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A CONCEPT OF A SIMPLIFIED VISUAL NAVIGATION SYSTEM FOR MOBILE PLATFORMS

ABSTRACT

The concept of visual navigation is based on comparing images from navigation sensors with the data stored in the system memory. A control and navigation system based on information from simplified image sensors was developed for smart missiles. The system was based on images acquired by infrared sensors distributed along the rotating line. The system was tested by simulations giving adequate results. In this paper an extension of the system for application to other vehicles is presented. The main advantages of the proposed system are the ruggedness, simplicity and low cost.

Keywords:
visual navigation, images comparison.

INTRODUCTION

The modern navigation systems which nowadays are operating, designed or planed are mainly based on GNSS technology due to its accuracy and global availability. The satellite systems have also some weak points. The satellite signal may be suppressed, jammed or spoofed by hostile actions or purposely deteriorated by the operator of the system. These leads to a demand for navigation sensors/systems based on other physicals phenomena than electromagnetic waves. The alternatives to GNSS are magnetic, inertial or visual sensors. Due to continuous development of computer technology and microelectronic sensors (cameras) the application of visual navigation system is becoming more feasible.

In the recently completed research the simple navigation and control system was designed for small mortar missile. In this paper the base ideas of the missile system are reviewed and the concept for extension of the system to other moving platforms is described.

VISUAL SENSOR

The visual sensor was composed of infrared photodetecting elements grouped along the straight line, fixed to the missile (fig. 1). The sensing line was perpendicular to the missile longitudinal axis, which is the rotation axis of the missile during its flight. The forward looking angle of observation depends on the sensing distance and the length of the sensor. It is assumed that the angle of target visibility was 12 deg with the distance 1000 m.

The resolution of the system depends on the number of sensing elements distributed along the straight line. There may be from tenths to several hundreds of infrared point sensors. The detector is spinning with the missile, so the information of the non-moving objects will be received and refreshed once per revolution, as the distance between the missile axis and the sensed point along the line.

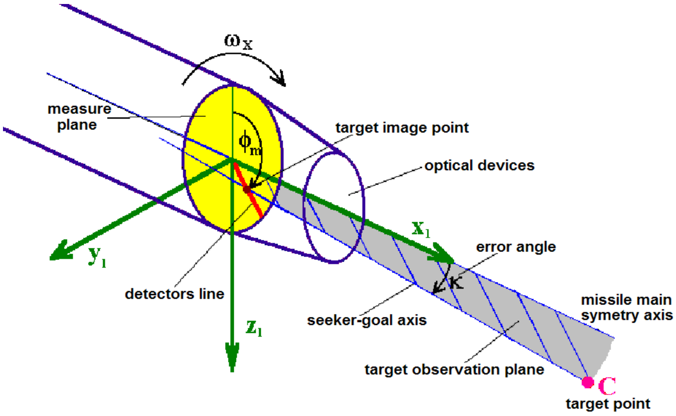

Fig. 1. Sensing element

This sensor was used for target recognition and for determination of the attitude. The sensor provides one dimensional information, which was used for missile control in vertical and horizontal planes. The advantage of the applied system are the lack of moving parts and no need for gyroscopic devices.

THE FLIGHT AND CONTROL SYSTEM OF A MISSILE

After the mortar missile is fired, the first phase of its flight is uncontrolled motion along the ballistic curve, which takes 80% of flight time (fig. 2). At the first phase of the flight the missile is propelled by the rocket engine. The missile is rotating due to the skewed fins mounted in the rear part of the fuselage. The rate of rotation depends on the velocity of the missile forward flight, and varies between 3 and 15 Hz.

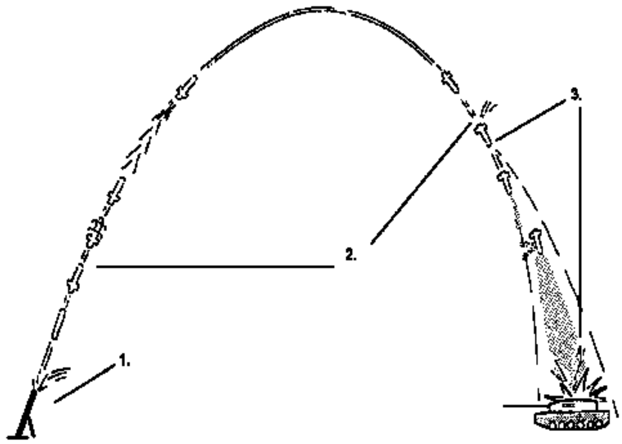

Fig. 2. Phases of flight: launch, ballistic phase, guidance phase

It may be assumed that the relation between the velocity and the rate is linear (see fig. 3). After passing the top of the ballistic curve the control system is initiated. During this phase of flight the velocity of the missile increases due to descending flight. Missile is guided using information from the sensing elements. The controlled phase of the flight takes about 5 s. Within that time the target should be identified and the missile controlled to hit it.

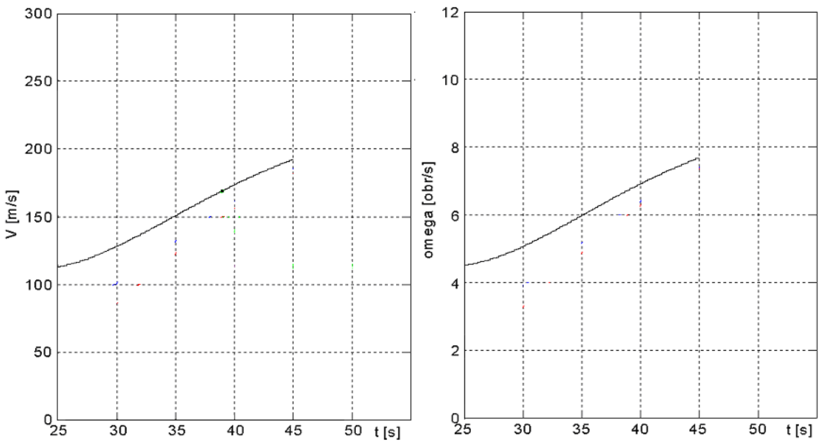

Fig. 3. The relation of the missile base speed V and angular rate ω
in the full time range of the flight

The scheme of missile control system is shown in fig. 4. The main parts of control system perform the following functions:

– the external observer acquires the initial information about the regions of target position; the initial settings for flight are entered into the system by the operator;
– the mortar missile is fired;
– after completing the first phase of flight the guidance system is initialized;
– the missile performs the controlled flight until it hits the target.

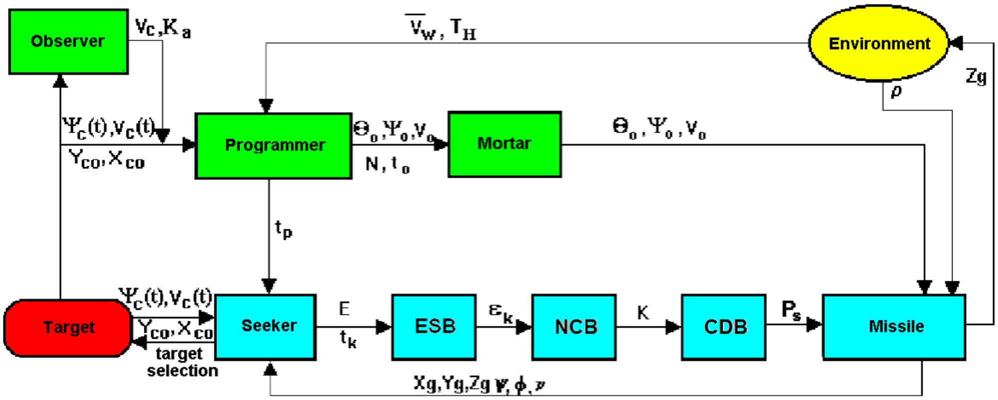

Fig. 4. Block scheme of missile guidance system

The control block, marked blue in fig.4 performs the following functions:

– sensing and signal conditioning block, where the input impulse signal from the sensor is transformed into continuous one and then filtered and the prediction of the next phase of the flight is performed; the output of this block is the angle between the target line and the missile longitudinal axis;
– navigation and control block; it starts the control, estimates attitude between the target and the missile and generates control signal which is calculated using the input signal;
– actuators block, which transfers the signals from control block into the control device actions; in this missile control system the impulsive propulsion engines are used.

SYSTEM FOR GUIDANCE AND ATTITUDE DETERMINATION

The main information provided by the linear sensor to the missile control system is the angle of target visibility. In the actual system application it may be treated as error E which should be corrected by the missile control system. Assuming that the target is a point, the angle of visibility varies stepwise in time. The sampling time is equal one rotation and varies with flight velocity (fig. 5).

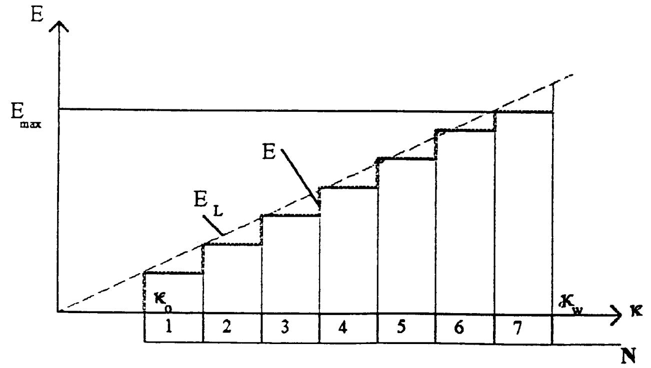

Fig. 5. Characteristic of impulse error signal: E_L – proportional error signal, E – discrete error signal, κ_o – dead zone, N – element number, κ_w – angular range of the imaging sensor

IMAGE PROCESSING

A 256 bit infra red image is the input information, transferred in the visual navigation system into target location in by the following calculation steps.

Simplification of the image – reduction the color depth of the images, the final depth is 1 bit.

Edge detection – reduction of the size of data file; filtering out useless information, while preserving the structural properties of the image. Edge detection done by identifying local discontinuities in pixel values by Sobel method.

Segmentation – distinguishing the objects from the background. A region--based method was applied. The image was partitioned into connected regions by grouping neighboring pixels of the same intensity levels, and a matrix with subsequent numbers denoting that the separable objects was obtained.

Target recognition – matching the resulting groups (edges or filled objects) to the patterns saved in the memory of the system. This task was completed by the artificial networks method.

The sample results of target recognition is shown in fig. 6.

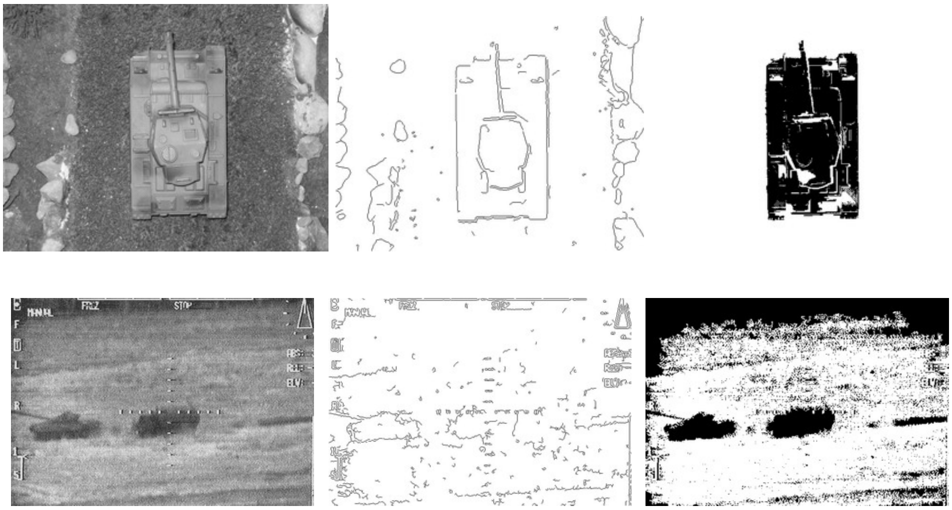

Fig. 6. Features extracting: a) source image, b) edge detection, c) segmentation

The initial data are entered into the system before the flight:

- the distance from mortar to the target;
- approximate flight velocity in various flight phases;
- the time of starting control and seeking the target.

For control system the an input data are:

- the angular position of the target at the sensor plane;
- angular rate of the missile.

CONCEPT OF A NEW SYSTEM

The actual objective of the research is to design the fully autonomous visual navigation system, independent of the sources of external signals, capable to provide guidance of the missile toward the target.

The crucial information for reaching the target is the angle of the target in the plane of sensor rotation. It helps to distinguish the targets which are too far for actual flight conditions.

In fig. 7 two cases of extreme target position are shown in the moment of initiating controlled flight. In the case (1) the target is seen above the axis of the missile, and in the case (2) the target is seen below the axis of the missile. The missile trajectory, marked by solid line describes the uncontrolled flight. As there are no direct attitude measurement sensors, it is difficult to distinguish between these two cases.

The three layer neural network was used for distinguish the target position relative to the missile axis. The variation of the visibility angle in time and the rotation velocity of the missile was the input for the neural network algorithm.

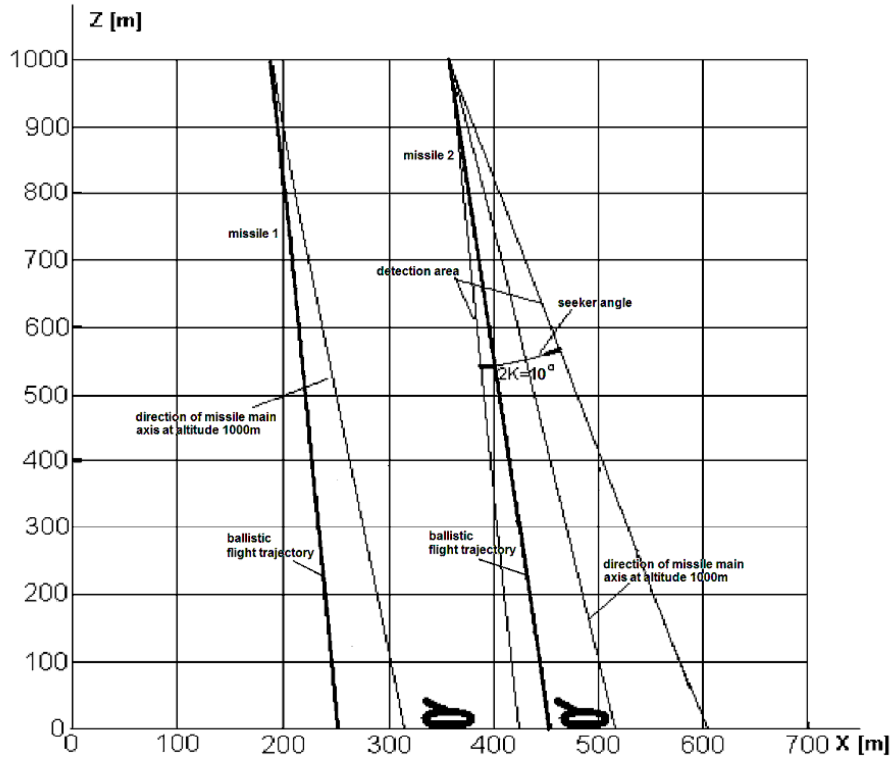

Fig. 7. Flight trajectories and target tracking form 1000 m altitude
for two cases of missile position

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