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AUTOMATIC LANDING SYSTEM FOR UAV

INTRODUCTION

The Unmanned Aerial Vehicle (UAV) system is designed for the real time safe and low cost TV or IR aerial reconnaissance, monitoring of contaminated and inaccessible areas, artillery fire monitoring, radio reconnaissance and jamming, border patrol, search and rescue (SAR) assistance, or it can be used as an aerial target.

UAV control is either semi- or fully automatic. The flight plan can be preprogrammed before take-off or during flight.

Navigation is via GPS and there is real-time data-link between the UAV and its Ground Control Station (GCS), allowing the ground crew to monitor real-time on-board optoelectronic sensors and the airplane position (displayed on a digital map). The main flight data are displayed on displays at GCS:

V_{gl} — gliding velocity (usually: $V_{gl} = 1.3 * V_p$);
V_p — atalling speed (= 100km/h);
ϑ_{gl} — grade of the UAV on the glide;
V_y — vertical speed;
$V_{yd} = -0.5 \div -0.6\ ms^{-1}$ is acceptable vertical speed at the touch point, ie. $V_{yd} \cong 0.8\text{-}0.9 * V_{gl,}$

For our purposes is best suitable the exponencial trajectory of landing. The shape of exponencial trajectory see Figure 1.

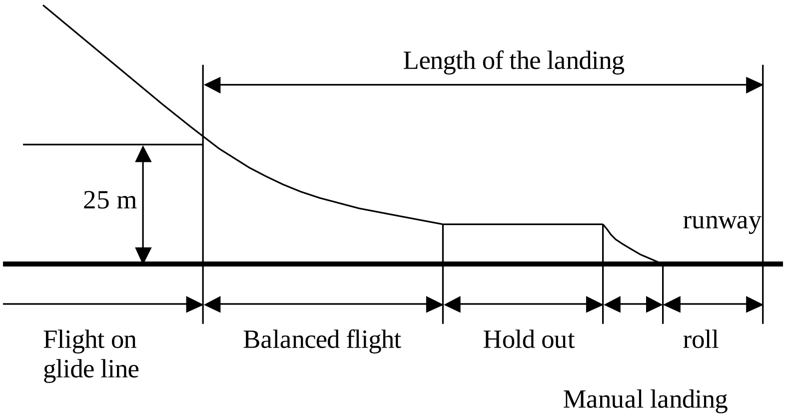

Fig. 1. Stages of the landing the UAV

STAGES OF THE LANDING

The UAV is aproaches to the runway at the altitude H of the speed V. At the given distence from runway starts the UAV gliding, it is caused manualy or automaticaly, the trajectory slope ϑ_{gl} at this moment is 2.5°-3°. To reduce the vertical speed V_y during the flight on glide line, it is necessary to minimize the grade. This stage of crossing fom flight on glade line to the parallel flight with runway is called balanced flight. Durinf the manual flight the plane is lead to the trajectory parallel to runway, this stage is called hold on, on this stage, the plane flights at the altitude H= 0.5-1m above the ground and gradually loosing its speed. At the end of hold on stage is velocitu aproaching the landing speed. To hold on the lift the pilot is increasing the angle of attack during this stage α.
Concernig all possible balanced trajectories we will take into account only axponencial trajectory, which were accepted for landing of civil aircrfats. We obtain this trajectory assuming, that in every point the vertical speed Vy of the UAV will be proportional to the actual altitude H, ie.:

$$-H'(t) = cH(t), \tag{1}$$

where:

c — is a proportional figure;
H(t) — altitude;
H´(t) — vertical speed.

Denote T=1/c exponential figure, then we can transform the equitation (1), using Laplace transform to the form (zero initial conditions):

$$(Ts+1)\,H(s) = 0 \tag{2}$$

Solving this diferential equitation (resp. its picture) with initial altitude condition H_0 (25m), we obtain the function of the altitude during the flight.

$$H(t) = H_0\, e^{-t/T} \tag{3}$$

Where:

H_0 — is initial altitude;
T — is exponential figure.

With respect to effective landing, the hold on stage isn't used during the automatic landing. Then the balanced flight is finished by touching the runway.

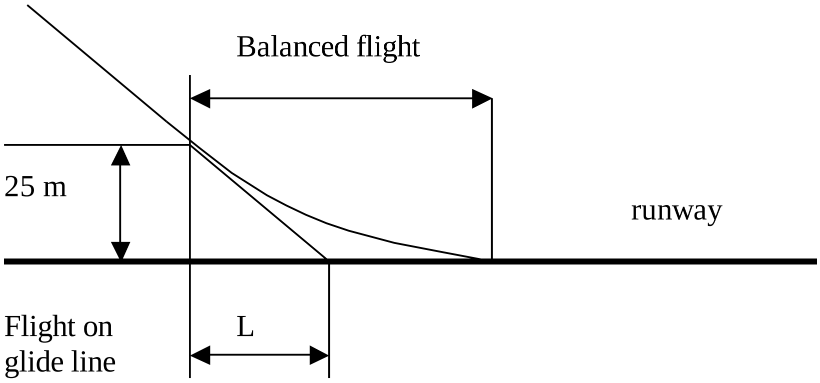

Fig. 2. Stages of the landing the UAV, no stage hold on

Let us consider that during the stage of balanced flight the velocity changes little, for that we will assume the velocity steady and equal to V_{avg} (average speed = $(V_{gl} - V_{land})/2$). In that case the equitation of trajectory has the form::

$$H(l) = H_0 e^{-l/L} \quad (4)$$

Where:
$l = Vt$ — Distance from the beginig of balanced flight stage;
$L = VT$ — Exponential figure of balanced flight.

To accomplish crossing from balanced flight to hold on stage it is necessary that glide line is equal to the hold on exponential at the begining of flight on glide line. That is true when this condition is also true:

$$L = H_0 / \vartheta_{gl} \ (= H_0 / tg(\vartheta_{gl})) \quad (5)$$

or

$$T = H_0 / V\vartheta_{gl} \quad (6)$$

During the flight of the UAV on the exponetial trajectory according the equitation (1), the Uav is aproaching the runway. Theoretically it will never touch the ground. Distance l from the begining of balanced flight stage to the point of altitude H(l) is given by:

$$l = L \ln (H_0 / H(l))$$

Due, the altitude H(l) is null at the end of landing, we obtain $l = \infty$, distance of balanced flight is infinite. It shoulb be shorten, we let the UAV to has some vertical speed at the moment of touching the ground V_{ytouch} (H'_{ytouch}). In coincidence with the equitation (2) has the UAV such a vertical speed at the altitude:

$$H = T H'_{ytouch} \tag{7}$$

Proto, aby letoun měl při dosednutí vertikální rychlost H'_{ytouch} je nutné aby asymptota k exponenciální přistávací traektorii byla pod povrchem VPD ve vzdálenosti H_{as} dané závislostí (7). Při T = 2-5s a $H'_{dosednutí} = 0.3 – 0.6\ ms^{-1}$ asyptota exponenciály musí být pod povrchem VPD $H_{as} = 0.6 – 3m$.

FUZZY DATA BASE

For the automatic landing task we divided input space ΔVy = (Vyp - Vy) to the five fuzzy sets:

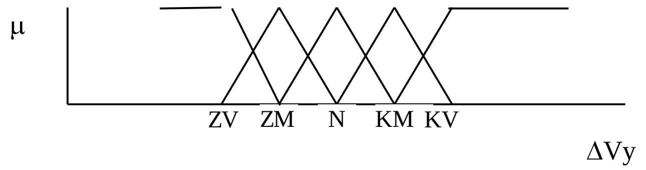

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Fig. 3. Division of Input space of landing autopilot

Output space δv we divided by the same way:

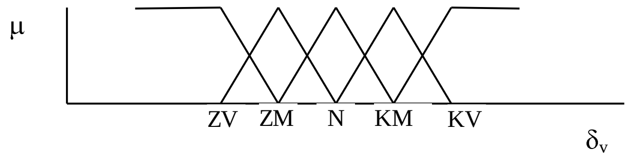

Fig. 4. Division of Output space of landing autopilot

As fuzzy membership function we used the L and Λ functions. Choice of input and outup intervals of fuzzy sets.

All intervals were set by evaluation of real flight data recorded during the flight of UAV Sojka III TV/TVM, which was developped in the Air Research Institute Prague.

ΔVy = -9 ÷ 9,
ωz = -0.6 ÷ 0.6,
δv = -0.05 ÷ 0.05,

FUZZY RULE BASE

On the base of theoretical analysis will be automatic landing process controlled by fuzzy autopilot as follows:

- Ap to altitude 25m will UAV steadily descent — ie. control of altitude and pitch.
- At the altitude 25m the fuzzy landing controler will be switched on. Vertical speed $Vy_{p\ \mathrm{is}}$ proportional to the actual altitude H.
- At every point there will be disproportion between actual and required vertical speed. This disproportion will be input parameter to the fuzzy autopilot.
- Output parameter of the fuzzy autopolit will be movement of elevator so that the disproportion is minimized.

When Vyp = Vy the UAV is in the state 1 ΔVy=N. UAV is in steady parallel flight. Let us assume the positive change of required vertical velocity Vyp , ie. (Vyp - Vy) > 0. UAV state is changed to the state 2 : ΔVy =KV, 1→2. In this case it is necessary to move the elevator to negative deviation. The torgue, caused by move of elevator will cause change of pitch ie.θ'>0, and this will lead to change of vertical speed. When the vertical speed increases to the required value Vy → Vyp we get to the state 3.
By the same way we can derive the rules for (Vyp - Vy) < 0.

Fuzzy Rules Table for vertical speed control Table 1.

ΔVy	**ZV**	**ZS**	**ZM**	**N**	**KM**	**KS**	**KV**
	KV	KS	KM	N	ZM	ZS	ZV

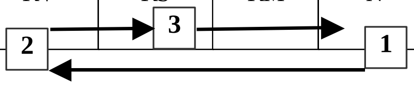

Table 1 can be displayed in the form if-then rules.

If-then rules of landing autopilot Table 2.

1. If (ΔVy is ZV) then (dv is KV) (1)
2. If (ΔVy is ZS) then (dv is KS) (1)
3. If (ΔVy is ZM) then (dv is KM) (1)
4. If (ΔVy is N) then (dv is N) (1)
5. If (ΔVy is KM) then (dv is ZM) (1)
6. If (ΔVy is KS) then (dv is ZS) (1)
7. If (ΔVy is KV) then (dv is ZV) (1)

CONCLUSION

Figures 5,6,7 shows the output – vertical speed, altitude, pitch and elevatr during simulation of the landing process. From the figures, we can see that the proces is steady and non flitting.

Concerning the complexity of the automatic landing process we can state that designet fuzzy autopilot is effective. Taking int account, that there is no automatic systém for landing of the UAV Sojka, it is also appreciable, that this landing systém can be used in real UAV.

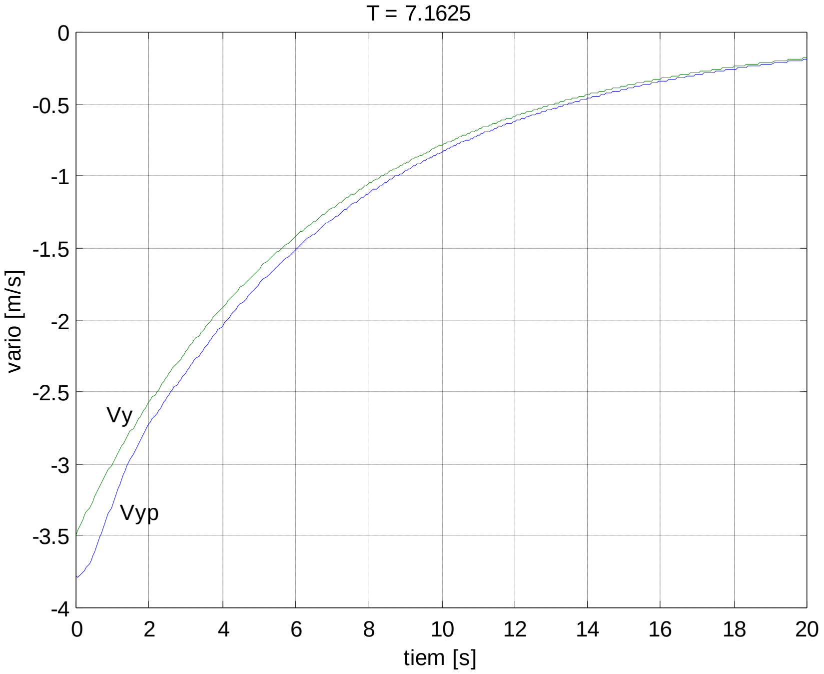

Fig. 5. Vertical speed – actual and required

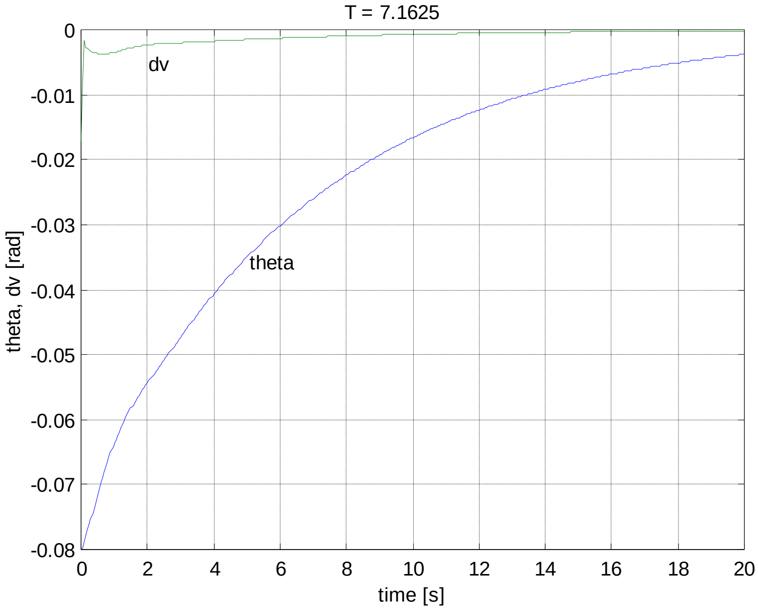

Fig. 6. Elevator and Pitch

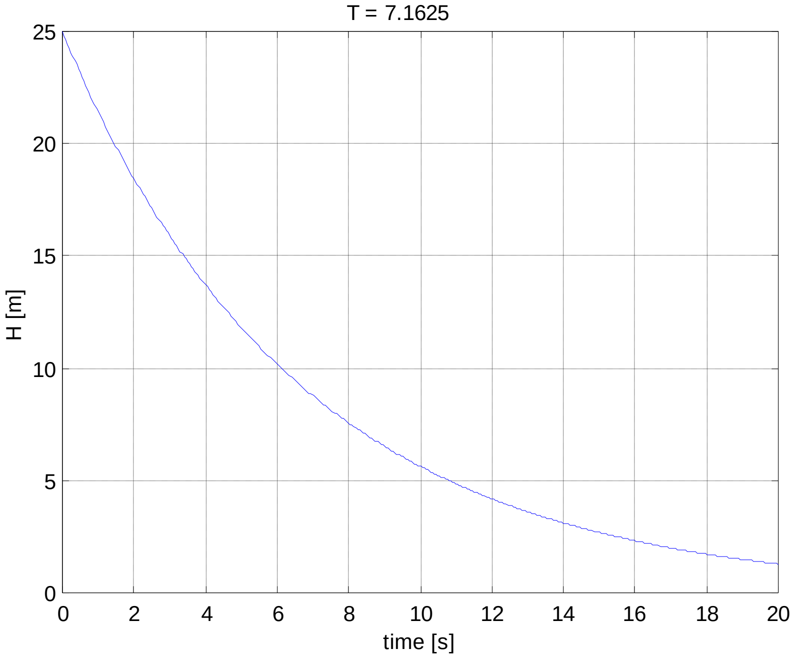

Fig. 7. Altitude