Andrija Krtalić, MSc in Technical Sciences

Andrija Krtalić finished his postgraduate studies at the Faculty of Geodesy of the University of Zagreb on December 12, 2006. The subject of his thesis was *Fusion and interpretation of airborne digital images for visible, near infrared and thermal wavelengths*. The Committee for Evaluation and Defense of the Thesis was composed of the following persons: Prof. Dr. Teodor Fiedler (chairman), Prof. Dr. Milan Bajić (mentor and member), Prof. Dr. Ladislav Feil (member) and Prof. Dr. Miljenko Lapaine (member).

Andrija Krtalić was born on March 30, 1969 in Mostar. He moved with his family to Sisak in 1975, where he completed primary and high school. In 1987, he finished high school CUO Vladimir Majder-Kurt in Sisak, profession in informatics and mathematics.

After he completed his military service, he enrolled the Faculty of Geodesy of the University of Zagreb, where he graduated on photogrammetry with theme: *Linking of raster and vector database using software package IDRISI* in 1997. In 1999, he enrolled a postgraduate study at the same faculty. He passed the State exam in 2000 and obtained the vocation clerk of the I degree.

In 1998, he got a job at the Faculty of Geodesy, Department of Photogrammetry as a professional associate, and in 2002, he became an assistant at the same faculty and department.

He participated in two scientific projects: *Airborne Minefield Area Reduction* (ARC) and *Space and airborne mined area reduction tools* (SMART), both related to humanitarian demining in Croatia and financed by the European Commission. He also participated in the project *Application of remote sensing in sustainable development and mountain protection*.

His Master's thesis *Fusion and interpretation of airborne digital images for visible, near infrared and thermal* wavelengths contains a total of 118 pages and a supplement with 38 pages, an abstract and a glossary in Croatian and English, and additional 98 images, 31 tables, bibliography (34 titles and 9 URL addresses), CD contents and the CD with originals.

The thesis is divided into 10 chapters:

1. Introduction
2. Data fusion
3. Airborne digital image acquisition system
4. Selection and image preprocesing
5. Image fusion of colected image by MS3100 and THV1000 cameras
6. Classification
7. Analysis of results
8. Conclusion
9. Literature
10. Appendix (List of tables, List of figures, Contents of enclosed CD, Curriculum Vitae)

The Introduction defines the role and the importance of fusion in various applications; the research methods are also presented. The limitation of the papers is that satellite images are not considered, while airborne images which were collected within the ARC project in which the author participated are considered.

In the second chapter, methodological and theoretical foundations of fusion are elaborated, accompanied by different definitions, features of information, methodes of image fusion, fusion levels. Special attention was paid to the criteria for fusion assessment according to L. Wald, and methods of fusion (projective and substitutional, relative spectral, principal components analysis, transformation IHS – RGB, relative spectral range, multiplicative method).

The system that was used for airborne collection of images analysed in this work (digital camera with three visible and one near infrared channel, MS3100, longwave infrared camera, THV1000) was described in the third chapter. A transfer modulation function (MTF) and spatial resolution are identified for these cameras. MTF of MS3100 was identified by mesuring the reflection of black and white fields. Polynomial models of the MTF for each channel of both cameras (MS3100 and THV1000) were calculated.

The selection process and the initial processing of the images, geometrical transformations and first results of the registration accuracy are part of Chapter four. Sets of images from three different geographical areas were selected, with very different content, relief, vegetation, climate (Milekovići region, between Petrinja and Glina, Tulove grede above tunnel Sveti Rok and Vrankovići region, near Vransko jezero). These images were collected from differents altitudes , 500 and 900 m above the terrain. Every set of images consists of three visible , one near infrared (VNIR) and one longwave infrared (thermal) channel (TIR). Variability of images' contents was provided by choosing different types of terrain. Original images: TIR500 (taken from altitude of 500 m with resolution of 0.30 m), T900 (taken from altitude of 900 m with resolution of 0.53 m), VNIR900 (taken from altitude of 900 m with resolution of 0.21 m) were registered on VNIR500 images (taken from altitude of 500 m with resolution of 0.12 m). After that all images were reduced to the same size. The realized accuracy of registration was analysed.

Fusion and interpretation of airborne digital images for visible, near infrared and thermal wavelengths

The fifth chapter deals with the contribution of the fusion of TIR and VNIR images in order to determine:

a) the improvement of a spatial resolution of TIR images,
b) the increase of the accuracy and reliability of classification when fused TIR image replace original TIR image in clasification,
c) the criteria and the protocol (L. Wald) assessment for analysis of quality of TIR and VNIR image fusion,
d) the improvement of the resolution of VNIR images.

The following criteria for the assessment of the advantages of fusion were used: the correlation coefficients, the coefficients of linear regresion, the scatter diagram, the differences

Andrija Krtalić, magistar tehničkih znanosti

Andrija Krtalić završio je poslijediplomski znanstvnei studij na Geodetskom fakutlketu Sveučilišta u Zagrebu 12. prosinca 2006. obranom magistarskog rada *Fuzija i interpretacija zrakoplovnih digitalnih snimaka za vidljivo, infracrveno blisko i termalno valno područje*. U Povjerenstvu za ocjenu i obranu magistarskog rada bili su: prof. dr. sc. Teodor Fiedler (predsjednik), prof. dr. sc. Milan Bajić (mentor i član), prof. dr. sc. Ladislav Feil (član) i prof. dr. sc. Miljenko Lapaine (član).

Andrija Krtalić rođen je 30. ožujka 1969. u Mostaru. Godine 1975. odlazi s obitelji u Sisak gdje završava osnovno i srednje obrazovanje. Godine 1987. na tadašnjem Centru za usmjereno obrazovanje Vladimir Majder-Kurt stječe zvanje matematičar-informatičar.

Nakon odsluženja vojnog roka upisuje se na Geodetski fakultet Sveučilišta u Zagrebu, gdje je diplomirao 1997. na području fotogrametrije s temom Povezivanje rasterske i vektorske baze podataka uporabom programskog paketa IDRISI. Godine 1999. upisao je poslijediplomski znanstveni studij na Geodetskom fakultetu. Državno-stručni ispit položio je 2000. i stekao zvanje pristav I vrste zvanja.

Stručnim suradnikom u Zavodu za fotogrametriju na Geodetskom fakultetu postaje 1998, a 2002. prelazi u suradničko zvanje mlađi asistent.

Sudjelovao je na dva projekta: Airborne Minefield Area Reduction (ARC) i Space and airborne mined area reduction tools (SMART) povezana s humanitarnim razminiranjem u Hrvatskoj, a koje je financirala Europska komisija. Sudjelovao je na projektu Primjena daljinskih istraživanja u održivom razvoju i zaštiti planina.

Magistarski rad *Fuzija i interpretacija zrakoplovnih digitalnih snimaka za vidljivo, infracrveno blisko i termalno valno područje* ima 118 stranica i 38 stranica priloga, sažetak i ključne riječi na hrvatskom i engleskom jeziku, 98 slika, 31 tablicu, popis literature (34 naslova i 9 URL adresa), pregled sadržaja CD-a i CD s izvornicima.

Rad je podijeljen na 10 poglavlja:

1. Uvod
2. Fuzija podataka
3. Zrakoplovni digitalni sustav za prikupljanje snimaka
4. Odabir i predobrada snimki
5. Fuzija snimki snimljenih MS3100 i THV1000 kamerama
6. Klasifikacija
7. Analiza rezultata
8. Zaključak
9. Litertura
10. Prilozi (Popis tablica, Popis slika, Sadržaj priloženog CD-a, Životopis i Curriculum Vitae)

U Uvodu je definirano mjesto i uloga fuzije u različitim područjima primjene, prikazana je struktura rada. Istaknuto je ograničenje da se u radu ne razmatraju satelitske snimke nego zrakoplovne snimke koje su dobivene u okviru projekta ARC u kojem je autor bio jedan od vrlo aktivnih istraživača.

U drugom poglavlju opisane su metodološke i teorijske osnove fuzije, različite definicije, značajke informacija, metode fuzije slika, razine fuzije. Posebna pozornost posvećena je kriterijima za ocjenu fuzije prema L. Waldu, te metodama fuzije (projektivna i supstitucijska, relativna spektralna, analiza glavnih komponenti, transformacija IHS – RGB, relativni spektralni udio, multiplikativna metoda).

U trećem poglavlju opisan je sustav kojim je obavljeno zrakoplovno prikupljanje slika koje su upotrijebljene u radu (digitalna kamera s tri vidljiva i jednim bliskim infracrvenim kanalom, MS3100, dugovalna infracrvena kamera, THV1000). Identificirane su njihove prijenosne modulacijske funkcije (MTF) i statičko razlučivanje; za MS3100 na temelju mjerenja odziva na uzorku crno bijelih polja. Dani su polinomski modeli MTF-a po kanalima za MS300 i za THV1000.

U četvrtom poglavlju opisani su odabir i predobradba snimaka, geometrijske transformacije, te dani rezultati točnosti registracije. Odabrani su skupovi snimki iz tri geografska područja s vrlo različitim sadržajem, reljefom, vegetacijom, klimom (Milekovići, između Petrinje i Gline, Tulove grede iznad tunela Sveti Rok i Vrankovići, pored Vranskog jezera), snimani s visina 500 m i 900 m iznad terena. Skupovi snimki sadrže tri vidljiva i jedan bliski infracrveni kanal (VNIR) i jedan dugovalni (termalni) infracrveni kanal (TIR). Izborom različitih vrsta terena osigurana je varijabilnost sadržaja snimaka. Izvorni snimci TIR500 (visina snimanja 500 m, razlučivanje 0,30 m), T900 (visina snimanja 900 m, razlučivanje 0,53 m), VNIR900 (visina snimanja 900 m, razlučivanje 0,21 m) registrirani su na snimke VNIR500 (visina snimanja 500 m, razlučivanje 0,12 m) i isječeni tako da pokrivaju iste površine terena (s veličinom poksela 0,12 m, ali je razlučivanje ostalo kao i kod izvornika). Analizirana je ostvarena točnost registracije.

Fuzija i interpretacija zrakoplovnih digitalnih snimaka za vidljivo, infracrveno blisko i termalno valno područje

U petom se poglavlju istražuje doprinos fuzije snimaka TIR i VNIR s ciljem da se utvrdi:

a) poboljšanje prostornog razlučivanja TIR snimaka,
b) povećanje točnosti i pouzdanosti klasifikacije, ako se izvorni TIR snimak zamjeni TIR snimkom dobivenim fuzijom,
c) procjena kriterija i protokola L. Walda za analizu kvalitete fuzije snimaka TIR i VNIR,
d) poboljšanje razlučivanja VNIR snimaka.

Kao kriteriji za procjenu dobitka fuzije primijenjeni su: koeficijent korelacije, koeficijenti linearne regresije, dijagram

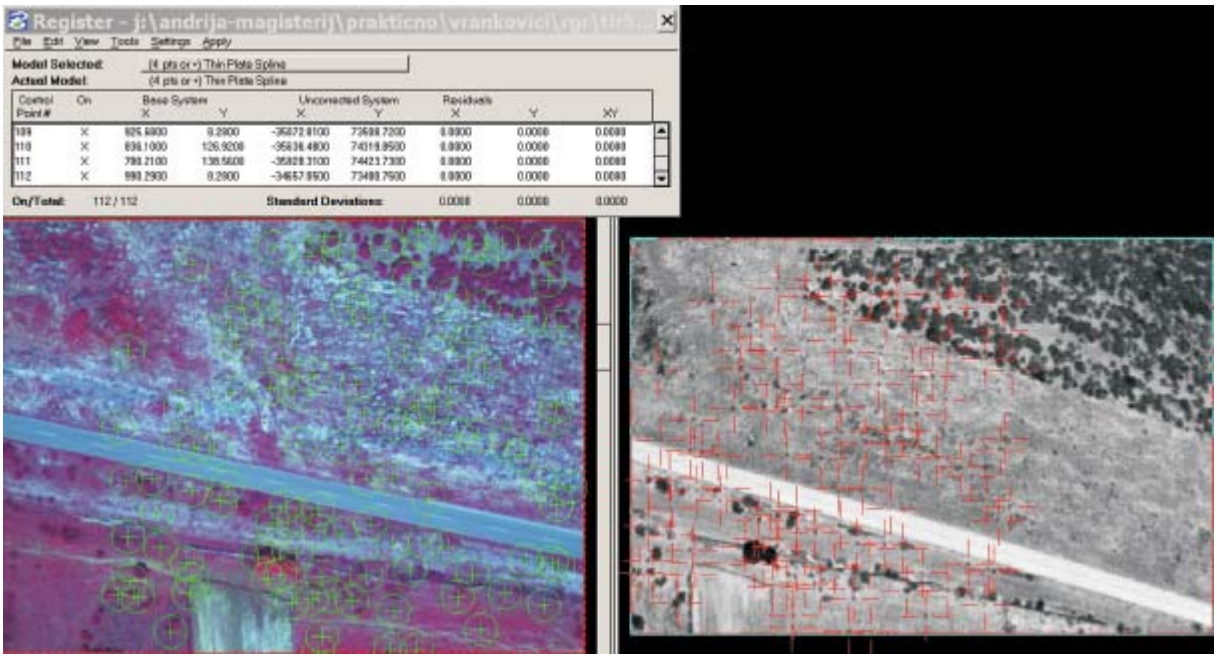

Fig. 1. Image TIR500 (right) registration over the reference image VNIR500 (left) of the Vrankovići area (near Vransko lake)

Sl. 1. Registracija snimke TIR500 (desno) na referentnu snimku VNIR500 (lijevo) područja Vrankovići (u blizini Vranskog jezera)

in the means and standard deviations, the median; a visual assessment of similarities, , visual assessment of improvements of spatial resolution and radiometry according to L. Wald. Also, the contribution of the fusion for each geographical area for selected fusion methods was determined (the results by the selected criteria were given). The author's original contribution is the fact that the second or first principal component (PCA) in VNIR and TIR images fusion provides a significant improvement of the resolution and radiometric characteristic of TIR images on terrains with rare vegetation. The PCA method seems to be the most successful method for this purpose, and after that the multiplication of images.

In the sixth chapter, the confusion matrix (overall accuracy of classification, producer's accuracy, user's accuracy) and the Kappa coefficient were applied (measuring actual and probable harmony) for objective measuring of image fusion contribution to the classification results. A total of 4 (Tulove grede region) and 6 (Milekovići and Vrankovići regions) images combinations was used. The analysis results were subject to a critical interpretation according to scene contents, supposed initial list of classes (objects), and list of classes which can be separated according to available images, with help of interactive feature mapping, unsupervised and supervised classification.

The discussion of the results was given in the seventh chapter of the thesis. The assets of fusion according to aims (fifth chapter) of research were explained in this chapter. A critical abstract of new contribution to the fusion of TIR and VNIR channels obtained within this research was given in the Conclusion. The original images, the registered images, the fusion products, a list of tables and figures and the contents of supplemented CD were given in the Appendix.

Within this thesis, A. Krtalić has proved the competence for complex analyses of the fusion method as shown on the infrared long wave (thermal) images and the images from visible and near infrared wavelengths,applying several methods of image fusion, series of criteria for assessments of fusion products, with introduction of the confusion matrix and the Kappa coefficient. The original contributions of this work are:

- proof of significant improvement in resolution of TIR images using PCA and multiplicative methods, on images with smaller degres of vegetation cover
- increase in classification accuracy (+8,1%) and Kappa coefficient (9,6%) in the case of the mountain terrain, and more than 2% for other type of terrain if the VNIR and TIR image fusion was done,
- the criteria of L. Wald were supplemented for a quality assessment of fusion with introduction of classification parameters from the confusion matrix and Kappa coefficients.

After all mentioned, the Committee for Evalution and Defense concluded that the work of Andrija Krtalić graudate engineer of geodesy was produced according to the rules of the Faculty of Geodesy and with application of scientific research methodology. The Committee also concluded that the work splendidly elaborated the aims, methods, conditions and results of the research, and gave several original contributions.

Prepared by Miljenko Lapaine

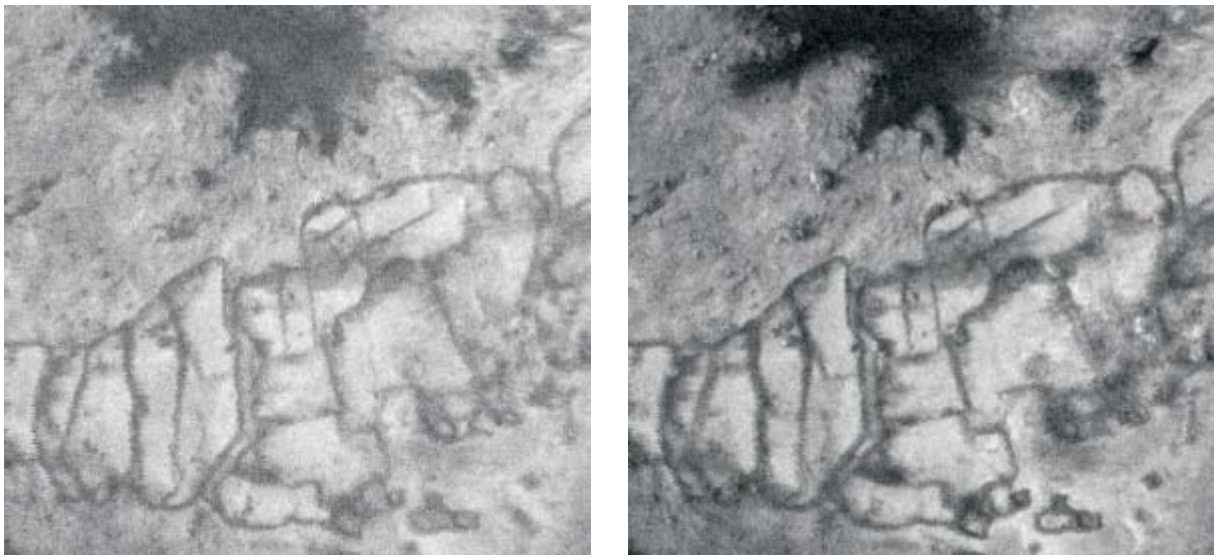

Fig. 2. (left) Original image TIR500 of the Tulove grede area (Velebit), (right) the result of the image fusion (second principal component of the B-G-R-IR-TIR combination) based on principal component method (PCA)

Sl. 2. (lijevo) Izvorna snimka TIR500 područja Tulove grede (Velebit), (desno) rezultat fuzije slika (druga glavna komponenta kombinacije B-G-R-IR-TIR) nastao metodom glavnih komponenti (PCA)

rasipanja, razlike srednjaka i standardnih devijacija, medijan; vizualna procjena sličnosti, vizualna procjena poboljšanja prostorne razlučivosti i radiometrije prema L. Waldu. Analiziran je doprinos fuzije za svako geografsko područje za odabrane metode fuzije, dani su rezultati prema odabranim kriterijima. Originalan doprinos autora je nova činjenica, da druga ili prva glavna komponenta (PCA) fuzije snimaka TIR i VNIR osigurava značajno poboljšanje razlučivanja i radiometrijskih karakteristika TIR snimaka na terenima s rijetkom vegetacijom. Od analiziranih metoda najuspješnijom se pokazala metoda glavnih komponenata (PCA), a zatim multiplikativna metoda.

U šestom poglavlju primijenjena je matrica konfuzije (ukupna točnost klasifikacije, točnost interpretatora, točnost korisnika), te Kappa koeficijent (mjerenje stvarnog i vjerojatnog suglasja) za objektivno mjerenje doprinosa fuzije razultatima klasifikacije. Analizirano je 4 (Tulove grede), odnosno 6 (Milekovići, Vrankovići) kombinacija snimaka. Rezultati analize kritički su interpretirani u odnosu na sadržaje scene, početni pretpostavljeni popis klasa (objekata), i popis klasa koje je moguće izdvojiti na temelju raspoloživih snimaka, s pomoću interaktivnog izdvajanja obilježja, nenandzirane i nadzirane klasifikacije.

Diskusija dobivenih rezultata dana je u sedmom poglavlju, gdje su objašnjeni dobitci fuzije u skladu s ciljevima istraživanja (peto poglavlje). U zaključku je kritički dan sažetak novih saznanja o fuziji infracrvenih dugovalnih (termalnih – TIR) snimaka i snimaka iz vidljivog i bliskog infracrvenog valnog područja (VNIR) dobivenih provedenim istraživanjem. U prilogu su dani izvorni i registrirani snimci, proizvodi fuzije i pregledi tablica, slika i sadržaja priloženog CD-a.

U ovom je radu A. Krtalić dokazao osposobljenost za kompleksnu analizu metoda fuzije na primjeru infracrvenih dugovalnih (termalnih) snimaka, te snimaka iz vidljivog i bliskog infracrvenog valnog područja primjenom više metoda fuzije, primjenom niza kriterija za ocjenu rezultata fuzije, uvođenjem matrice konfuzije i Kappa koeficijenta. Izvorni doprinosi rada su:

- dokazano je značajno poboljšanje razlučivanja infracrvenih dugovalnih (termalnih) snimaka metodama glavnih komponenata i multiplikativnom metodom, za terene s manjim postotkom vegetacijskog pokrova
- povećana je točnost klasifikacije (+8,1%) i Kappa koeficijenta (9,6%) za slučaj planinske vrste terena, i više od 2% za ostale vrste terena, ako se koriste fuzijom dobiveni TIR snimci
- dopunjeni su kriteriji L. Walda za ocjenu kvalitete fuzije, uvođenjem parametara klasifikacije iz matrice konfuzije i Kappa koeficijenata.

Na temelju navedenoga Povjerenstvo za ocjenu zaključilo je da je rad Andrije Krtalića, dipl. inž. geodezije izrađen u skladu s važećim pravilnicima Geodetskog fakulteta, primjenom metodologije znanstvenog istraživanja, da je rad izvrsno obradio ciljeve, metode, uvjete i rezultate istraživanja, te da je dao nekoliko izvornih doprinosa.

Pripremio Miljenko Lapaine