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## ACHIEVING POSITION ACCURACY AGAINST MOVING TARGET ANALYZE

### ABSTRACT

Each navigator has to be able to achieve position by own ship against all types of targets. Maneuver calculations depend mostly on target position and movement vector measurements accuracy. This article presents how the time and maneuver course changes when changes target movement and position data accuracy changes.

### Keywords:

tactical maneuver, target tracking.

### INTRODUCTION

Navigator's maneuver decision efficiency and making tactical maneuver precision is close connected with sea target tracking in real time systems (for instance: ARPA — Automatic Radar and Plotting Aid) accuracy. Tactical maneuvers have to be understood as maneuver tasks (battle, collision prevent, rescue and others) in reference to targets which known position in the polar co-ordinates system and movement vector elements by distance, bearing, true bearing change. Usually tactical maneuvers are used to searching, ship's recognition, smoke-screen making etc. Each maneuver must be started with vital data receiving mostly from CMS, radar or ARPA as follow:

- target distance and bearing;
- movement elements (target course  $\kappa KR$  and speed  $\kappa V$ );
- approaching parameters (CPA, TCPA).

Modern radars are able to make maneuver calculations automatically. Output data after estimation have enough accuracy to make maneuver calculations by operator. In spite of well accuracy data have errors. The maneuver object position errors make more effect to maneuver precision than movement vector calculation errors,

because of tracking device (ARPA, radar, CMS) accuracy mostly. Excepting combat systems (which have good angular and range discrimination often in laser finder equipped), popular radar devices cannot be counted as well accurate. Measured parameters accuracy hardly depends on: probing signal delay, synchronization accuracy error, time base scale discrepancy etc.

Companies producing radar devices give tabular technical parameters like object radar echo coordinates in the polar co-ordinates system accuracy: bearing  $\pm 1^\circ$ ; distance 25–50 m (radar range  $\leq 3$  NM) or 0,01% of radar range (radar range  $> 3$  NM). That data accuracy level is proper for searching and tracking tasks only but it is insufficient for making true position and object localization.

### TRACKED OBJECT POSITION ERROR IN LOCAL SHIP'S CO-ORDINATES SYSTEM

When operator or commanding officer tries to calculate and determine tactical maneuver according to radar (or tactical in polish language) navigation rules, mostly has not knowledge about errors, which will present during his work. Target coordinates accuracy determines maneuver precision and sometimes realizability. It is well known than calculations can give only approximate maneuver course and time. Tactical maneuver must be controlled and corrected on line, sometimes also recalculated in real time. Operator cannot precisely define following parameters like: yawing, rolling, and steering accuracy etc. influence on maneuver precision. During tactical navigation the object position presented as bearing and distance in reference to own ship in the polar co-ordinates system, and calculations will be proceed in mentioned system too. Also the tactical maneuver will be controlled and corrected by using radar screen in the polar co-ordinates system. Object echo position coordinates are known as radar bearing and distance. If position line from radar data mean error is known than we can easy determine the position line mean error in local ship's co-ordinates system. The position lines are cross-cut in right angle than mean error formula will be simple:

$$M = \sqrt{m_1^2 + m_2^2} = \sqrt{a_E^2 + a_E^2}, \quad (1)$$

where:  $m_1, m_2$  — position lines mean errors;

$a_E, b_E$  — mean error ellipse major semi-axes.

During tactical maneuver planning we usually determine echo's course as relative object course but authors suggest to take the mean position error into considerate. This error is circle or elliptical. More precise is elliptical and when we use circle error into consideration, the relative course determines error will increase during some maneuvers and finally calculated maneuver course will not accurate too. This problem is presented on fig. 1.

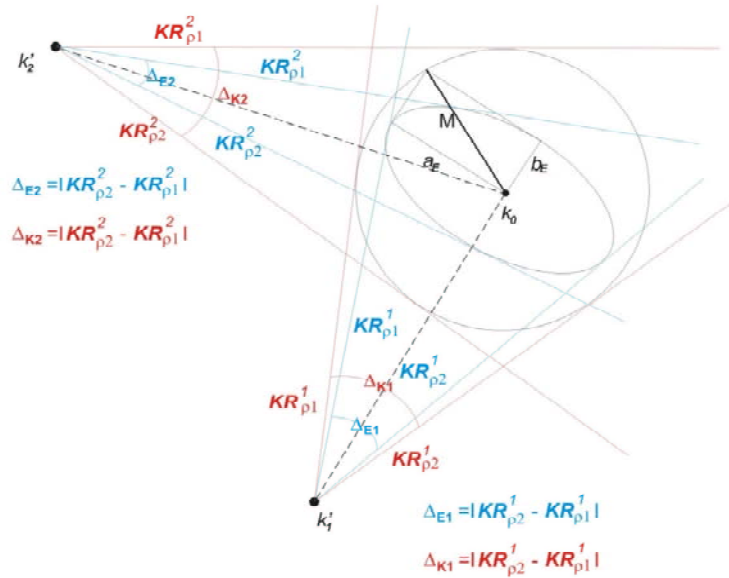


Fig. 1. Differences between relative courses in dependence on kind of mean position error taken into consideration (circle or ellipse)

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If  $\Delta_{E1}$  means difference between possible relative object courses for echo going to position,  $k_1'$  set up then 'start' position error  $k_0$  is determined by mean error ellipse but  $\Delta_{K1}$  means difference between possible relative object courses for mean error position, the difference between relative course calculation errors can be described as follow:

$$\Delta_{\rho}^1 = |\Delta_{K1} - \Delta_{E1}| \tag{2}$$

And for echo going to position  $k_2'$  when difference means  $\Delta_{\rho}^2$  :

$$\Delta_{\rho}^2 = |\Delta_{K2} - \Delta_{E2}| \tag{3}$$

It is known from picture then  $\Delta_{\rho}^1$  and  $\Delta_{\rho}^2$  values depend on how to  $k_o$  'start' position is situated in proportion to  $k_1'$  or  $k_2'$  end position. Distance from  $k_o$  to  $k_1'$  or  $k_2'$  means relative echo trajectory during maneuver time. For situations when  $\Delta_{\rho}$  is close to 0 or achieves small values, the operator can take circle mean position error into consideration only because of summary error will not be significant. This situation can be observed for 'start' echo position where ellipse major semi-axis proportion:  $b_E/a_E$  is close to 1. Mean error ellipse shape is mostly similar to circle than its surface can be almost equal to mean error circle surface. In previous situation the mean position error might be described as:

$$M = a_E \sqrt{2} = b_E \sqrt{2} . \quad (4)$$

Object position in that defined circle (with radius  $R$ ) present probability is 63,2% or (63,2%). On radar screen places like previous can be determined by circle where distance measurement mean error is equal to bearing measurement mean error. With echo distance increasing in our ship ratio than proportion  $b_E/a_E$  achieves values from 1 to 0. In this case the mean error circle (with radius  $M$ ) surface increasing faster than mean error ellipse surface and different between  $\Delta_{\rho}^1$  and  $\Delta_{\rho}^2$  also increases:

$$\Delta_{\rho}^2 > \Delta_{\rho}^1 . \quad (5)$$

Described situation is presented on figure 2. The mentioned circle radius  $D$  can be calculated by using formula:

$$D = 57.3 \frac{m_{DR}}{m_{NR}} . \quad (6)$$

For bearing measurement mean error in value  $m_{NR} = 1^{\circ}$  and distance measurement mean error in value  $m_{DR} = 50$  m, the object position real error in distance  $D = 2865$  ( $\cong 1,5$  NM) can be defined by the circle error using. When distance between own ship (radar screen center) is more than 1,5 NM using ellipse error make calculates results more accurate. From all others figures (circle and parallelogram with the same surfaces) the mean error ellipse can the most precisely characterize the position accuracy because real object position present probability is the highest.

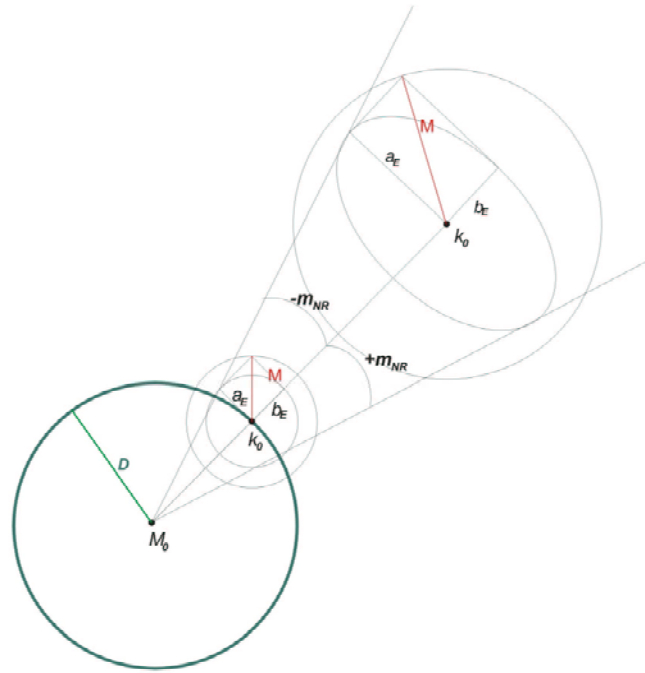


Fig. 2. Echo positions geometric place (circle with radius  $D$ ) where error ellipse semi-axes proportion is equal to 1  
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### MANEUVER COURSE AND TIME ERRORS

Determinate maneuver course and time errors depend on two groups of parameters. Firstly parameters which are describe ‘start’ object echo position  $k_o$  error (see text part 2), secondly parameters of own ship’s and object movement vector factors: own ship course  $KR_M$ , own ship speed  $v_M$ , object course  $KR_K$  and speed  $v_K$ . Usually object movement vector factors are determinate and estimated in ARPA systems, for instance. The rule is that the estimated target (object) movement vector factors  $KR_K$  and  $v_K$  are much more accurate than just measured by radar during object tracking time but still have unavoidable errors. After target movement vector factors estimation ARPA system calculates and estimates the relative movement vector factors as parameters: relative speed  $v_\rho$  and relative course  $KR_\rho$ . Estimated  $v_\rho$  and  $KR_\rho$  parameters determine the target (object) movement vector factors parameters  $v_K$  and  $KR_K$  accuracy. This parameters estimation errors are correlated with estimated relative movement  $v_\rho$  and  $KR_\rho$  errors values as follow: for course up to

$\pm 0.5$  and for speed up to  $\pm 0.25$  knots (calculated by authors basing on [1]). During next calculation steps that errors level can be omitted. Much more meaning for own ship maneuver course determination will have the target (object) echo 'start' position  $k_0$  precision and its true movement vector speed parameter  $v_K$  to own ship's speed  $v_M$  proportion  $v_K/v_M$ . Maneuver course calculating error value is inversely proportional to previous proportion. Maneuver time, highly important for navigator during tactical maneuver calculation and realization, will depend on: object (target) echo relative path  $\rho D$  (calculated as distance between echo positions  $k_0$  and  $k_1$  or  $k_0$  and  $k_2$ ) and relative speed  $v\rho$ . According to mentioned relationships for maneuver object coordinates in own ship's co-ordinates system calculated with accuracy described by elliptical error the maneuver time and course errors can be easy predicted. This errors might be calculated for every possible maneuvers realized with maneuver task speed  $v_M$ . This situation presents figures added below.

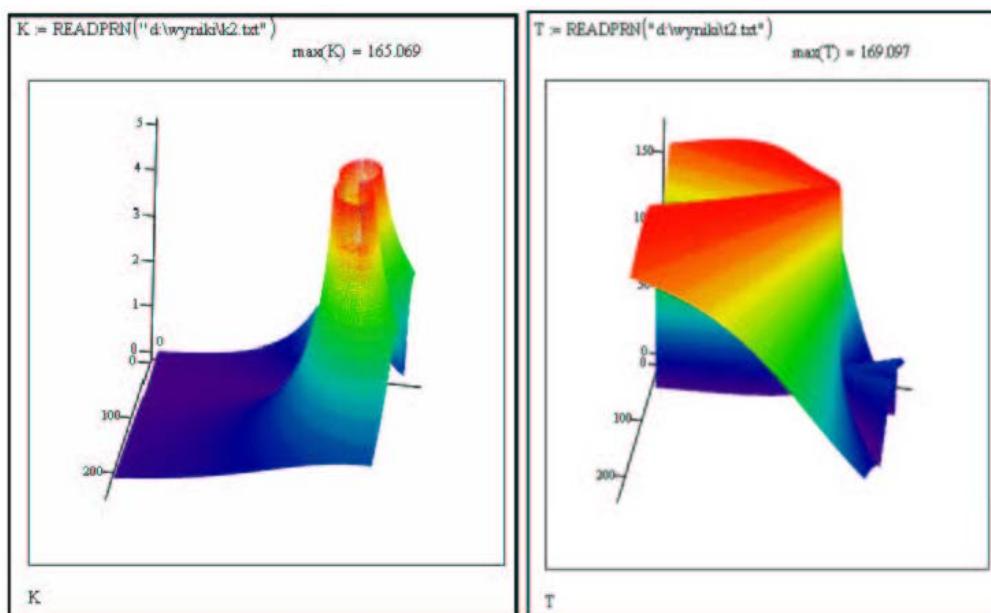


Fig. 3. Maneuver course ( $K$ ) and time ( $T$ ) errors for both objects movement data:  $v_M$ ,  $KR_K$ ,  $v_K$  and 'start' target echo position coordinates in the polar co-ordinates system  $k_0$

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On previous figures  $X_0$  and  $Y_0$  axes illustrate the maneuvering area with  $24 \times 24$  NM borders. Axis  $Z_0$  represents the own ship maneuver course calculation error in angle degrees  $[0,000^\circ]$  for picture ( $K$ ) and the predicted maneuver time error

in time seconds (figure  $T$ ). Presented results were achieved for following data:  $v_M = 15$  kn,  $KR_K = 045^\circ$ ,  $v_K = 10$  kn and 'start' echo position  $k_0$  coordinates:  $NR_0 = 045^\circ$ ,  $D_0 = 9$  NM. For used radar device the bearing measurement mean error  $m_{NR} = 1^\circ$  and distance measurement mean error  $m_{Dr} = 50$  m (for scanning radar range up to 3 NM and 1% for larger range).

## CONCLUSIONS

Previous analysis and calculations let authors to formulate the following conclusions:

1. The echo position coordinates in local ship's pole co-ordinates system determine errors have the most effect on planned and realized tactical maneuver accuracy.
2. Maximal own ship maneuver course error can make real maneuver impossible to realize in real conditions.
3. The echo's relative position correction maneuvers have usually very high errors value.
4. Predicted maneuvers should be planned carefully because of the maneuver time errors small value might involve the highest maneuver course errors value.
5. Presented errors discussion can show the high rank of mentioned occurrence for operators and Commanding Officers which have to realize tactical maneuvers during search and rescue, fire using or maneuver training tasks.

## REFERENCES

- [1] Kantak T., Stateczny A., Urbański J., Fundamentals of the automatisaton of the navigation (in Polish), Akademia Marynarki Wojennej, Gdynia 1988.

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