain the longitudinal force and pitching moment balance. After leaving ground, the ground restraint is lost, and then only longitudinal force and pitching moment are generated by the self gravity and rotor tension.

In order to solve the problem of torque imbalance before takeoff, force sensors are installed at the bottom of four feet of landing gear to feel the vertical force on the ground. Later, they are added to the control channel to realize the automatic trim before takeoff, so that unmanned helicopter can take off vertically and automatically stably, shown in Figure 5.

In Figure 5, different forces are $\{N_A, N_B, N_C, N_D\}$, and then pitching moment and roll moment are respectively

$$M = (N_A - N_C)\sqrt{b^2 - a^2};\ N = (N_B - N_D)\sqrt{b^2 - a^2} \tag{2}$$

Introducing above four forces into the feedback control system to achieve moment levelling, then we achieve the force equilibrium in the vertical direction during the stay-on-ground process, thus resulting in

$$G\cos\theta\cos\phi + F_{yr} - N_A - N_B - N_C - N_D = 0 \tag{3}$$

where F_{yr} is rotor pull force.

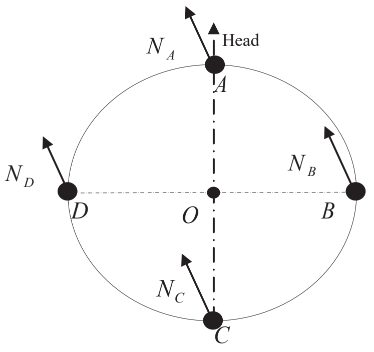


Figure 5. Supported force before takeoff

To make attitude be zero during takeoff process, Equation (3) shows the longitudinal control before leaving the ground is transformed to $N_A = N_B$, and transverse channel control is $N_C = N_D$.

Set

$$N_x = N_A - N_C \tag{4}$$

$$N_y = N_B - N_D \tag{5}$$

To satisfy $N_A = N_B$ and $N_C = N_D$, i.e., two errors are all zero, i.e., $N_x = N_y = 0$, we apply attitude and longitudinal-lateral slip to suppressing attitude change and longitudinal-lateral slip after leaving the ground, plotted in Figure 6, i.e., one takeoff control structure.

In Figure 6, $G_N(s)$ is the direct force control, $G_\theta(s)$, k_{ω_z} constitute attitude control. $G_x(s)$, M_h, $k_{\dot{x}}$, k_θ establish slip control loop. $G_N(s)$, $G_\theta(s)$, $G_x(s)$ are all PI controllers.

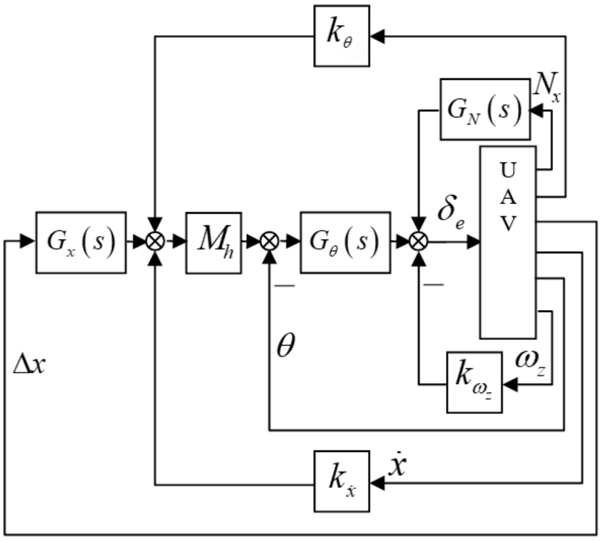


Figure 6. Takeoff control structure

M_h is the varying saturated factor, k_{ω_z}, $k_{\dot{x}}$, k_θ are feedback parameters. ω_z is pitch angle velocity. Δx, $\dot{x}$, θ are longitudinal slip, linear velocity, and linear acceleration, respectively. δ_e is longitudinal distance.

Taking into account that near ground constraint, closed loop input u_{x_i} and closed loop output u_{x_0} are constrained to be

$$u_{x_0} = \begin{cases} \alpha(h) & u_{x_i} > \alpha(h) \\ \alpha(h) & \|u_{x_i}\| \le \alpha(h) \\ -\alpha(h) & u_{x_i} < -\alpha(h) \end{cases} \tag{6}$$

Based on above proposed takeoff control strategy in Figure 6, the detailed steps for automatic takeoff control strategy are reformulated as follows.

Step 1: Set

$$N_{total} = N_A + N_B + N_C + N_D \tag{7}$$

If the initial rotor total distance is reduced to $p = 4°$, then turn to step 2.
Step 2: Increase rotor total distance p at 0.2°/s until

$$N_{total} < 0.05 N_{z_0} \tag{8}$$

then turn to step 3, where N_{z_0} is the weight at takeoff.
Step 3: Set the total variable as that

$$p = p_0 + k_h(h_d - h) - k_{\dot{h}}\dot{h} \tag{9}$$

where p_0 is the initial total variable, and $\dot{h}$ is velocity. k_h and $k_{\dot{h}}$ are control parameters, and h_d varies according to that
1) Increase h_d with 0.2 m/s, $h \in$ constraint range.
2) Increase h_d with 0.5 m/s until 20 m, $h \notin$ constraint range.
In case $h_d = 20$, then the entire automatic takeoff process is completed.

3.3. **Automatic landing control.**

Similarly, considering the other automatic landing control analysis, the important consideration of automatic landing is to control the descending velocity and avoid the bumps in the landing transient from the point of altitude channel. In addition, under the circumstance of the longitudinal and transversal channel, the key is to suppress slip.

For simplicity of discussion, the main steps for automatic landing are reformulated as follows.

Step 1: Unmanned helicopter returns to one appropriate position above the landing point and descends to 20 m, until hovering, then the heading is maintained, and both longitudinal-transverse channels are transformed to that control structure in Figure 6, so turn to step 2.
Step 2: That initial variable p is computed from Equation (9), and h_d varies according to that
1) Decrease h_d with 0.5 m/s, $h \notin$ constraint range.
2) Decrease h_d with 0.2 m/s, $h \in$ constraint range.
until the landing gear arbitrary foot force sensor senses the support force, then turn to step 3.
Step 3: Decrease p to 4° at 1°/s, then turn off engine.

Generally, during the whole automatic landing process, the longitudinal and horizontal channels enter hat takeoff control structure, meaning that in case of outside the constraint height, the longitudinal and horizontal directions mainly suppress the deviation of the landing point, but on the contrary, in case of within the constraint height, we must ensure the attitude satisfies the constraint and reduce the risk of landing overturn. Meanwhile, the force sensor installed on the landing gear foot, is used to judge whether to land or hover yet. After landing, the total distance is controlled to reduce the rotor pull force rapidly, so as to avoid the flutter or overturn, caused by the instantaneous bump.

4. **Supervisory Multi-Switching Control.** From our previous descriptions about automatic takeoff and landing processes for unmanned helicopter and Figures 2 and 3, we see both automatic takeoff and landing processes are divided into many subprocesses, referring to Figures 2 and 3. As the control design processes for both automatic takeoff and landing are the same with each other, without loss of generally, here we only use automatic takeoff process as an example to exemplify our proposed control strategy.

Observing Figure 2 again, the entire automatic takeoff process is divided into five subprocesses, i.e., 1) stay-on-ground process, 2) near ground flight process, 3) stabilized climb process, 4) fixed point hovering process, and 5) hovering forward flight process. These five subprocesses constitute the entire automatic takeoff process, plotted in Figure 7.

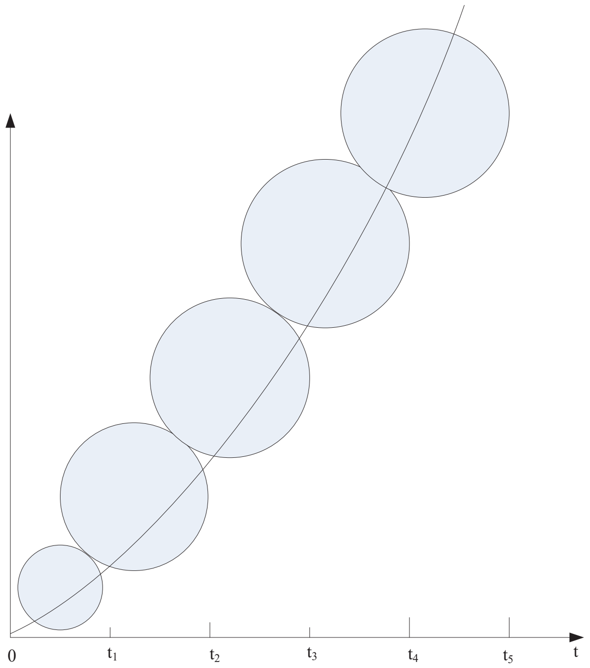


Figure 7. Five subprocesses for automatic takeoff

Specifically in Figure 7, the whole time interval $[0,T]$ for completing automatic takeoff is divided into five time subintervals, i.e., $[0,T] = [0,t_1] \cup (t_1,t_2] \cup (t_2,t_3] \cup (t_3,t_4] \cup (t_4,T]$, where T is the total time period, and no intersection exists between two adjacent subinterval, i.e., $(t_1,t_2] \cap (t_2,t_3] = \emptyset$.

It is well known that not any one control strategy can be suited for all different circumstances, meaning different circumstances need different controllers, so the following multi-switching control strategy with one supervisor mechanism is constructed for automatic takeoff control, as shown in Figure 8.

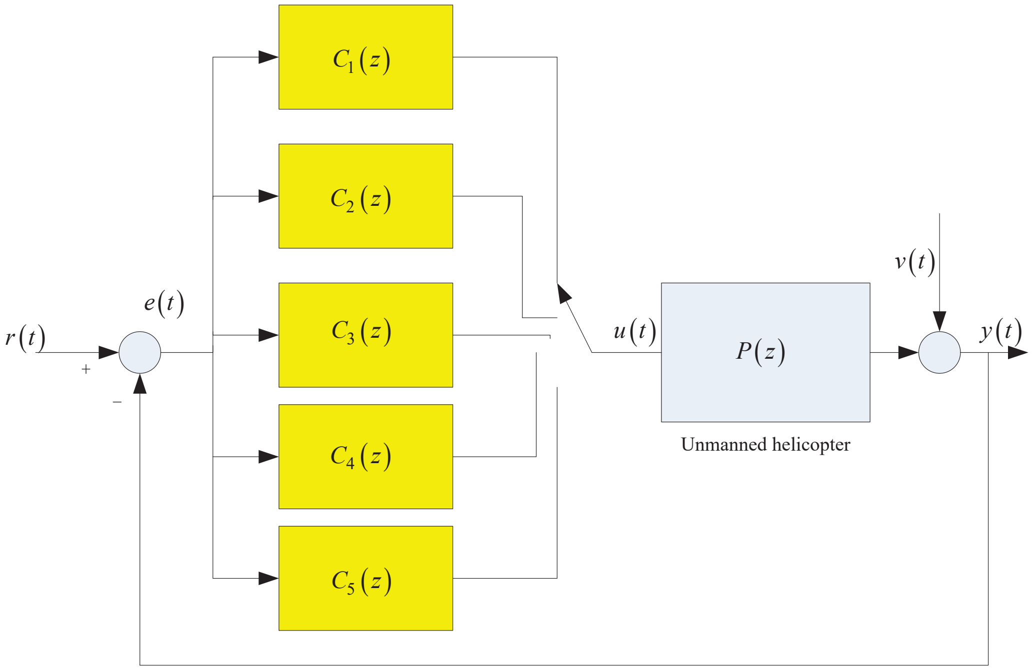


Figure 8. Multi-switching control

In above Figure 8, $P(z)$ is one mathematical model for unmanned helicopter, $r(t)$ is the force from engine, $y(t)$ is output, corresponding to some physical variables from unmanned helicopter flight mode, error signal $e(t) = r(t) - y(t)$, $u(t)$ denotes the controller output, $v(t)$ is the external noise or disturbance, and z is one shift operator.

Five controllers $\{C_i(z)\}_{i=1}^{5}$ are five designed candidate controllers in priori, meaning each controller $C_i(z)$ is applied for the ith subprocess, i.e.,

$$u(t) = \begin{cases} C_1(z) & t \in [0, t_1] & \rightarrow & \text{stay-on-ground} \\ C_2(z) & t \in (t_1, t_2] & \rightarrow & \text{near ground} \\ C_3(z) & t \in (t_2, t_3] & \rightarrow & \text{stabilized climb} \\ C_4(z) & t \in (t_3, t_4] & \rightarrow & \text{fixed point hovering} \\ C_5(z) & t \in (t_4, T] & \rightarrow & \text{hovering foreard flight} \end{cases} \tag{10}$$

where the switching mechanism is done with time increases.

The worker must only concern on the accurate time instant, for example, when t approaches to the end point t_1 in subinterval $[0, t_1]$, then he or she needs to switch the controller from $C_1(z)$ to $C_2(z)$. To replace human being by one machine, we further construct one supervisor mechanism to real-time switch automatically, plotted in Figure 9, while those five subcontrollers $\{C_i(z)\}_{i=1}^{5}$ are all parametrized by their own controller parameters $\{\theta_i\}_{i=1}^{5}$, such as PID controller, i.e.,

$$C_i(z, \theta_i) = \alpha(z)\theta_i;\ \alpha(z) = \begin{bmatrix} 1 & z & z^{-1} \end{bmatrix} \tag{11}$$

In addition, these five subcontrollers $\{C_i(z, \theta_i)\}_{i=1}^{5}$ can be also designed from Figure 6 in priori for each subprocess or each time subinterval. Similarly, our proposed supervisory multi-switching control is also applied for unmanned helicopter automatic landing process.

5. **Simulation.**

In order to ensure the safety of takeoff and landing, unmanned helicopter adopts inertia-radio combination altitude measurement, fully utilizes the characteristics of radio altimeter with high accuracy in low altitude and adopts the above automatic takeoff

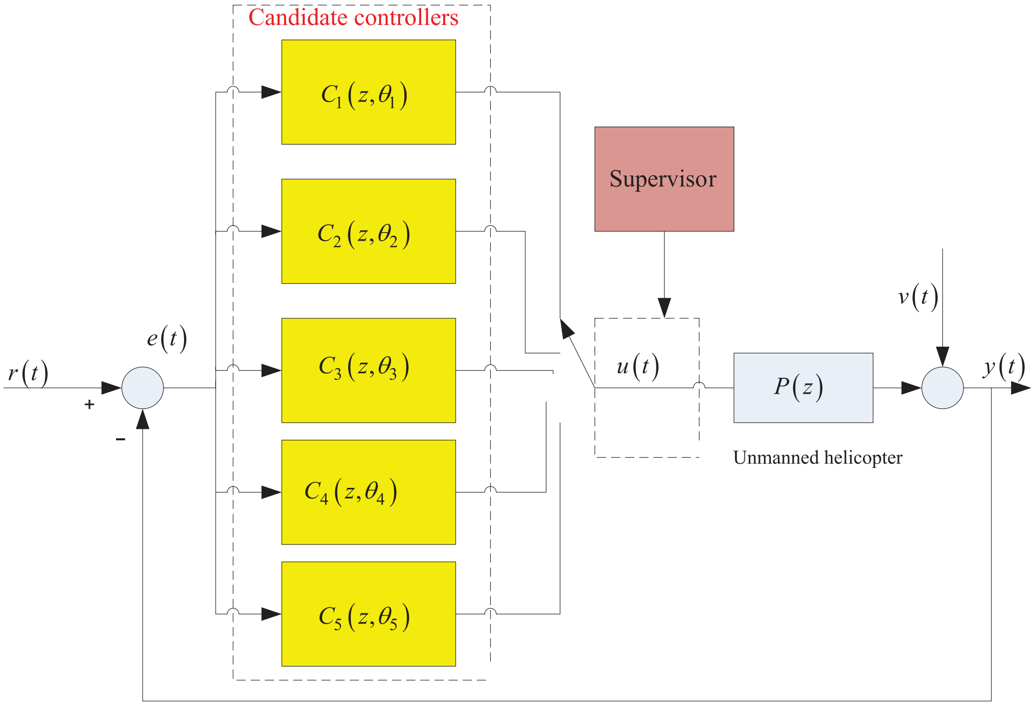
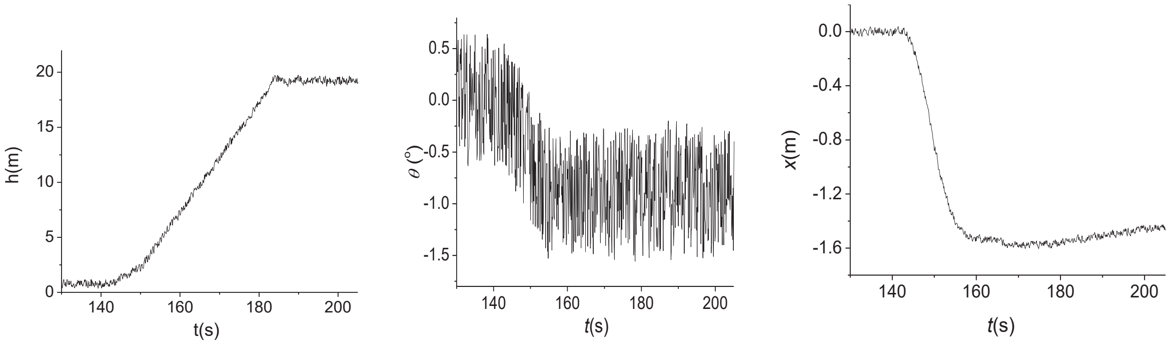


FIGURE 9. Supervisory multi-switching control



(a) Altitude changes in takeoff (b) Pitch angle changes in takeoff (c) Longitudinal slip distance in takeoff

FIGURE 10. Simulation results

and landing control strategy. After engine is started on ground, the throttle is gradually increased according to the requirements of the engine control, and then the engine closes the loop so that the rotor rotating velocity reaches the rated rotational velocity. The flight control program automatically adjusts the rotor total pitch and longitudinal and transverse cyclic pitch according to the above takeoff control strategy after the rotor rotational velocity reaches. When the rotor velocity reaches the rated velocity, ground station sends the takeoff command to unmanned helicopter through the ground remote control, and the flight control program automatically adjusts the rotor total distance and the longitudinal and transverse cycle pitch according to the above takeoff control strategy. The recording curves are shown in Figure 10 as relative altitude, pitch angle and longitudinal slip curves of unmanned helicopter during automatic takeoff process, respectively.

From Figure 10, when unmanned helicopter adopts the automatic takeoff control strategy proposed here, the altitude of unmanned helicopter gradually rises from zero to 20 m during unmanned helicopter takeoff process, and it can be seen from the curves that the transition of automatic takeoff process is relatively smooth without fluctuations. In order to inhibit the longitudinal sideslip and prevent overturning, and ensure the safety of automatic takeoff process, and realize the vertical takeoff of unmanned helicopter, during automatic takeoff process, the pitch angle changes from 0° to -1° to ensure the balance of the takeoff moment, and the change of pitch angle is still within the constraints. Moreover from Figure 10(c), the longitudinal slip during automatic takeoff process is within 2 m, which is within the permissible range, and automatic takeoff has been realized perfectly.

6. **Conclusion.** To alleviate the gap between flight control and automatic takeoff or landing control, this paper studies the controller design problem only on automatic takeoff and landing of unmanned helicopter. To better understand the detailed control principles on automatic takeoff and landing of unmanned helicopter, some preliminaries are analyzed, for example, both entire automatic takeoff and landing process, force analysis, constraint analysis, and control mode. Making use of that the entire automatic takeoff and landing processes are separated into many subprocesses according to the time interval, we propose supervisor multi-switching control strategy to choose each controller for each subprocess sequently, while combining switching control, and supervised mechanism.

As this paper is our first one about this interesting automatic takeoff and landing control of unmanned helicopter, in the future we will study it in more depth. For example, this paper only proposes to construct one supervised mechanism to achieve that switching function, but that about how to construct it and make it learn adaptively is our next contribution.

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