

Method For Focusing A High-Energy Beam on A Reference Point on The Surface of A Flying Object in Flight

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TECHNICAL FIELD

10 The present invention relates to a method for focusing a beam of a high energy radiation source on a reference point on the surface of a flying object in flight. The beam of the high energy radiation source is preferably a high energy laser beam.

BACKGROUND OF THE INVENTION

15 When combating flying targets with high energy beam weapons, it is imperative to focus as much radiated energy as possible on a point on the surface of the flying object in question as rapidly as possible. According to standard practice, sites called "feature points", which are identifiable using specific features of a flying object, are selected on a two-dimensional image of the object as reference points for tracking
20 the target and used for calculating a reference point for focusing the high energy beam. Because the third dimension is missing from this approach, even relatively small changes in aspect angle or the slightest flying manoeuvre of the flying target make it impossible to track the reference point exactly. Furthermore, a three-dimensional movement of the flying object in space causes the features in the area
25 surrounding the reference point to change, so that the one or more feature points used to define the reference points may no longer be identifiable, and a reference point marked on the two-dimensional image of the flying object for example may disappear completely or a reference point that is referenced using several focus points may be shifted significantly. All of these disadvantages combine to make it
30 impossible to focus the high energy beam rapidly and effectively on a point on the surface of the flying object.

BRIEF DESCRIPTION OF THE INVENTION

The object of the present invention is therefore to describe a method for focusing a beam from a high energy radiation source on a reference point on the surface of a flying object in flight, with which it is possible to maintain the focus for a prolonged period once it has been established, and to destroy the flying object as rapidly and effectively as possible.

This object is solved with the method according to patent claim 1.

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To this end, in the method for focusing a beam from a high energy radiation source on a reference point on the surface of a flying object in flight, the following steps are carried out:

- 15 a) Recording a number of consecutive two-dimensional images of the flying object in flight with an imaging method using an image acquisition device;
- b) Determining the trajectory of the flying object's flight path as a sequence of three-dimensional waypoint;
- c) Simultaneously determining the line of sight angle between the image acquisition device and the position of the flying object in synchronisation with the image;
- 20 d) Calculating a three-dimensional model of the flying object from the two-dimensional images recorded in step a) on the basis of the relative geometry to be calculated from the line of sight angles calculated in step c) and the trajectory obtained in step b), and on the basis of predefined model assumptions about the flying object;
- 25 e) Displaying the currently acquired two-dimensional image of the flying object in flight via an image reproduction device;
- f) Marking the reference point on the displayed two-dimensional image of the flying object;
- 30 g) Calculating the three-dimensional reference point on the surface of the flying object starting from the two-dimensional reference point marked in step f)

- using the three-dimensional model of the flying object calculated in step d),
and
- h) Focusing the beam of the high energy radiation source on the three-dimensional reference point and causing the focus point of the beam directed
5 at the reference point to track said reference point.

The trajectory of the flying object is measured for example as a sequence of three-dimensional waypoints by means of an "external" device (e.g., a radar system) and converted into three-dimensional waypoints synchronised temporally with the
10 images. A three-dimensional model of the flying object is calculated from the two-dimensional images of the flying object with the aid of very simple model assumptions about the flying object based on the knowledge of the relative geometry gained in step d) and using the flight trajectory calculated in step b). In this context, the term relative geometry is understood to mean the position of the significant three-
15 dimensional axes of the flying object (e.g., axis of the fuselage, axis of the wings, etc.) relative to the line of sight of the image acquisition device.

A two-dimensional reference point marked in a two-dimensional image of the flying object shown "online" in a display device is projected onto the model and converted
20 into a corresponding three-dimensional reference point, and this three-dimensional reference point is then projected into the subsequent images. The high energy beam is then focused on the object and tracks after it based on this three-dimensional reference point. In this way, it is possible to achieve a significantly longer focusing time on the reference point than was previously the case, if the aspect angle of the
25 recording device changes for image acquisition of the flying object in flight, or even if the flying object carries out flying manoeuvres that change the flight attitude of the flying object in space.

30 ADVANTAGES

Thus, a significantly higher degree of precision is achieved when tracking a marked three-dimensional reference point in the two-dimensional image than when tracking a two-dimensional reference point. The risk of losing the reference point if the flying object undertakes flying manoeuvres is also reduced considerably. The method according to the invention also makes it possible to calculate the geometric visibility or concealment of the reference point, so that the emission of the high energy beam can be stopped if the reference point is no longer visible or is obscured by other parts of the flying object, thus reducing the risk of endangering third parties due to unnecessary radiation. Moreover, with the method according to the invention the use of general, very simple model assumptions means that it is not absolutely necessary to have a range of three-dimensional target models of certain flying objects ready for use, which must then first be identified.

Further preferred and advantageous design features of the method according to the invention constitute the subject matter of subordinate claims 2 to 7.

The method according to the invention is used to particularly good advantage if the beam of the high energy radiation source is a laser beam, and the radiation source is thus a laser radiation source.

It is particularly advantageous if the imaging method is an optical image acquisition method, preferably a high resolution optical image acquisition method in the visible or infrared spectral range. With such an image acquisition system, it is possible to achieve reliable, precise target object acquisition even over great distances.

It is also advantageous if a two-dimensional line model of the flying object's contour is first created from the recorded images of the flying object in flight in order to calculate the three-dimensional model in step d), and then depth information is added to the line model based on the knowledge of relative geometry, and finally the three-dimensional model is calculated using a predefined model assumption. This approach saves computing time and computing capacity.

In this context, it is particularly advantageous is one of the model assumptions is the assumption of a fuselage of the flying object that is cylindrical or consists of cylindrical sections.

- 5 It is also advantageous if one of the model assumptions is the assumption that the flying object has flat, board-like wings and/or aerodynamic control surfaces. These simplifying assumptions also help to reduce the computing effort required to calculate a three-dimensional model of the flying object "online" and extremely rapidly, that is to say practically in real time, without the need to carry out a complex identification of
10 the flying object first, or use a specific model of the flying object.

It is also advantageous if further model assumptions are made about the relative orientation of and position of characteristic visible elements of the flying object, such as a wing or a vertical stabiliser, relative to the fuselage.

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It is preferably sufficient to assume that the fuselage is symmetrical for the purpose of creating the three-dimensional model of the flying object.

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It is also advantageous to assume that the angular position of the lengthwise axis of the fuselage is parallel to the tangent to the flight trajectory.

Preferred embodiments of the invention with additional design details and further advantages are described and explained in greater detail in the following text with reference to the accompanying drawing.

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BRIEF DESCRIPTION OF THE DRAWING

In the drawing:

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Fig. 1 is a diagrammatic scene in which a flying object is captured simultaneously by a radar station and an electro-optical image acquisition device and engaged by means of a radiation source.

5 PRESENTATION OF PREFERRED EMBODIMENTS

Fig. 1 is a diagrammatic representation of a scene in which a flying object in flight 1 is captured simultaneously by an electro-optical image acquisition device 2 and a radar station 6 and engaged by means of a radiation source 3. Image acquisition device 2
10 is located as close as possible, or ideally in the radiation source 3, so that the high energy beam 30 emitted by radiation source 3 and image acquisition line of sight 20 of image acquisition device 2 have substantially parallel beam paths.

Flying object 1 is an unmanned aerial vehicle with a fuselage 10, wings 12 and
15 aerodynamic control surfaces 14 (vertical stabiliser 14' and elevator unit 14"), travelling along a flight path F in the direction of a trajectory T.

In order to obtain waypoints on trajectory T of flying object 1, in the example shown a radar station 6 detects flying object 1 with radar beams 62 emitted along a radar line
20 of sight 64 of radar antenna 60 and tracks it along flight path F. The information about flight trajectory obtained in this way is made provided with low latency to an image analysis device 5 (arrow 66).

The optical image signal beam 22 originating from flying object 1 is received and
25 registered by the electro-optical image acquisition device and is supplied as image signal stream 24 to an image reproduction device 4. Consequently, two-dimensional images 1' of flying object 1 are displayed consecutively on a monitor 40 of image reproduction device 4. Image reproduction device 4 is coupled with image analysis device 5, to which the image signal stream 24 is also supplied.

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In the two-dimensional image 1' of the flying object 1 displayed on monitor 40 of image reproduction device 4, an operator marks a reference point HP' on the surface

of the displayed image 1' of flying object 1 as the target for focusing the high energy beam 30, a laser beam for example, emitted by radiation source 3. The two-dimensional coordinate data of this marked two-dimensional reference points HP' is supplied to image analysis device 5 as reference point data stream 42.

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A computer 50 of image analysis device 5 first calculates a three-dimensional model of flying object 1 from the image data of flying object 1 received with image data stream 24 using predetermined simplified model assumptions for flying object 1.

10 These simplified model assumptions assume for example that fuselage 10 of flying object 1 is substantially cylindrical or that it consists of cylindrical sections, and that the wings 12 and aerodynamic control surfaces 14 are flat and board-like. Model assumptions that are simplified in this way can be applied to practically any flying object, and enable the creation of a three-dimensional model of flying object 1 which is crude but adequate for the purpose at hand, without requiring the use of a specific
15 model of the flying object in question, which if used would necessitate an identification of the flying object.

With this three-dimensional model and the relative geometry derived from the consecutively recorded images of flying object 1 and the temporally synchronised
20 flight trajectory points on trajectory T, it is now possible to determine the attitude of flying object 1 in space and transfer the two-dimensional reference point HP' marked on monitor 40 from the two-dimensional coordinate data associated with the two-dimensional reference point HP' to the three-dimensional model as three-dimensional reference point HP. The coordinate data of this three-dimensional reference point HP
25 is then transmitted as target object data stream 52 to a computer 32 of radiation source 3, which actuates alignment and focusing equipment (not shown) for the high energy beam 30 emitted by radiation source 3 in order to bring the focus point of high energy beam 30 into alignment with the three-dimensional reference point HP and to follow the movement of flying object 1 with beam 30 in such manner that the focus
30 point remains coincident with three-dimensional reference point HP.

The method according to the invention presupposes the availability of information about flight trajectory T, which can be determined from the radar information supplied by radar station 6. It is also necessary that image acquisition device 2 is located in a fixed position on the ground, and the line of sight angle in azimuth and elevation of
 5 image acquisition device 2 must also be known.

The following further simplified model assumptions are made:

- The flying object 1 is flying in the direction of the longitudinal axis of its fuselage, the wings 12 are perpendicular thereto, and the vertical stabiliser 14'
 10 of the aerodynamic control surfaces 14 is in turn perpendicular to both,
- Fuselage 10 of flying object 1 consists of conical cylinder elements, and the wings and the vertical stabiliser are each "board-shaped".

The angle orientations of the primary axes of flying object 1 (fuselage, wings, vertical
 15 stabiliser) can be calculated in the image in advance from the line of sight angles and the data of the flight trajectory. A two-dimensional line model of the contour of flying object 1 is created using edge filters and logical connections adapted to these orientations. The lines of this model are classified by their associations (fuselage, control surfaces, vertical stabiliser) according to orientation and the model
 20 assumptions. Then, a virtual depth in the image can be added to the end points of the classified lines using a combination of line of sight angles and angle orientations of the primary axes. Finally, the virtual three-dimensional lines are transformed into a standard position for the three-dimensional model. Due to the variation over time of the image acquisition line of sight 20 and the flight trajectory T, small changes in the
 25 aspect angle in terms of azimuth and elevation are inevitable, and enable the model to be fine-tuned over time.

The model can also be improved by means of additional plausibility assumptions. For example, the position of the wings can be estimated based on the assumption that
 30 wings 12 are arranged symmetrically relative to fuselage 10. This symmetry can also be used to improve the model directly, by mapping the wings symmetrically relative to fuselage in the model.

Errors in the flight trajectory data can be compensated via a correction from the standard position by assuming that the fuselage axis of flying object 1 extends exactly parallel to the X-axis of the flight attitude, and the plane of the wings extends
5 exactly parallel to the Y-axis of the flight attitude.

Reference signs in the claims, the description and the drawing serve purely to provide a better understanding of the invention, and are not intended to limit the scope of protection.

List of reference signs

Elements in the drawing are identified as follows:

	1	Flying object
5	1'	Two-dimensional image of the flying object
	2	Image acquisition device
	3	Radiation source
	4	Image reproduction device
	5	Image analysis device
10	6	Radar station
	10	Fuselage
	12	Wings
	14	Aerodynamic control surfaces
	14'	Vertical stabiliser
15	14"	Elevator unit
	20	Image acquisition line of sight
	22	Image signal beam
	24	Image signal stream
	30	High energy beam
20	32	Computer
	40	Monitor
	42	Reference point data stream
	50	Computer
	52	Target object data stream
25	60	Radar antenna
	62	Radar beam
	64	Radar line of sight
	F	Flight path
30	HP	Three-dimensional reference point
	HP'	Two-dimensional reference point
	T	Flight trajectory

Patent claims

1. Method for focusing a beam (30) of a high energy radiation source (3),
 5 particularly a laser beam, on a reference point (HP) on the surface of a flying object in flight (1), including the following steps:
 - a) Recording a number of consecutive two-dimensional images of the flying object (1) in flight with an imaging method using an image acquisition device (2);
 - 10 b) Determining the trajectory (T) of the flight path of the flying object (1) as a sequence of three-dimensional waypoints;
 - c) Simultaneously determining the line of sight angle between the image acquisition device (2) and the position of the flying object (1) in synchronisation with the image;
 - 15 d) Calculating a three-dimensional model of the flying object (1) from the two-dimensional images recorded in step a) on the basis of the relative geometry to be calculated from the line of sight angles calculated in step c) and the trajectory (T) obtained in step b), and on the basis of predefined model assumptions about the flying object (1);
 - 20 e) Displaying the currently acquired two-dimensional image (1') of the flying object (1) in flight via an image reproduction device (4);
 - f) Marking the reference point (HP') on the displayed two-dimensional image (1') of the flying object (1);
 - g) Calculating the three-dimensional reference point (HP) on the surface of the flying object (1) starting from the two-dimensional reference point (HP') marked in step f) using the three-dimensional model of the flying object (1) calculated in step d), and
 - 25 h) Focusing the beam (30) of the high energy radiation source (3) on the three-dimensional reference point (HP) and causing the focus point of the beam (30) directed at the reference point (HP) to track said reference point (HP).
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2. Method according to claim 1,

characterised in that

the imaging method is an optical image acquisition method in the visible or
infrared spectral range.

3. Method according to claim 1 or 2,

characterised in that

for calculating the three-dimensional model in step d), first a two-dimensional
line model of the contour of the flying object is created from the recorded
images of the flying object (1) in flight;
then depth information is added to the line model using knowledge of the
relative geometry, and
finally the three-dimensional model is calculated using predefined model
assumptions.

4. Method according to claim 3,

characterised in that

one of the model assumptions is the assumption that the fuselage (10) of the
flying object is cylindrical or consists of cylindrical sections.

5. Method according to claim 3 or 4,

characterised in that

one of the model assumptions is the assumption that the wings (12) and/or
aerodynamic control surfaces (14) of the flying object (1) are flat and board-
shaped.

6. Method according to claim 3, 4 or 5,

characterised in that

further model assumptions are made about the relative orientation and
position of characteristic visible elements (12,14) of the flying object (1)
relative to the fuselage (10).

7. Method according to any one of the preceding claims,
characterised in that
a symmetry relative to the fuselage (10) is adequate for creating the three-
5 dimensional model of the flying object (1).