ROUGH PILOT DECISION-SUPPORT ALGORITHM

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Abstract. In this paper, a new application for the theory of rough sets is proposed. The theory of rough sets has been introduced into one of the most complicated fields, military aviation. The problem is to generate a pilot's decision-support algorithm for the task of dropping a bomb on a target located behind an obstacle detected during flight. The aim of this algorithm is to simultaneously facilitate the performance of this task for the pilot; it will minimize pilot error caused by imperfect accuracy in estimating the situation and limited experience in a given situation.

Keywords: flight trajectory, dropping bomb, rough sets, decision support.

Introduction

Configured terrain is a terrain with obstacles that aircraft has to avoid. To avoid those obstacles the aircraft has to maneuver (change its altitude). This maneuver takes place in vertical plane (longitudinal motion) [1]. It can take place according to various rules. The first case occurs when the shape of the terrain is known and we can define flight trajectory. Another case concerns control when devices for detecting obstacles detect their existence on the flight route. In both cases, assuming that the aircraft has to bypass terrain obstacles, the aircraft control method can use two controls: elevator deflection and a change in the throttle setting [1].

Complex systems such as, for instance, those used for military purposes, need precise control procedures to obtain desirable results. This paper will focus on one of those systems, namely, an aircraft-bomb system. The problem is that an aircraft needs to be controlled from initial to final state in such a way that this control will ensure that a bomb dropped from the aircraft at its final state will bypass the obstacle detected during flight and reach the target, with the aircraft being invisible to the other side of the obstacle. Simultaneously, it will ensure the minimally required distance between the aircraft at its final state and the obstacle for the pilot to manoeuvre and return to base.

However, dropping bombs is not something easy, particularly when we talk about gravity bombs, for which the pilot has to precisely determine the target location and estimate the time lag before dropping the bomb. This means that the accuracy of performing the task depends on the pilot's accuracy in estimating the situation and his experience. Gravity bombs have to be dropped precisely because they cannot distinguish targets. This demands that the pilot bring the aircraft into a state at which the aircraft (altitude, velocity, etc.) will assure successful performance of the task.

Because the simultaneous choice of all those parameters is a difficult task for the pilot, the cockpit has been equipped with different systems that support the pilot in performing various tasks.

For air to ground attacks when using gravity bombs, three bombing modes are used:

1. *Continuously Computed Impact Point* mode (CCIP). CCIP is a visual bombing mode in which the pilot has to see the target. In this method, the computer continuously shows on the Head-Up Display (HUD) where the bomb will hit when released at a given instant. All the pilot has to do is to get the CCIP piper that moves on the main screen of the HUD to the exact target and release the bomb.
2. *Continuously Computed Release Point* mode (CCRP). CCRP is a "blind" bombing mode that is used especially for bombing invisible targets because of bad weather conditions or when an operation takes place at night. CCRP works in conjunction with the air-to-ground radar that helps to identify the target. After the target has been identified, bomb fall line will appear on the HUD. Then all the pilot has to do is to keep the target on this line, and the computer will automatically release the bomb at the right moment.
3. *Dive Toss* mode (DTOS). This is another visual bombing mode that does not use radar to identify the target. The pilot must therefore keep his eye on the target and put the Target Designator (TD) box over the target on the HUD. After the TD box has been located over the target, it can be considered as identified. And as in the previous mode, the bomb fall line will appear on the HUD, the pilot has to keep the target on this line, and the computer will automatically release the bomb at the right moment.

Summing up, both CCIP and DTOS are visual bombing modes, which means that the pilot has to see the target. The task is to reach a target that is behind an obstacle that the pilot can't bypass, however. On the other hand, in the CCRP, the computer does not take into consideration the possibility of an obstacle existing between the aircraft and the target. Thus, the application possibility of all previous modes in this task has to be eliminated. This question therefore arises: How we can help the pilot perform this task successfully?
This paper proposes a method based on the rough sets theory to generate a rough decision-support algorithm that facilitates the performance of this task for the pilot and satisfies all its conditions.

1. Bomb-dropping problem
1.1 Illustration of the problem

The illustration of the problem discussed is shown in figure1. The symbols in the figure have the following meanings:
V_0 – velocity of aircraft at the moment of drop [m/sec];
S_1 – distance between initial and final states of aircraft, i.e. distance at which bomb is carried by aircraft [m];
S_2 – minimally required distance between the aircraft at its final state and the obstacle for the pilot to make manoeuvre and return back to base [m];
S_3 – the distance between the obstacle and target [m];
H_0 – initial altitude of aircraft [m];
H_1 – altitude of aircraft at the moment of drop [m];
H_2 – height of obstacle [m];
γ – bomb drop angle [rad].

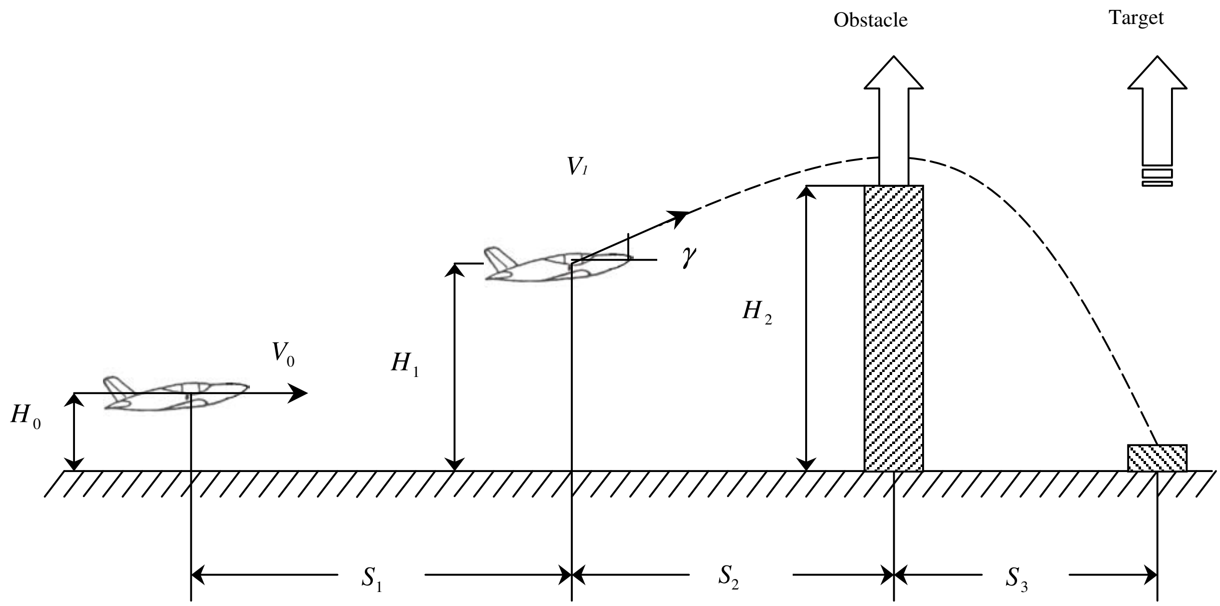

Fig 1. Illustration of problem. The interrupted line is the trajectory of the bomb after it has been dropped

1.2 Aircraft dynamics

In this paper, the Stevens and Lewis linearized longitudinal model of an F-16 has been used, which in matrix notation has the form [5]:

$$\begin{bmatrix} \dot{V} \\ \dot{\alpha} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} X_V & X_\alpha & X_q & -g \\ Z_V & Z_\alpha & Z_q & 0 \\ M_V & M_\alpha & M_q & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} V \\ \alpha \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} X_{\delta e} & X_{\delta th} \\ Z_{\delta e} & Z_{\delta th} \\ M_{\delta e} & M_{\delta th} \\ 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} \delta_e \\ \delta_{th} \end{bmatrix}, \tag{1}$$

where V – aircraft velocity [m/sec];
α – angle of attack [rad];
q – pitch rate [rad/sec];
θ – pitch angle [rad];
are the state variables, while:
δ_e – elevator deflection [rad];
δ_{th} – throttle setting [0.0 – 1.0], are the controls;
X_i, Z_i, M_i – aerodynamic derivatives;
g – gravity acceleration [m/sec^2].

An aircraft elevation problem is met in the vertical plane (XOZ). To determine the flight trajectory of the aircraft, Newton's second law of motion has been used:

$$F_x = m.a_x \tag{2}$$

$$F_z = m.a_z \tag{3}$$

where m – aircraft mass [kg];
a_x, a_z – horizontal and vertical acceleration, respectively [m/sec^2];
F_x – the sum of the forces acting on the aircraft in X direction [N].

$$F_x = -L.\sin\gamma - D.\cos\gamma + T.\cos(\theta + \theta_z), \tag{4}$$

where F_z – the sum of the forces acting on the aircraft in Z direction [N].

$$F_z = -L.\cos\gamma + D.\sin\gamma - T.\sin(\theta + \theta_z) + W, \tag{5}$$

where: θ_z – engine angle of incidence [rad];
γ – weight, lift, drag and thrust forces, respectively.

The values of these forces depend on the aerodynamic coefficients, where (C_w, C_l, C_d, C_T) are the weight, lift, drag and thrust forces coefficients. These coefficients can be calculated using the Zukowski method. This method states that while the aircraft is in flight the three forces acting on it are the resultant of aerodynamic forces (lift and drag), weight force, and thrust force. The vectors of these forces form a closed triangle [2].

For this purpose, we use the aircraft's polar curve on which we can determine the triangles of the coefficient vectors of the forces that have been mentioned previously for different angles of attack and different flight path angles. The values of these angles are the sum of their initial values and their change in time, that we obtained from the mathematical model (1) after applying the controls $\boldsymbol{\delta}_{\mathrm{e}}$ and $\boldsymbol{\delta}_{\mathrm{th}}$.

However, mathematical model (1) had been linearized about a given flight condition but, as is known, aerodynamic derivatives that are included in mathematical model (1) are proportional to the square of velocity and inversely proportional to the altitude.

In this paper, this fact has been taken into consideration when determining aircraft flight trajectory for different velocities and different altitudes.

After the calculation of the values of those coefficients and the forces at each step in time, they have been introduced into equations (2) and (3). By integrating those equations twice, we get aircraft coordinates at each step in time, and hence we get the flight trajectory of the aircraft.

For simplicity, some assumptions are made:

- time of flight will not be long enough for the weight to change;
- thrust is nearly aligned with the velocity vector, hence $\theta_z \approx 0$ [6].

1.3 Bomb kinematics

Bomb equations of motion have been derived using the general principles of kinematics for bodies in free fall. In the projectile motion of a body in free fall, the only force acting on it is gravity.
For simplicity, some assumptions are made:

- we neglect air resistance. Hence, $a_x = 0$;
- we neglect any effect due to the rotation of the earth,
- we assume that the bomb will not rise high enough for the acceleration of gravity to change.

After the bomb is released, its motion can be described by the following equations.
Bomb coordinates at time (t) are:

$$x = x_1 + V_1.\cos\gamma.t, \tag{6}$$

$$z = H_1 + V_1.\sin\gamma.t - \frac{1}{2}.g.t^2, \tag{7}$$

where: a_x, a_z – horizontal and vertical accelerations respectively [m/sec^2];
V_1 – bomb velocity at time of drop [m/sec];
x_1, H_1 – bomb coordinates at time of drop [m];
γ – bomb drop angle [rad].

1.4 Illustration of exemplary flight trajectory

An illustration of the flight trajectory of the problem discussed is showed in figure 2.

The continuous line is the flight trajectory of the aircraft and bomb together, while the interrupted line is the trajectory of the bomb after it has been dropped from the aircraft. Both horizontal and vertical axes are given in meters.

Particular points are:

(Xs, Zs) – coordinates of the place at which the pilot coordinates of the place at which the bomb is dropped;

(Xo, Zo) – coordinates of the highest point of the obstacle;

(Xt, Zt) – target coordinates.

2. Application of theory of rough sets to problem

2.1 Basic concepts of theory of rough sets

In the theory of rough sets, an information system is defined as an ordered 4-tuple [4]:

$$S = \langle U, A, V, f \rangle \tag{8}$$

where U – a nonempty set called the universe;

A – a finite set of attributes;

V – a set of attributive values, $V = \bigcup_{a \in A} V_a$;

f – an information function;

$f : U \times A \to V,\ f(u,a) \in V_a\ , \forall a \in A \quad \forall u \in U$.

Taking a decision on the basis of the universe can be done after modifying the information system S [3]. This modification requires the introduction of a new set of attributes called decision attributes.

Thus, we get a so-called decision system that can be defined as an ordered 5-tuple:

$$DS = \langle U, A, D, V, f \rangle \tag{9}$$

where A – a finite set of condition attributes;

D – a finite set of decision attributes;

V – a set of attributive values, $V = \bigcup_{i \in A \cup D} V_i$;

f – an information function;

$f : U \times (A \cup D) \to V, f(u,i) \in V_i, \forall i \in A \cup D \quad \forall u \in U$.

2.2 Decision System of the Problem

For the problem being discussed, the condition attributes are aircraft initial velocity V_0, aircraft initial altitude H_0, the distance between aircraft initial and final states S_1, and the obstacle height H_2, while the decision attribute is elevator deflection angle δ_e. Although it is more accurate to classify throttle setting δ_{th} as a decision attribute, it has been classified as another condition attribute for simplicity.

The attributes can take different values. Unifying the notation of attributes values can be done by giving them interval numbers of the domain that is divided into either equal or unequal parts [3]. The chosen intervals for the problem being discussed are given in table 1.

On the basis of aircraft dynamics and bomb kinematics for different attributes values, the decision system of the problem has been generated. Its universe consists of 100 arbitrary cases that present the elements of this universe. This has been done on the assumption that the target is about 6 km from the obstacle. A part of this decision system is given in table 2.

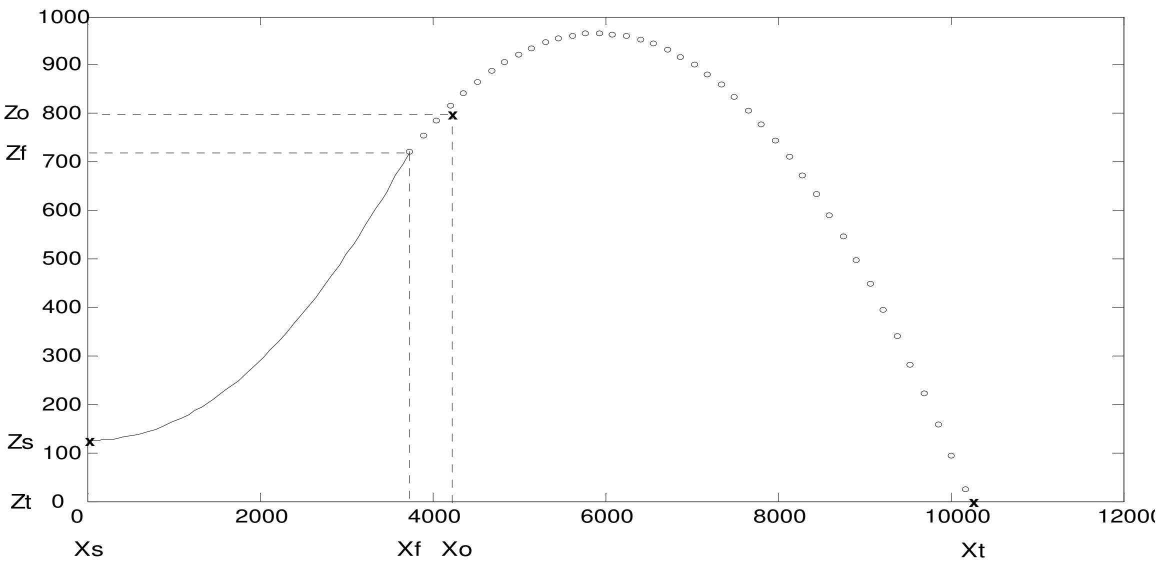

Fig 2. Illustration of exemplary flight trajectory

Table 1. The Chosen intervals

Interval number	*V_0 [m/sec]*	*H_0 [m]*	*S_1 [m]*	*H_2 [m]*	δ_{th} *[0-1]*	δ_e *[deg]*
1	280 ÷ 290	100 ÷ 150	2000 ÷ 2500	800	0.10 ÷ 0.15	-2 ÷ -3
2	290 ÷ 300	150 ÷ 200	2500 ÷ 3000	900	0.15 ÷ 0.19	-3 ÷ -4
3	300 ÷ 310	200 ÷ 250	3000 ÷ 3500	1000	0.19 ÷ 0.22	-4 ÷ -5
4	310 ÷ 320	250 ÷ 300	3500 ÷ 4000	1100	-	-5 ÷ -6
5	-	-	-	1200	-	-6 ÷ -7
6	-	-	-	1300	-	-7 ÷ -8

Table 2. Part of the decision system

Element number	V_0	H_0	S_1	H_2	δ_{th}	δ_e
1	1	1	4	3	2	2
2	1	4	3	5	1	2
3	3	2	4	1	1	1
4	2	1	1	4	2	6
5	4	2	2	2	2	3
6	3	3	2	6	1	4
7	4	4	3	3	1	1
8	3	3	3	3	2	2
9	2	3	2	6	1	5
10	1	1	2	5	2	5

2.3 Reduction in attributes

Let $DS = \langle U, A, D, V, f \rangle$ be the decision system of the problem, where $A = \{V_0, H_0, S_1, H_2, \delta_{th}\}$ is the set of condition attributes, and $D = \{\delta_e\}$ is the set of decision attributes.

The aim of this part of the paper is to find the reduction B of the set A relative to the decision $d = \delta_e$, where $(B \subseteq A)$. After analysing the dependency of condition attributes, one attribute, throttle setting δ_{th}, can be removed, without losing more than 1 % of system quality for the universe generated [3]. Hence, $B = \{V_0, H_0, S_1, H_2\}$ is the redact of the set A.

2.4 Decision rules

The main advantage of the redacts is minimizing the number of decision rules. After the reduction has been found, decision rules can be easily constructed.

These rules can be either exact or approximate depending on whether the decision system is consistent.

In this work, 85 % of the decision rules were exact, and 15 % of them were approximate.

For the problem being discussed, on the basis of the exact decision rules obtained, a rough pilot decision-support algorithm has been generated, part of which is shown as a decision tree in figure 3, in which *de* is the pilot's decision of how much he has to deflect the elevator in a given situation to perform this task successfully.

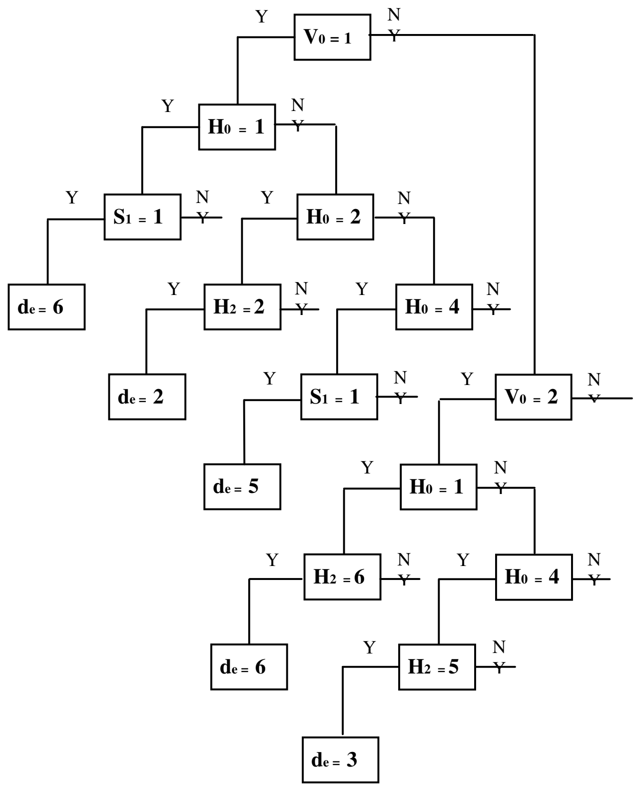

Fig 3. Pilot decision-support algorithm

Conclusions

In this paper, a new application for rough sets is proposed. The theory of rough sets has been used to generate a pilot decision-support algorithm. The results obtained are satisfying. For this reason, I am planning to continue this work by increasing the number of universe elements and decreasing the intervals of condition attributes. This will increase the number of exact rules and decrease the number of approximate rules, thereby increasing the accuracy of this method.

Undoubtedly, when classifying the throttle setting as a decision attribute instead of condition attribute, the decision system will be modified, giving the pilot more possibilities to control the aircraft. This will increase the accuracy when performing the task. The practical realization of a solution to the discussed problem needs very accurate equipment to measure various flight parameters. Also, to calculate pilot decision support algorithms, an onboard converter is needed to work in cooperation with measurement equipment, giving the pilot accurate controls for each flight situation in such a way, that the task will be done successfully with minimum error. For such complex and responsible tasks, however it is worth investing in such ideas, and this confirms the variety of the applications of rough sets.

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