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CONCEPT OF A MARINE REMOTE CONTROLLED ARTILLERY-MISSILE SYSTEM

ABSTRACT

This paper presents general assumptions and concept, block diagram of the operation principle as well as control algorithm of a short range Marine Remote Controlled Artillery-Missile System (MZSSAR). Its main purpose is to combat low-flying manoeuvring air targets. In relation to existing set 'Wróbel II', an additional opportunity of autonomous search, detection, identification, tracking and effective target combat will appear. An increase of combat capabilities of a modified set, including in particular operation speed and range of target detection, will be possible.

Key words:
Marine Autonomous Remote Controlled Artillery-Missile System, air defence, control.

INTRODUCTION

The task of a modern system of a short-range air defence is to provide effective search, tracking and possible destruction of air targets while ensuring high reliability of operation. These factors might be improved, i.a., by eliminating human factors and replacing human labour with automated processes. This idea leads to the concept of a short range Marine Remote Controlled Artillery-Missile System (MZSSAR), a main component of which is an Intelligent Artillery-Missile System (ISAR) enabling fully automatic detection and tracking of air targets. A ship, i.e. a moving object, which an artillery missile set is located on, is subject to oscillating movements at a sea wave [1, 11, 12]. This fact should be included in the set control algorithm during searching and tracking air targets. Oscillating movements result in deviation of cannons' line from currently set line of aim tracking, which should be properly compensated.

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ASSUMPTIONS REGARDING A MARINE REMOTE CONTROLLED ARTILLERY-MISSILE SYSTEM

The most important aspect, with regard to MZSSAR operation, is to eliminate the need for an operator on a fire position. Currently, in the most commonly applied marine sets ZU-23-2MR ('Wróbel II') [9] in Poland, the operator's work is conducted directly on a fire position and consists in controlling (aiming) an artillery--missile set manually, which entails significant disadvantages. The first disadvantage is an increased risk of the operator's injury, as he is almost directly exposed to aggressor's fire. If the operator is harmed, and thus, prevented from further work, effectiveness of a defence system drastically decreases. Limited human psycho--psychical and motor skills, which, especially in combat conditions, may further deteriorate, constitute another disadvantage. Manual tracking of fast flying and manoeuvring air targets is a very difficult task and requires a long-term and expensive training [10] from the staff. As presented in MZSSAR set, the above mentioned drawbacks are expected to be eliminated by applying a remote control. It should be noted that are conducted research and development on a similar system equipped with a 35 mm calibre gun [2, 3]. In the first mode of MZSSAR control — the so-called autonomous mode, the set with the use of e.g. an optoelectronic scan-track head [6], will make automatic search of airspace, interception and target tracking possible. Firing a shot (or a series of shots) will be possible only after confirmation by the operator. The second mode — the so-called manual mode, will include a manual remote set control as well as firing a shot. It is supposed to be an alternative in case of a failure of elements in the autonomous mode system. For both operation modes, the operator's stand will be located in a safer place, e.g. under the ship deck, and target observation and identification (by the operator) will be possible with the use of cameras and binaural audio transmission as well as IFF codes.

GENERAL CONSTRUCTION AND OPERATION RULES OF THE SET

Three main elements might be distinguished in the system of combating means of air attack in the system suggested herein:

1. Artillery-missile set (ZAR).
2. Optoelectronic scanning and tracking seeker (OGSS).
3. Control system (US).

Figure 1 presents a general scheme of ZAR together with an indicated base reference system *xyz*. It is a right-handed Cartesian system, the beginning of which is located at the intersection of the axes of azimuth drives and set elevation, and *xy* plane of this system is parallel to the Earth's surface.

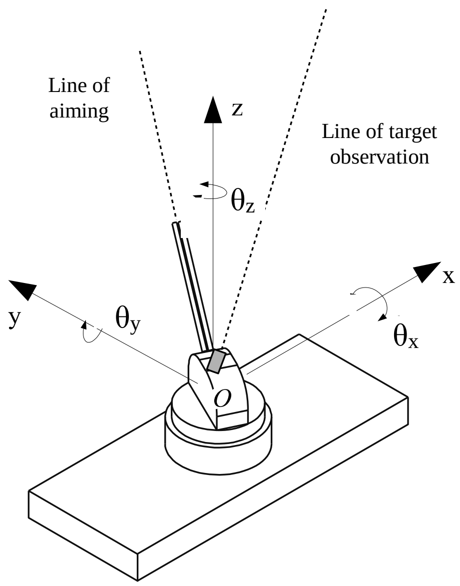

Fig. 1. General turret view with the main coordinate system [own work]

Angular ship displacements θ_x, θ_y, θ_z are indicated around the axis of the base coordinate system. It is conducted in US control system by processing signals from the accelerometers. The angles achieved are then used to compensate for the distortions resulting from rotational movements of the ship. The compensation mentioned above will be a very important element of the system operation, which allows to obtain a satisfactory accuracy in a stormy sea. In order not to complicate the structure and to avoid additional costs, this compensation is assumed to be carried out using the existing drives of elevation and azimuth axes. However, if the tests show that the power of drive engines have to be extremely great, an additional stabilizing gyroscope platform [2] will be taken into consideration. In figure 1 a line of target observation determined by the IR seeker was indicated. Coordinates of the observation line of target ψ and ϑ are given in relation to base coordinate system *Oxyz* [5, 8]. Line coordinates of cannons' axes α and β are relative to rectangular system $Ox'y'z'$, associated with the base, which is subject to rotation at the angles of θ_x, θ_y, θ_z. The purpose of the control system is to direct the lines of autocannons' axis to the point of the expected target position, the position of which takes the following issues into account: angular ship displacement, predictive trajectory and ballistic corrections. This point is indicated in figure 2a and 2b, which are projections of figure 1 on *xy* and *yz* planes, together with the moving target placed therein.

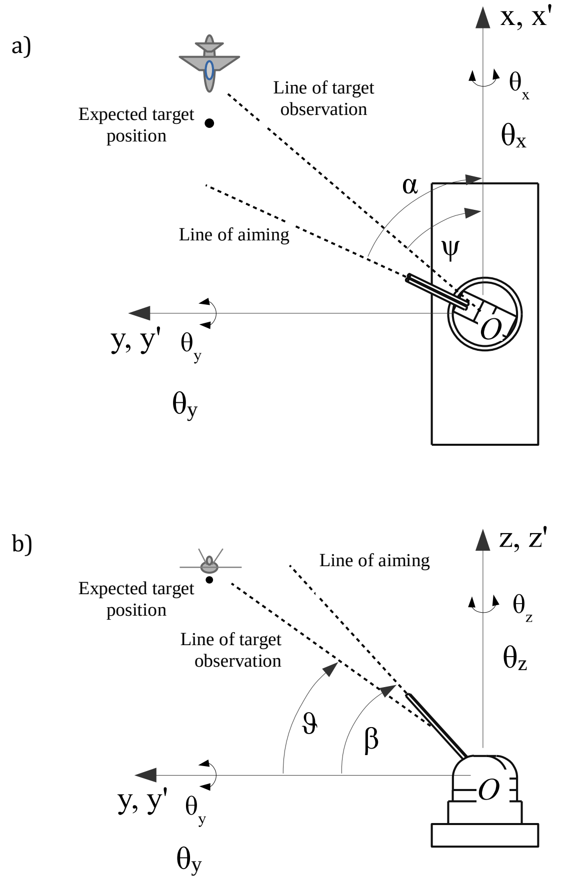

Fig. 2. Key quantities related to location and target tracking: a) projection on horizontal plane *xy*; b) projection on vertical plane *yz* [own work]

With regard to the above mentioned assumptions, general equations describing the error of location of the line of cannons' axis e_α and e_β might be written as:

$$e_\alpha = \psi - \alpha + \Delta_\alpha \dot{\psi} + k_\alpha + \theta_\alpha ; \tag{1}$$

$$e_\beta = \vartheta - \beta + \Delta_\beta \dot{\vartheta} + k_\beta + \theta_\beta , \tag{2}$$

where:

α — deviation angle (azimuth) of cannons' axis;

β — lifting angle (elevation) of cannons' axis;
ψ — deflection angle of the line of target observation;
ϑ — inclination angle of the line of target observation;
Δ_α, Δ_β — coefficients of advance (prediction) of the target trajectory;
k_α, k_β — ballistic corrections;
θ_α, θ_β — angles of azimuth and elevation compensating the ship angular movements.

SYSTEM BLOCK DIAGRAM AND CONTROL ALGORITHM

Figure 3 presents block diagram MZSSAR, which shows its main elements. As it was mentioned in the introduction, the Intelligent Artillery Missile System (ISAR), which allows a fully automatic search and subsequent tracking of the detected target in a previously set area, will constitute the core aspect. ISAR consists of the following main subsystems: artillery-missile set (ZAR), optoelectronic scan-track seeker (OGSS) and control systems (US) and drive systems (UW).

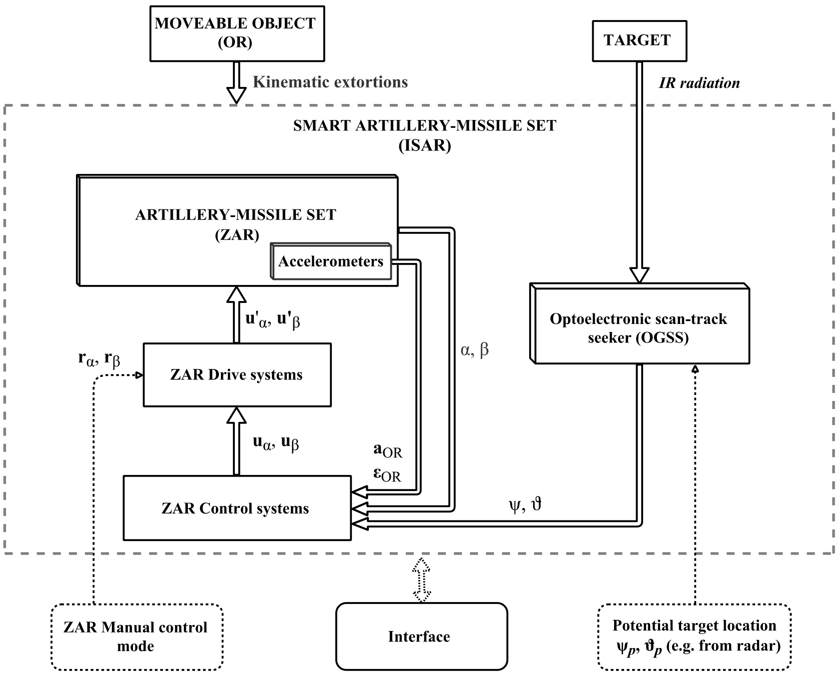

Fig. 3. A simplified block system of a Marine Remote Controlled Artillery-Missile System, where: a_{OR}, ε_{OR} — linear and angular accelerations of set's base; r_α, r — manually given azimuth and elevation angles, u_α, u_β — controller output signals (i.e. voltage); $u`_\alpha$, $u`_\beta$ — driving systems output signals (driving torques) [own work]

An artillery-missile set might consist of an universal doubly coupled cannon of 23 mm calibre with four anti-aircraft launchers of GROM or Piorun missiles. Application of a modified IR seeker described in [4] might be suggested as a scanning and tracking IR seeker, detecting and capturing the object (i.e. identifying the target observation line). In the remaining part of the article, figures 4 and 5 will serve to describe the principle of system operation.

After starting the system, with the use of user interface, a potential location of target ψ_p and ϑ_p is set manually or the quantities can be downloaded from another source, e.g. radar. Then, barrels of the set together with homing missiles, are initially set in the anticipated attack direction. It will minimize the time required to switch them onto a detected target. At the same time, the IR seeker starts to operate in the software control mode, searching a specified area of airspace. If infrared radiation that is believed to originate from the target, falls on the seeker detector, then the seeker starts running in tracking mode and passes successively determined angles of location of the target observation line ψ and ϑ.

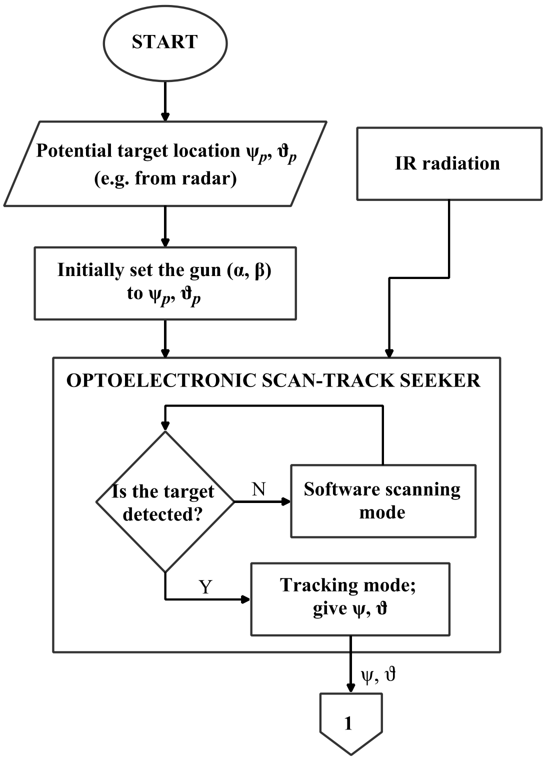

Fig. 4. Procedure of detecting and tracking targets in control algorithm MZSSAR [own work]

Subsequently (fig. 5), the coordinates of the target observation line (ψ, ϑ) are transmitted to the control algorithm of ZAR. In the block of control algorithm ZAR particular algorithms responsible for the following issues are placed:

– calculation of predicted position and ballistic corrections for a given target observation line;
– determination of base rotation angles θ_x, θ_y, θ_z (disturbances) and their compensations in drive coordinates ZAR;
– determination of current angles of azimuth α and elevation β which are feedback to the control system.

Then, after calculating the deviations of location of lines of cannons' axis e_α and e_β, the controller generates control signals u_α and u_β, and the programme in the user interface checks whether the deviations with set accuracy equal zero. If the condition is met, the operator is informed about the possibility of firing a shot. Depending on the selected drives, amplifiers (inverters) or hydraulic servo-valves amplify signals u_α and u_β, in order to drive the actuators with quantities: u_α and u_β.

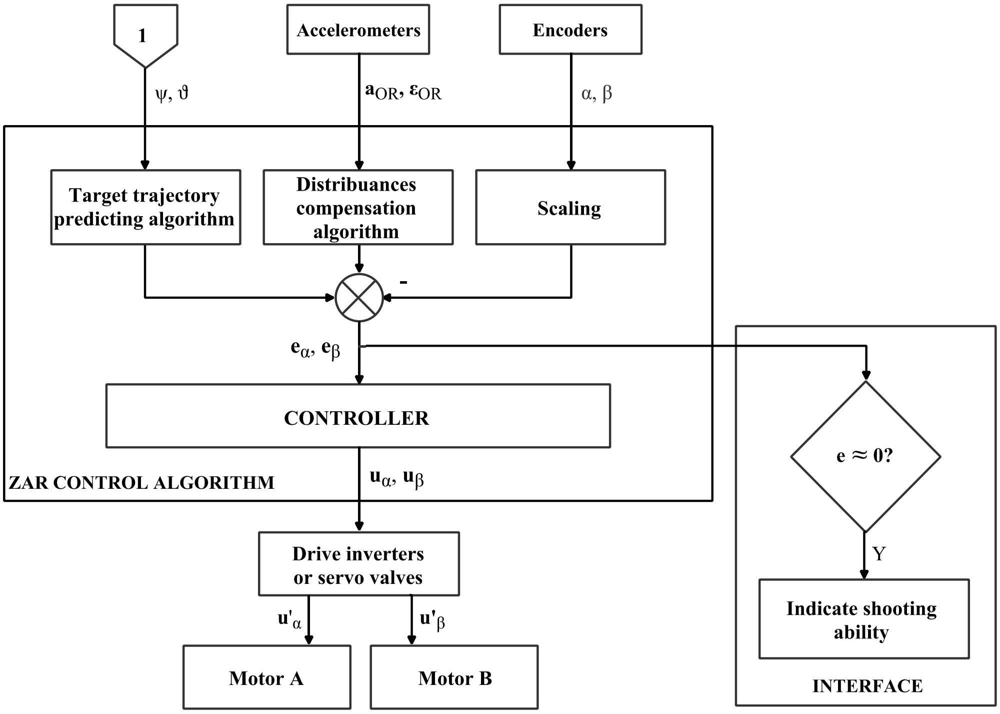

Fig. 5. Control procedure of system during target tracking [own work]

INFLUENCE OF ANGULAR DISLOCATIONS OF A MOVEABLE OBJECT ON SET ACCURACY

A non-stabilized artillery missile set submitted to angular extortions of a moving object (the ship) is exposed to significant accuracy deterioration. It is illustrated by drawings presenting basic cases. Figure 6 shows a diagram of set rotation around *x* axis, i.e. side tilting of the ship. It is assumed that a stationary object in *yz* plane is aimed at.

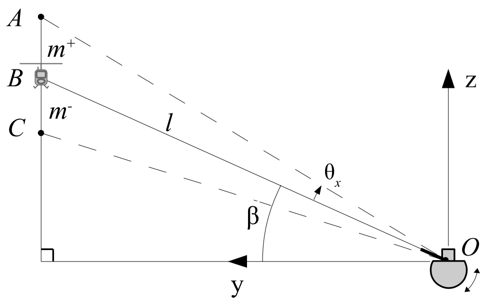

Fig. 6. Diagram of deviation formation as a result of side tilting of the ship, where: $l = |OB|$ — target distance, $m^+ = AB$ — missing over the target, $m^- = -|BC|$ — missing under the target, β — cannons' lifting angle (elevation), θ_x — directed tilt angle of a moving object (ship) around axis *x* [own work]

As a result of tilting at angles θ_x^+, θ_x^-, miss m^+ and m^- will be formed presented with the following equations:

$$m = l \cdot \left[\cos\beta \cdot \mathrm{tg}(\beta + \theta_x) - \sin\beta\right]. \tag{3}$$

Assuming that $\theta_x^+ = |\theta_x^-|$, then $m^+ > |m^-|$. Hence, miss characterization for section m^+ for different tilt angles (fig. 7a) and various elevation angles (fig. 7b) in the function of target distance *l* was presented.

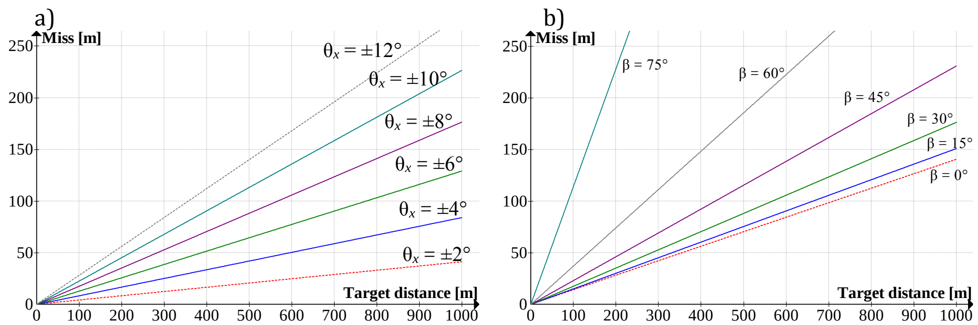

Fig. 7. Values of misses m^+: a) for different side tilt angles and fixed elevation angle $\beta = 30°$; b) for different elevation angles and maximal tilt amplitude $\theta_x = \pm 8°$ [own work]

With a miss defined in such a way on the above characteristics, it can be noticed that increasing tilt angle θ_x proportionally influences increase of the miss value, while increasing the elevation angle with a given amplitude of deviations deteriorates accuracy with respect to the vertical axis. The case of deviation (ship yawing) is shown in figure 8.

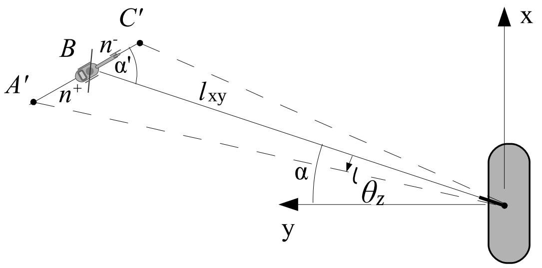

Fig. 8. Diagram of deviation formation as a result of ship yawing (deviation), where: $l_{xy} = l \sin \beta$ target distance in plane *xy*; $n^+ = A'B$ — missing in front of the target; $n^- = BC'$ — missing behind the target; α — azimuth angle of cannons' axis; α' — angle between cannon axis and longitudinal axis of the target; β — elevation angle of cannons' axis; θ_{z+}, θ_{z^-} — deviation angles of a moving object around axis *z* [own work]

Assuming that $\theta_{z+} = |\theta_{z^-}|$, then as a result of deviation presented in figure 8, miss $n^+ > |n^-|$ will be formed with the following equation:

$$n = l \cos \beta \frac{\theta_z}{\alpha' - \theta_z}. \tag{4}$$

As it results from the above mentioned formula, the value of misses depend in this case on deviation angle θ_z, angle α', target distance l and gun elevation angle β. In an extreme case for angle $\beta = 90°$, a theoretical miss is 0 meters, regardless of the target distance. Figures 9a and 9b show the values of missing in front of the target (section m^+) for a change of deviation angle θ_z with a constant angle between the cannons' axis and target longitudinal axis $\alpha' = 60°$ and for different angles α' with a constant angle $\theta_z = 3°$, respectively.

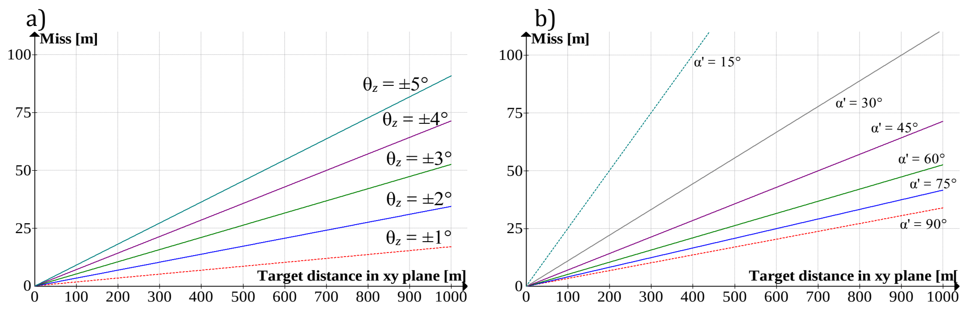

Fig. 9. Values of a miss n^+: a) for different deviation angles θ_z with a constant angle between the cannons' axis and target longitudinal axis $\alpha' = 60°$; b) for different angles α' with a constant angle $\theta_z = 3°$ [own work]

CONCLUSIONS

This article presents the concept of construction and operation of a Marine Remote Controlled Artillery-Missile System intended for combat means of air attack in a short range. A negative impact of a moving object on accuracy of the set was shown, thus, proving a necessity for a sufficiently accurate compensation of these disturbances. An overall system construction was suggested, specifying the major key subsystems, which are already nowadays produced or developed. It contributes to a considerable cost reduction of possible project implementation. The block diagram and initial system control algorithm were presented. It should be noted that the key elements in forming a defence system of new generation will be to design control algorithms and control systems that meet stringent requirements regarding accuracy and positioning time of cannons in terms of a manoeuvring air target. It is therefore required to develop an accurate physical and mathematical model of electro-mechanical subsystems, which, first and foremost, include an artillery-missile set placed on a ship together with drives of azimuth and elevation axes. Considering angular extortions that come from the ship will require acquisition of experimental data in real conditions.

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KONCEPCJA MORSKIEGO ZDALNIE STEROWANEGO SYSTEMU ARTYLERYJSKO-RAKIETOWEGO

STRESZCZENIE

Artykuł przedstawia ogólne założenia, koncepcję, schemat blokowy i algorytm sterowania morskiego zdalnie sterowanego systemu artyleryjsko-rakietowego średniego zasięgu (MZSSAR). Głównym zadaniem tego systemu jest zwalczanie nisko lecących celów manewrujących. W obecnym zestawie „Wróbel II" pojawią się dodatkowe opcje: autonomicznego poszukiwania, wykrywania, identyfikacji, śledzenia i skutecznego zwalczania celu, możliwy będzie też wzrost zdolności bojowych, w szczególności prędkości operacyjnej i zasięgu wykrywania celu.

Słowa kluczowe:

morski autonomiczny zdalnie sterowany system artyleryjsko-rakietowy, obrona powietrzna, sterowanie.