The Theory of Search for Moving Objects: Maritime Observation System's Applications

Vasily V. Popovich, Oksana V. Smirnova

SPIIRAS, OOGIS Lab, 14 Liniya, 39,
194156, St. Petersubg, Russia
{popovich, sov}@oogis.ru

Abstract. The report will be presented as a short overview of the theory of search for moving objects (TSMO) and their applications for Maritime Observation systems (MOS). TSMO is an axiomatic description of main aspects of B.O. Koopman's ideas and is a next evolution of the classical theory. The theory has been developed at the end of 90th of the last century in SPIIRAS, OOGIS Lab. Theoretical aspects of the theory are used in MOS for different problems such as search and rescue operations modeling and support, target tracking and many others.

Keywords: Theory of Search for Moving Objects, Maritime Observation Systems.

1 Introduction

The theory of search (TS) was developed during a short time period when after the Second World War some reports of the USA scientists were published. They considered results of research completed during the Second World War, and currently they are well known as the reports by B.O. Koopman [10-15]. Rather soon many different theoretical approaches were developed based on them and followed by the methods of operations research.

The goal of our ideas is not a selection, classification or enumeration of all published manuals, monographs, articles, tasks and so on about TS, it is sooner developing a system of rules that we call "Theory of search for moving objects", developing the New Class of Search Problems for Moving Objects within the frames of this system [20-24].

2 TSMO Short Overview

2.1 Development of the axiomatic basis for TSMO

For TSMO only a case of search for moving objects has been studied. The reasons why this class of search was selected are as follows:

- it is necessary to determine limitations within which one can guarantee theoretical integrity, completeness and consistency for well-known and new TS problems;
- it is necessary to interpret quantitative data for real operations of search;
- implementation of TSMO for MOS.

With due regard to the above reasons research has been done in the following order:

- Axiomatic approach for TS (creating TSMO).
- Numerical interpretation of theoretical results.
- Development TSMO's applications for MOS.

2.1 Analysis and classification of search problems

The basis of the theory of search was developed by B.O.Koopman, though his results were published some time later [10-15]. Papers written by Koopman were important bases for the other authors. Many researchers working in the theory of search developed the main Koopman problems and created certain new approaches, such as Game Theory and others.
Some main problems were divided into three groups and their consideration was published by Koopman in three reports as follows:

- Kinematic bases;
- Target detection;
- The optimum distribution of searching efforts.

The following problems have been studied in our research:

- The analytical description of equations of target and observer moving (under constant course and velocity);
- The analytical description of equations of connecting region and probability estimated value of connecting an observer and a target;
- The analytical equation describing the randomly distributed targets;
- The analytical equation describing the evenly distributed targets;
- The probability estimation of the randomly distributed targets;

- The analytical description of instantaneous probability for target location;
- The analytical description of location probability (depending on targets and observers tracks);
- The analytical description of horizontal distance distribution;
- The analytical description for a common case of a random search;
- The analytical description for a particular case of parallel sweeps;
- The analytical description of the forestalled detection of a target by an observer.

3 TSMO's Applications for MOS

MOS are developed for various applications in the interests of navigation (safety, anti-piracy actions, monitoring of narcotics' nonproliferation, illegal immigration and business). Additionally MOS are characterized by intensive information flows arriving form heterogeneous sources and by the necessity to make decisions within short time period (with minimal delay). According to this theoretical results of TSMO can be used for business logic for MOS development. Let us to select most important of them here:

- Probability of target detection in defined region by random and parallel sweeps
- Calculation of search efforts for different targets and environment conditions
- Target tracking problems
- Effectiveness of complex observation system

Acknowledgments. We are grateful to ONRG for support the project #1993P.

References

1. Isaacs R. Differential Game. - M.: Mir,1967 - 433c.
2. Alpern S. The rendezvous search problem - SIAM J. Control and Optimization. Vol. 33, No. 3, pp. 673 – 683, May 1995
3. Anderson E.J., Fekete S.P. Two dimensional rendezvous search – Operations Research, Vol. 49, No. 1, January – February 2001, pp. 107 – 118. (Printed in USA)
4. Bather J.A. Search models // J. of Applied Probability, 1992. – Vol.29, No. 3, pp.605-615.
5. Danskin J.M. A theory of reconnaissance. I,II// Operations Research. – 1962.- V. 10., No.3.
6. De Guenin J. Optimum distribution of effort an extension of the Koopman basic theory// Operations Research. – 1961.- V. 9., No.1.
7. Garret R. A., I.Phillip London. Fundamentals of Naval Operation Analysys. USA.1970.

8. Hohzaki R., Iida K. Optimal ambushing search for a moving target – European J. Oper. Res. 133 (2001), no. 1, 120-129.
9. Howard J.V. Rendezvous search on the interval and circle – Operations Research, Vol. 47, No. 4, July-August 1999, pp. 550 – 558. (Printed in USA)
10. Koopman B.O. The axioms and algebra of intuitive probability – Annals of Mathematics, Vol.41, No.2, April, 1940.
11. Koopman B.O. The bases of probability – Bulletin of the American Mathematical Society, 46 (1940).
12. Koopman B.O. Theory of search:1.Kinematic bases \\Operations Research. - 1956.-v.4, No.3.
13. Koopman B.O. Theory of search:2.Target detection \\Operations Research.-1956.-v.4, No.5.
14. Koopman B.O. Theory of search:3.The optimum distribution of searching efforts \\Operations Research.-1956.-v.4,No.5.
15. Koopman.B.O. Search and screening. Pergamon Press inc.1980, 369pp.
16. Koval V.N., Kuk Y.V. Optimal systems for the detection and classification of moving objects // Cybernet. Systems Anal. 29 (1993), No. 5, pp. 747-753.
17. Lim W.S., Alpern S., Beck A. Rendezvous search on the line with more than two players – Operations Research, Vol. 45, No. 3, May-June 1997, pp. 357 – 364 (Printed in USA)
18. Lukka M. On the optimal searching tracks for a moving target// SIAM J. On Appl. Math.- 1977.- V. 32, No. 1.
19. Mangel M., Probability of success in the search for a moving target// Operations Research. – 1982.- V. 30., No.1.
20. Popovich, V.V., Ivakin, Y.A., Shaida, S.S. Theory of search for moving objects// The proceedings of the International Conference “Oceans 2002”, ”, Biloxi, Mississippi, October 29-31, 2002. – pp.1362-1375
21. Vasily V. Popovich, Vladimir F. Shpak. Evaluation of effectiveness complex observation systems. - Navy Magazine N2, 1995 – pp.23-31.
22. Vasily V. Popovich, Vladimir F. Shpak. Model of evaluation of effectiveness complex observation systems. - Navy Magazine N6, 1995 – pp.23-37.
23. Vasily V. Popovich. Modeling, evaluation of effectiveness and optimization observe systems (theory of search for moving objects).- SPb, KNA, 2000 - 424c.
24. Vasily V. Popovich. Mathematical Basis of Knowledge Discovery and Autonomous Intelligent Architectures. Task#3. New Class of Search Problems for Moving Objects. Final report of the Project#1993P- ONRG, SPb, 2002 – 70pp
25. Yavin Y. A search for a randomly moving object: a numerical study // Computers Math. Applic. ,1992. - Vol.23, No. 10, pp.41-49.