TALLINN UNIVERSITY OF TECHNOLOGY
DOCTORAL THESIS
37/2020

Hyperspectral Signatures of Military Objects in Battlefield, Radiation Field and Information Field Integrated Model

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for doctoral or equivalent academic degree.

Martin Jürise

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ISSN 2585-6898 (publication)
ISBN 978-9949-83-599-7 (publication)
ISSN 2585-6901 (PDF)
ISBN 978-9949-83-600-0 (PDF)
Printed by Koopia Niini & Rauam

TALLINNA TEHNIKAÜLIKOOL
DOKTORITÖÖ
37/2020

Kaitseotstarbeliste objektide hüperspektraalsignatuurid lahinguvälja, kiirgusvälja ja infovälja integreeritud mudelis

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TAL TECH KIRJASTUS

ABSTRACT

Hyperspectral signatures of military objects in battlefield, radiation field and information field integrated model

The present thesis is devoted to the application of hyperspectral imaging technology to hide or detect military objects in the presence of natural background. Work is divided to 5 chapters. In the first chapter is discussed the history of spectroscopy and advent of modern multispectral and hyperspectral technologies during the last decades. In the second chapter is analysed the development of electronic warfare (EW) and hyperspectral (HS) technologies employment in armed forces in the world and in Estonia. The urgent need for intensification has been highlighted for both EW and HS technologies. The third chapter describes the real results obtained in 9 field exercises of EDF and 3 laboratory experiment series with hyperspectral imaging camera. The need for essential improvement of masking quality of different EDF objects, equipment and supplies is pointed out. The fourth chapter describes simulation results of green vegetation spectra with state-of-the-art bio-optical models PROSPECT-D and PROSAIL. The overall good simulation quality for aerial/satellite observer was concluded. Besides that, some accuracy problems regarding simulation of ground observer spectral curves were pointed out. The fifth chapter describes the construction of a novel compact model COMSPECT for green vegetation reflection spectrum modelling in wavelength range 400 nm – 900 nm. The model may be used in compact form with 4 parameters defined and also in a maximally compact form with only 2 most important parameters – the relative heights of green apex and red edge step defined.

The dissertation is presented in English on 104 pages, contains 47 figures and 12 tables and 70 references to literary sources.

LÜHIKOKKUVÕTE

Kaitseotstarbeliste objektide hüperspektraalsignatuurid lahinguvälja, kiirgusvälja ja infovälja integreeritud mudelis

Käesolev doktoritöö on pühendatud hüperspektraalse vaatlus- ja pilditehnoloogia võimaluste rakendamisele looduskeskkonnas nii sõjaliste objektide peitmiseks/varjamiseks kui ka avastamiseks, tuvastamiseks ja identifitseerimiseks. Töö on jagatud viieks peatükiks. Esimeses peatükis käsitletakse spektroskoopia ajalugu ja tänapäevaste multispektraalsete ja hüperspektraaltehnoloogiate kasutuselevõttu viimastel aastakümnetel. Teises peatükis analüüsitakse elektroonilise sõjapidamise (EW) ja hüperspektraal (HS) tehnoloogia arengut maailmas ja Eestis relvajõududes. Töös on ära märgitud, et EW sektoris on vajalik intensiivistada HS tehnoloogiate kasutuselevõttu ning leida uusi paremaid lahendusi objektide varjamiseks ja ka objektide tuvastamiseks. Kolmandas peatükis kirjeldatakse tegelikke tulemusi, mis saadi EDF-i 9 välimõõtmiste ja kolme laboratoorse katseseeria käigus hüperspectraalkaamera abil. Juhitakse tähelepanu, et EKV-l on vajadus oluliselt parandada erinevate objektide, seadmete ja tarvikute moondamis- ning varjamismeetodeid. Neljandas peatükis kirjeldatakse rohelise taimestiku spektrite simulatsioonide tulemusi nüüdisaegsete bio-optiliste mudelite PROSPECT-D ja PROSAIL-ga. Õhust/satelliidilt vaatleja seisukohalt leiti, et simulatsioonikvaliteet on hea. Lisaks seoses spektraalkõverate simuleerimisega toodi välja mõned maapealt vaatleja seisukohast tekkivad täpsusprobleemid. Viiendas peatükis kirjeldatakse uudse kompaktse mudeli COMSPECT ülesehitust rohelise taimestiku peegeldusspektri modelleerimiseks lainepikkuste vahemikus 400 nm – 900 nm. Mudelit võib kasutada kompaktsel kujul, kus on määratletud 4 parameetrit, ja ka maksimaalselt kompaktsel kujul, millel on ainult 2 kõige olulisemat parameetrit – määratletud on rohelise tipu (*green apex*) ja spektri punase astme (*red step*) suhteline kõrgus.

Väitekiri on inglise keeles 98-leheküljeline, sisaldab 49 joonist ja 14 tabelit ning 109 viidet kirjandusallikatele.

INTRODUCTION

Topics of the present thesis is implementation of modern hyperspectral (HS) imaging technologies in military application field in order to improve concealment and detection of military objects in the presence of natural background.

The main reason for selection of this topics is caused by the fact that the potential military forces of opponent have launched the perspective large programs for development of electronic warfare (EW), and, in particular, the hyperspectral observation technologies. The EDF and NATO must be prepared for remarkably higher readiness for extensive use of EW and HS technologies in near future. Additional practical reason is that Tallinn University of Technology purchased in 2015 the HS cameras suitable for this kind of research.

Purpose of studies discussed in present thesis is to assess the quality of EDF military objects and equipment from viewpoint of HS observation, and, additionally, to characterise and model the optical spectral signatures of those objects and equipment and natural background. Tasks of the thesis arise from the objectives mentioned above.

Methodology is based of experimental observation of military objects, equipment and natural background using HS cameras (field and laboratory tests) and a compact spectrometer (laboratory tests). The second part of methodology is investigation of mathematical models of natural background reflection spectra. This includes also development of a novel compact empirical model COMSPECT and application of state-of-the-art models PROSPECT and PROSAIL developed by the remote sensing community.

Theoretical novelty is associated with development of compact model COMSPECT and demonstration of the fact that the well-recognized model PROSAIL is not giving the reliable results for the ground observer. Practical novelty is collection of optical signatures of military objects and equipment in 12 series of experimental tests in years 2015 – 2019 and demonstration of concealment weaknesses of those objects and equipment. Additional practical novelty is collection of typical optical signatures of green vegetation objects.

Approbation of outcomes is based on direct measurement of optical signatures of military objects, equipment and natural background. The adequacy of developed novel model COMSPECT is confirmed by fitting of calculated signatures against 7 averaged measurements series results obtained by 2 spectroscopic devices.

The results of the thesis have been published by 2 journal papers and by 2 conference presentations.