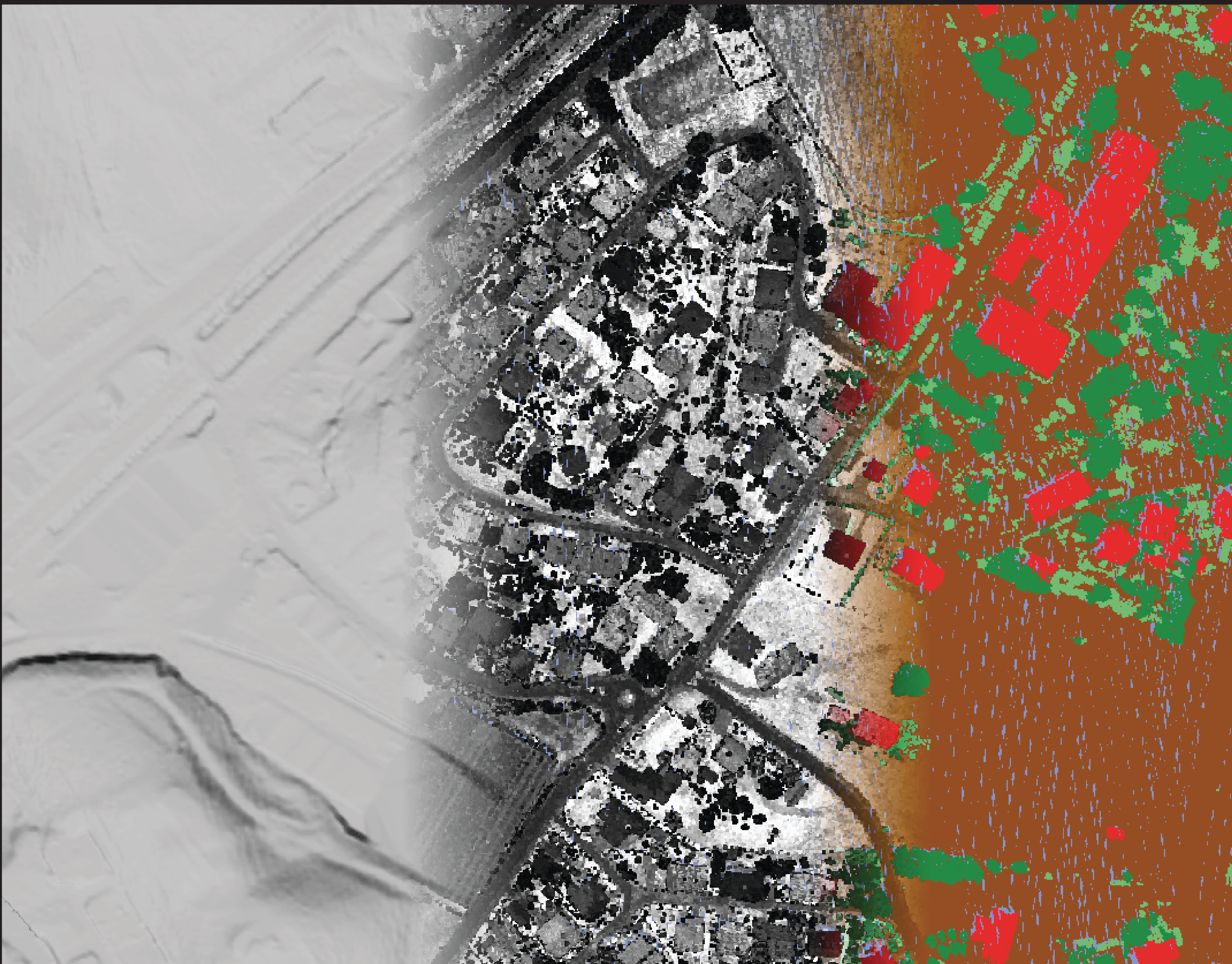
GeMMA 2000-2016: From Fundamental Geometric Algorithms to Advanced Methodologies for Pattern Recognition and Dynamics Modelling in Large Earth Observation Datasets



Edited by David Podgorelec

GeMMA 2000-2016: From Fundamental Geometric Algorithms to Advanced Methodologies for Pattern Recognition and Dynamics Modelling in Large Earth Observation Datasets

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University of Maribor
Faculty of Electrical Engineering and Computer Science

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Foreword

At the beginning of 2015, the Laboratory for Geometric Modelling and Multimedia Algorithms (GeMMA) at the Faculty of Electrical Engineering and Computer Science (UM-FERI) of the University of Maribor celebrated fifteen years of its existence. In those days, an idea was born to mark the anniversary with a book that would illustrate the lab's development from its early beginnings, when three original members intensively coped with development, improvements and implementation of algorithms of 2D computational geometry and attempts to link these algorithms with applications from civil and mechanical engineering, medicine and geographic information systems (GIS), to the current days when the team of 22 researchers is deeply involved in development of new algorithms, methodologies and applied solutions from the fields of geometric and remote sensing data processing, GIS, scientific visualization, data compression, simulation of green-energy resources, big data processing, predictive analytics, and data mining. Top results on an international scale have been recently achieved by GeMMA members particularly in developing new methodologies for LiDAR (Light Detection And Ranging) data processing and their practical validation. They include the United States patent for lossless LiDAR data compression and decompression, two Slovene national patents for progressive and lossy LiDAR data compression, a series of top scientific publications in the most prestigious international journals on remote sensing and several awards and honours at the international, national or faculty level.

Our current LiDAR-related research activities are being performed through two ongoing national (funded by the Slovenian Research Agency) research projects. These activities also represent the core of GeMMA's participation in the ongoing national research programme P2-0041, a strategic research direction of the Institute of Computer Science at UM-FERI. Consequently, this book is primarily aimed to support dissemination and to demonstrate possible practical usages of outcomes of these two projects and the programme. But, moreover, it is also a survey of selected research projects through the past 16 years, demonstrating how the GeMMA research group has gradually gained knowledge and experience necessary to participate in the aforementioned projects and programme, while the summarized applied projects from the past may additionally show some possible directions of the lab's latest research results utilization. This gradual development and progress are surveyed in more detail in the book editor's preface, in brief biographies of all actual and the majority of past members and, particularly, in the final part of the book in a form of lists of publications, awards and other achievements. Since the year 2000, GeMMA members have published over 100 journal papers and over 90 conference papers. GeMMA also got 10 patents, and two of them are international. 19 Ph.D. students finished their Ph.D. and about 150 B.Sc. and M.Sc. students graduated under supervision of the UM-FERI professors from GeMMA. 16 years after its establishment, GeMMA with its 22 members is recognized and respected as one of the strongest laboratories at UM-FERI.

Borut Žalik, Head of GeMMA

Kamnica, June 2016

Preface

2015 was a very successful year for the Laboratory for Geometric Modelling and Multimedia Algorithms (GeMMA) at UM-FERI. Eight top journal papers were published, a patent confirmed and several awards and honours received. All of these successes were the outcomes of two bigger ongoing scientific projects titled Morphological operators for pattern recognition in large point clouds (contract J2-5479) and Algorithms of ecosystems dynamics modelling with methods of mathematical morphology and lattice theory (J2-6764) which are both funded by the Slovenian Research Agency (ARRS) and closely related with GeMMA's participation in the ongoing national research programme Computer Systems, Methodologies and Intelligent Services (P2-0041), financed by the same agency. All annual goals of the aforementioned projects and programme were reached or even exceeded, and all the hypotheses were practically confirmed a year or two before the completion of the projects. Encouraged with these achievements, we got an idea to further disseminate them in a book. Unlike the published scientific papers, workshop presentations, technical and project progress reports, this book should not be primarily aimed for experts or project funders, but to raise awareness of usefulness of LiDAR data, feature detection from point clouds and ecosystem dynamics modelling among possible users from different, not necessarily technical fields. Consequently, we have decided to prepare the contents in an ordinary, non-technical manner, but this has immediately posed a new question whether we had enough materials if the scientific and technical details were reduced to a minimum. We had firstly intended to present only the two aforementioned research projects, some smaller applied projects utilizing the research outcomes of the former two, and their predecessor titled Processing of massive geometric LiDAR data, which was also mostly funded by ARRS, but that would hardly suffice for a reasonably complete book. Then we decided to additionally incorporate descriptions of some projects which had helped us to gain expertize in remote sensing in the past. Namely GeMMA's strong scientific background in computational geometry, geometric modelling, computer graphics, data compression and GIS, and its ability to transfer the knowledge into practical applications were a prerequisite to identify and tackle challenges of LiDAR data processing. At the end of 2015, a new book concept was consequently agreed in a form of a research chronicle from the early days of GeMMA to the latest advanced achievements in remote sensing data processing. After all, the book is also aimed to promote GeMMA's contributions to the P2-0041 research programme which started in 2004 and provided at least partial funding for the most of the research activities described in this extended book content. Finally, the new concept also revived the idea to mark the fifteenth anniversary of GeMMA with a book. As this happened a bit late, the idea was then upgraded to the sixteenth (hexadecimal 10 or binary 10000) anniversary celebration. To stress the contents of both research projects J2-5479 and J2-6764 and the research programme P2-0041, providing funding for the book, and to mark the lab's "anniversary", the book was titled GeMMA 2000-2016: from fundamental geometric algorithms to advanced methodologies for pattern recognition and dynamics modelling in large Earth observation datasets.

GeMMA was established as the sixth laboratory of the Institute of Computer Science at UM-FERI on January 1st, 2000. Its founder assoc. prof. Borut Žalik Ph.D. and both other original members, technical assistant Matej Gomboši B.Sc. and teaching assistant David Podgorelec B.Sc. (GeMMA's amateur historian and the editor of this book), used to work in the Laboratory for Computer Graphics and Artificial Intelligence (CGAI) at UM-FERI before they began this new chapter in their careers. The research work in the newly established lab was mostly focused onto 2D computational geometry and 3D geometric modelling. Possible applications were identified in such attractive fields as civil engineering, mechanical engineering, digital cultural heritage, medicine, and particularly the (at the time) emerging geographic information systems (GIS). Soon after its establishment, GeMMA received its first significant acknowledgment by successfully implementing robust modules for polygon triangulation and trapezoidation to be incorporated into a worldwide used commercial software product of the renowned graphic and modelling software producer AUTODESK. Few months later, GeMMA was successful in getting the young researcher position which was soon occupied by Sebastian Krivograd. At that time, the first Masters of Science graduated under Žalik's mentorship. Soon after that (2002), Podgorelec became GeMMA's first doctorand while Žalik was elected as full professor in 2003. Another two colleagues, Gregor Klajnšek and Mirko Zadravec, received the young researcher scholarship in 2002 to complete the classic GeMMA sextet.

In those days GeMMA had strong research connections with the University of West Bohemia from Pilsen, Czech Republic, strengthening its competences in computational geometry and computer graphics. Another important foreign partner was the Milton Keynes Campus of De Montfort University of Leicester, the United Kingdom, which raised our interest in medical visualization. In 2003 and 2004 GeMMA also participated in its first EU-funded project Virtual Heart of Central Europe (VHCE). Further personnel reinforcements came by the merit of extended educational work and, particularly, increasing number of industrial projects. Especially GIS applications brought and still bring important funds. As experts in computational geometry, we firstly did some consultancies, analyses and fundamental 2D geographic data processing implementations for the national Surveying and Mapping Authority. Later, about ten years ago, a very successful still lasting cooperation with IGEA d.o.o., one of the leading geospatial infrastructure providers in Slovenia started.

After the country entered the European Union, the three former young researchers and Gomboši, which all reached Ph.D. degrees in a meantime, left GeMMA to meet other challenges in their careers, but in spite of this, the number of members, publications and successfully realized projects were gradually growing. Žalik again and again fulfilled the conditions to be a mentor to three young researchers and, therefore, Vid Domiter, Denis Špelič and Domen Mongus occupied the released positions. Additionally, Boštjan Pivec replaced Gomboši as a teaching assistant, Blaž Repnik and Denis Žganec joined GeMMA to work on industrial GIS applications while Bojan Rupnik, Denis Obrul, Gregor Smogavec, Bogdan Lipuš Ph.D. and Sašo Pečnik partially worked on projects and the rest of the time as teaching assistants. In 2008, GeMMA extended its research activities to remote sensing data processing. A nearby company Geoin d.o.o. possessed airborne LiDAR data capturing technology, extensive real-world datasets, a commercial geometric modelling software enabling visualization and interactive manual segmentation of points, and a vision to automate LiDAR data processing as much as possible. GeMMA's new young researcher Domen Mongus found himself at the right place at the right time. In the subsequent years, he developed himself into a top European young scientist in the field of remote sensing. His systematic research on LiDAR point clouds visualisation and compression, ground extraction and digital terrain model construction has attracted co-financiers and research partners to jointly, under the leadership of GeMMA, propose for ARRS-funded research project titled Processing of massive geometric LiDAR data (2010-2013). Later on, GeMMA was successful in applying for two more LiDAR-related research projects which, as already stated, represent two central topics in this book. The focus has been moved to points' classification and feature recognition based on contemporary concepts of mathematical morphology and our newly developed algorithm for the estimation of locally fitted surfaces. Non-ground points of buildings, trees and power lines can already be recognized from LiDAR point clouds, and several other feature classes are being intensively studied. Besides this, the developed methodology can monitor the dynamics of extracted features and detect various events within large point clouds. Prominent outcomes of these three bigger research projects, several smaller end-user-oriented projects and continuous successful participation in the P2-0041 research programme brought to GeMMA an ability for further expansion. Simon Gangl, Niko Lukač and Denis Horvat formed the third generation of GeMMA's young researchers, while Danijel Žlaus became the best technical assistant ever in the world and the history. Renato Mikša, Primož Kovačič, Roman Čuk, Simon Lušenc and Damjan Roškar used to participate in a series of the lab's smaller projects for a while, and Matej Brumen, Denis Kolednik, Marko Bizjak, David Jesenko, Robi Cvirn, Amadej Pevec and Žiga Leber represent a young guard of current GeMMA researchers, programmers and teaching assistants. Finally, Simon Kolmanič Ph.D, Damjan Strnad Ph.D., Štefan Kohek and Andrej Nerat moved to GeMMA at the beginning of 2016 after the CGAI lab (the one which gave the first GeMMA members 16 years ago) was abolished due to retirement of its head. This reunion of former co-workers importantly upgraded GeMMA's skills in artificial intelligence, modelling and simulation.

The book is organized in three sections: Members, Activities and Achievements. CVs in the Members section are written by each member himself. The autobiography of the GeMMA's head prof. Žalik is followed by 21 CVs of the current members arranged in alphabetical order. The section is concluded with CVs of 11 previous members. Unfortunately, four former members (Gangl, Kovačič, Lušenc, Smogavec) haven't managed to submit their biographies before the edition of the book. There were or still are also some part-time members (prof. Franc Novak Ph.D., assoc. prof. Krista Rizman Žalik Ph.D., Simon Jurič Ph.D.) or employees for a very limited period (Rubén Dorado Vicente Ph.D., Saša Jevtić) in GeMMA, but their CVs are not included in the book. The Activities section contains brief descriptions of 35 selected projects. The majority refer to real contracted projects, but there are also presentations of some activities realized for advertisement purposes or even for curiosity or fun. The section is subdivided into seven blocks which directly reflect the purpose and the title of the book. The main stress is on remote sensing, particularly LiDAR-related projects, which are presented at the beginning. Then we return to the early days of GeMMA when the main challenges were found in computational geometry, geometric modelling and visualisation. The fourth block addresses GIS, the fifth one is about data compression, the sixth one summarizes our medical applications, while the last is a collection of miscellaneous applications which don't fit anywhere else, e.g. multimedia, human-computer interaction, data mining etc. Finally, the Achievements section surveys the selected categories of publications produced in GeMMA, and all the prizes, awards and honours received by GeMMA members. There are also lists of young researchers, Ph.D. and M.Sc. graduates supervised in GeMMA, and all our important functions and honours in national and international associations.

This book is a collaborative work of many GeMMA members. Nearly half of the stories were written by the editor, who summarized the materials listed in the Info part of each project description. The remaining contributions were prepared by Marko Bizjak, Robi Cvirn, Denis Horvat, Denis Kolednik, Bogdan Lipuš, Niko Lukač, Domen Mongus and Blaž Repnik. All figures were also authored by GeMMA staff, either as screenshots directly taken from running applications or as reproductions from the existing published or internal materials. Photographs of personnel were provided from private archives of each member. Andrej Nerat collected and formatted the majority of materials in the Achievements section, the proofreading was done by Marko Bizjak and the editor, while the design and layout were made by Denis Kolednik. We are also grateful to all other people and organisations who helped to live this successful story and to bring it onto these pages.

Editor

Maribor, July 2016

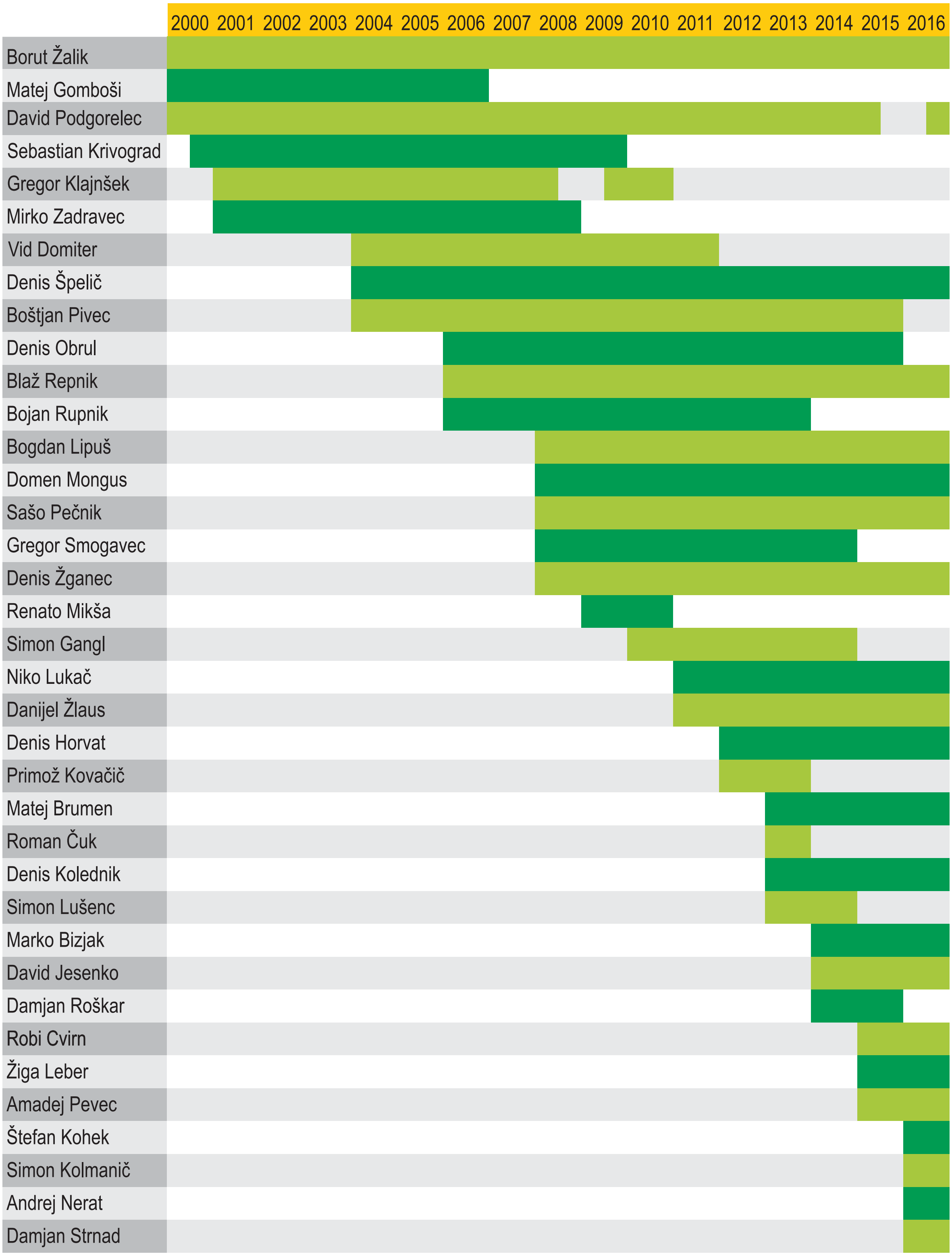
ACRONYMS

2.5D	2.5-dimensional
2D	2-dimensional
3D	3-dimensional
3OT	Three orthogonal symbol chain code
ACM	Association for Computing Machinery
API	Application programming interface
ARLE	Adaptive run-length encoding
ARRS	The Slovenian Research Agency (Slo. Javna agencija za raziskovalno dejavnost Republike Slovenije)
AVC	Advanced Video Coding
B.Sc.	Bachelor of Science
BGB	Basic geometric buffer
BWT	Burrows–Wheeler Transform
C_DDCC	Compressed directional difference chain codes
C_VCC	Compressed vertex chain codes
CAD	Computer-aided design
CDC	Chain-difference coding
CGAI	Laboratory for Computer Graphics and Artificial Intelligence
CGD	Computer generated datasets
CLSM	Confocal laser scanning microscopy
CM	Cutaneous melanoma
CORE@UM	Centre for Open Innovations and Research
CSF	Content sealed format
CT	Computed tomography
CV	Curriculum Vitae (biography)
d.o.o.	Company with limited liability (Slo. Družba z omejeno odgovornostjo)
D3	Device for damage detection
DDCC	Directional difference chain codes
DE	Differential evolution
DICOM	Digital Imaging and Communications in Medicine
DLL	Dynamic link library
DLR	German Aerospace Center
DMP	Differential morphological profile
DOF	Digital orthophoto
DTM	Digital terrain model
E, W, N, S	East, West, North, South
e.g.	For example (Lat. Exempli gratia)
EA	Evolutionary algorithm
EPSG	European Petroleum Survey Group
ERK	International Electro-technical and Computer Science Conference
EU	European Union
EUROGI	European Umbrella Organization for Geographic Information
F4, F8	The Freeman chain code in four and eight directions
FEM	Finite element method

FOV	Field-of-view
GB	Gigabyte
GeMMA	Laboratory for Geometric Modelling and Multimedia Algorithms
GIS	Geographic information system
GmbH	Company with limited liability (Ger. Gesellschaft mit beschränkter Haftung)
GPGPU	General purpose computing on graphical processing unit
GPS	Global positioning system
GPU	Graphical processing unit
GWT	Google Widget Toolkit
H1, H2, H3	Hypotheses 1, 2, 3
H.264	Currently one of the most commonly used digital video compression formats; MPEG-4 Part 10, Advanced Video Coding (MPEG-4 AVC)
HFD	High-frequency differences
ICCSIT	International conference on computer science and information technology
IEEE	The Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IS	Information Society
ISPRS	International Society for Photogrammetry and Remote Sensing
IT	Information Technology
JBIG	Joint Bi-level Image Experts Group (lossless image compression standard)
JPEG	Joint Photographic Experts Group (a suite of compression algorithms for digital images)
kB	Kilobyte
LAS	Laser file format
LDI	Layered depth images
LFM	Low-frequency mean
LiDAR	Light detection and ranging
LMIP	Local maximum intensity projection
LMS	Laboratory for Microcomputer Systems
LoCoVox	Lossless algorithm for compressing voxel-based 3D medical images
LoFS	Locally fitted surfaces
LSH	Locality sensitive hashing
LZ77	Lossless data compression algorithm published by Abraham Lempel and Jacob Ziv in 1977
LZ770	A simplified version of LZ77
M.Sc.	Master of Science
MM	Mathematical morphology
MP3	MPEG-1 Audio Layer III, lossy audio coding format for digital audio
MPEG	Moving Picture Experts Group
MrSID	Multiresolution seamless image database
MTFT	Move-to-front transform
NAD	Normalised angle-difference chain code
NMS	Number of monotone subarrays
NUK	National University Library
OGC	Open Geospatial Consortium
OŠ	Primary school
PC	Personal computer
PCA	Primary components analysis

PCL	Point Cloud Library
PCP	Planar cell polarity
Ph.D.	Doctor of Philosophy
POV	point of view
PSP	Partnerships in Science Project
PV	Photovoltaic
R&D	Research & development
RAR	Roshal Archive; a proprietary archive file format
RLE	Run-length encoding
RLE_0^L	The constant 0-symbol run-length encoding
RLE0	Run-length encoding to compress runs of 0-bits
ROI	Region of interest
RS	Republic of Slovenia
SCCG	Spring conference on computer graphics
SERŠ	Secondary School of Electrical Engineering and Computer Science
SPC	Student paper competition
SQL	Structured Query Language
SVM	Solverminds Solutions & Technologies
TB	Terabyte
TESTŠ	Technical Electro, Mechanical, and Textile high school
TF	Technical Faculty
TU	Technical University
TXT	Text file
UM	University of Maribor
UMCC	Unsigned Manhattanchain code
UM-FERI	UM, Faculty of Electrical Engineering and Computer Science
URSZR	Administration of the Republic of Slovenia for Civil Protection and Disaster Relief
US, U.S.	The United States of America
VCC	Vertex chain code
VHCE	Virtual Heart of Central Europe
VR	Virtual reality
VRML	Virtual reality modelling language
VTŠ	Higher Technical School
WCS	Web Coverage Service
WFS	Web Feature Service
WFS-T	Web Feature Service Transactional
WMS	Web Map Service
WPS	Web Processing Service
WSCG	International Conference on Computer Graphics, Visualization and Computer Vision (previously Winter School of Computer Graphcs)
WWW	World Wide Web
ZIP	An archive file format developed by Phill Katz in 1989

MEMBERS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Borut Žalik
Matej Gomboši
David Podgorelec
Sebastian Krivograd
Gregor Klajnšek
Mirko Zadravec
Vid Domiter
Denis Špelič
Boštjan Pivec
Denis Obrul
Blaž Repnik
Bojan Rupnik
Bogdan Lipuš
Domen Mongus
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Marko Bizjak
David Jesenko
Damjan Roškar
Robi Cvirn
Žiga Leber
Amadej Pevec
Štefan Kohek
Simon Kolmanič
Andrej Nerat
Damjan Strnad

Borut Žalik Ph.D.

In GeMMA:
Since 2000

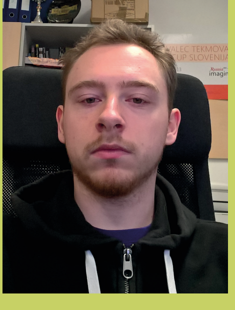
Borut Žalik finished primary school in Križevci pri Ljutomeru in the northeastern part of Slovenia. In 1976 he signed up for the Technical Electro, Mechanical, and Textile High School (TESTŠ). After military service, he entered the Higher Technical School (VTŠ) in 1981 and graduated in electrical engineering in 1985. The same year he was employed at the Technical Faculty Maribor as a technician and later as a teaching assistant. He obtained M.Sc. and Ph.D. in computer science from the University of Maribor in 1988 and 1993, respectively. In the same year he has been elected as an assistant professor of computer science. 5 year later he became associate professor. In 2003 he was elected as a full professor of computer science at the Faculty of Electrical Engineering and Computer Science, University of Maribor (UM-FERI). He spent half a year at Technical University Graz (Austria) as a research fellow in 1992. From 2000 to 2002 he has been the Visiting research Fellow at De Montort University in the United Kingdom. In 2000 he became the Head of the Laboratory for Geometric Modelling and Multimedia Algorithms (GeMMA). He was the Vice-Dean of Research at UM-FERI from 2003 to 2011. He has been a Dean of the faculty since 2011. He was a member of the management board of the Slovenian Research Agency in 2011 and 2012. In 2014 he became the member of the European Academy of Sciences and Arts. His main research interests include processing of geometric data and compression of multimedia information. He authored more than 70 papers in scientific journals with impact factor, 8 patents, and supervised 19 Ph.D. students. His hobby is radio-amateurism, where he operates under call-sign S58X.

Marko Bizjak

In GeMMA:
Since 2014

Marko Bizjak finished the primary school Braslovče in 2006. During those years he successfully participated in various national-level competitions which allowed him to be awarded with the Zois scholarship. Four years later he finished the Gymnasium Lava in Celje and enrolled in Computer Science and Information Technologies study programme at UM-FERI. He completed the programme in 2013 and continued his studies at the same programme on the master's degree level, which he completed two years later. During his studies, he actively collaborated in GeMMA doing research work, for which he received the Andrej Perlach's award, won a student paper competition (SPC) at ERK 2015 and was selected among five finalists of the IEEE Region 8 (Europe, Asia, Africa) SPC 2016. He started his first employment in December 2014 as a technical assistant at UM-FERI. The next year he began his Ph.D. in computer science and now works as a teaching assistant and researcher. His main research interests are remote sensing, energy optimisation and computational geometry while his hobbies include volleyball, table tennis and football.

Matej Brumen



In GeMMA:
Since 2013

Matej Brumen finished primary school called OŠ Benedikt in year 2006. After enrolling into the Secondary School of Electrical Engineering and Computer Science (SERŠ) in Maribor, he moved to his old home town Jurovski Dol. During the years spent at SERŠ he found the passion for coding. After finishing the secondary school in 2010, he decided to pursue a computer science career, so he enrolled atUM-FERI. Not knowing what he'd expect there, he quickly found the study interesting therefore finishing it became his main objective. During his 3rd year in December 2012 he was recruited by GeMMA and started his career there. Soon he graduated and obtained the title »dipl. inž. rač. in inf. tehnol.« in 2013 and enrolled M.Sc. of computer science course on the same faculty. His main interest is contributing code and ideas on the projects, while his hobbies consists of playing the guitar and coding stuff.

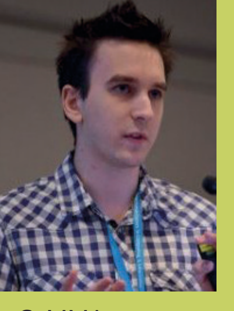
Robi Cvirn

Robi Cvirn finished his primary schooling in Podčetrtek in 2005. Four years later, he finished the Secondary School of Chemistry, Electrical Engineering and Computer Engineering in Celje as a golden graduate in the programme Computer technician. He then entered UM-FERI and received his bachelor's degree in 2012. During his master's study he travelled to Norway for an 8-month internship at WesternGeco AS Schlumberger in Oslo. He started his first employment in May 2015 as a technical assistant at UM-FERI. After that he received his master's degree in September 2015 and became a Ph.D. student in computer science. During his studies at secondary school and university he was a recipient of the Zois scholarship for outstanding students. His main research interests are detection of geometric objects in remote sensing data, while his hobbies are football, running and Krav Maga.

In GeMMA:
Since 2015

Denis Horvat

Between the years 1996 and 2008, Denis Horvat attended primary school in Gornja Radgona and Technical Gymnasium in Maribor, respectively. In 2008, he was accepted to UM-FERI in order to study computer science. He obtained his B.Sc. in 2011 and M.Sc. in 2013. Since 2012 he is also employed in GeMMA, where he worked first as a technical assistant and later as a young researcher. He is currently a Ph.D. candidate. In 2014, he also became a teaching assistant where he teaches computational geometry. His areas of research include computational geometry and pattern recognition in remote sensing data.



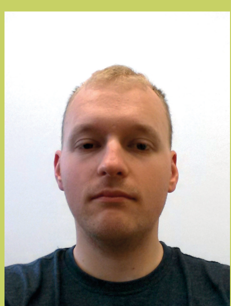
In GeMMA:
Since 2012

David Jesenko

In GeMMA:
Since 2014

David Jesenko finished his primary schooling in Šmarje pri Jelšah in 2005. Four years later, he finished the Secondary School of Chemistry, Electrical Engineering and Computer Engineering in Celje. In autumn 2009, he entered UM-FERI. He obtained bachelor's degree and master's degree in 2012 and 2014, respectively. He started his first employment in September 2014 as a young researcher at UM-FERI. During his studies at secondary school and university he was a recipient of the Zois scholarship for outstanding students. His main research interests are machine learning and complex networks, while his main hobby is football.

Štefan Kohek



In GeMMA:
Since 2016

Štefan Kohek finished the primary school in Ljutomer in 2003. In 2007 he graduated at SERŠ in Maribor as electrical-computer technician. He entered UM-FERI in the same year and in the years 2010 and 2012 obtained B.Sc. and M.Sc. in computer science, respectively. During the study he was occupied by a sole proprietorship as a programmer. In the year 2012 he became a technical assistant in the CGAI lab at UM-FERI and from 2013 onward he is employed as a teaching assistant. By joining the former laboratory to GeMMA in the year 2016, he has also joined the new laboratory. His current research interests include computer graphics, tree growth simulation, optimization techniques, and parallel computing.

Denis Kolednik

In GeMMA:
Since 2013

Denis Kolednik finished the primary school of Benedikt in 2004. Later he attended the Technical Gymnasium programme at SERŠ, which he finished in 2008. He started his study path at the UM-FERI in 2008. In 2011 he finished his bachelor's studies of Computer science and information technologies. In 2013 he finished his master's studies of the same study programme and got his first employment as a technical assistant in GeMMA in August 2013. At this point he also started his Ph.D. study from Computer science and informatics. Half a year later he started his research career as a researcher at GeMMA. In July 2014 he also became a teaching assistant. His current research topics include image processing, pattern analysis and change detection.

Simon Kolmanič Ph.D.

In GeMMA:
Since 2016

Simon Kolmanič was born on 12th of February in the year the first photograph of Mars was sent back to Earth. He visited the primary school Ormož between 1979 and 1987. He continued with his education on Secondary School of Natural Sciences and Mathematics Ptuj, which he finished in 1991. In the same year he entered UM-FERI. He finished this study in 1996 with B.Sc. degree. In the same year he joined the CGAI lab on the same institution as a technical assistant. In 1997 he started his M.Sc. study, which he finished in 1999. In the same year he also started working as a teaching assistant. In year 2000 he started his Ph.D. study which he finished in 2005. Between 2006 and 2011 he was a member of Electronic Communication Council of the Republic of Slovenia. In 2016 the CGAI lab joined GeMMA where he continues with his work.

He is active as volunteer firefighter and was the president of the Voluntary Fire Department Ormož between 2003 and 2011. In his spare time he is also an amateur player with some quite successful performances behind him. He also practices Aikido and still enjoys a good book when he finds one.

Žiga Leber

In GeMMA:
Since 2015

Žiga Leber finished primary school in Ruše in 2008. In the following years he attended the Anton Martin Slomšek Diocesan Gymnasium (Škofijska gimnazija Antona Martina Slomška) in Maribor. He graduated in 2012 with excellence. Subsequently he enrolled in UM-FERI and earned his bachelor's degree in computer science in 2015. Currently he is pursuing a master's degree in the same field. Since 2015, he has been employed as a technical assistant in GeMMA. His research interests include remote sensing and environmental simulations.

Bogdan Lipuš Ph.D.

In GeMMA:
Since 2008

Bogdan Lipuš completed the primary school in Oplotnica in 1990. In 1994 he successfully finished SERŠ in Maribor. After that, he entered UM-FERI and graduated in computer science in May 2000. In his student days in December 1999, he started to work as a technical assistant in the CGAI lab. In 2000 he got a position of a young researcher and entered the M.Sc. programme. After obtaining M.Sc. in computer science in 2003, he continued his study and received his Ph.D. in computer science in 2005. Two and a half years he worked as a software developer in Hermes Softlab. Returning from industry, he started to work in GeMMA. He participated in several applicative and scientific research projects. In 2015, he was elected as an assistant professor of computer science. His research interests include computer graphics, processing of geometric data, data compression and image processing. His hobbies include running and cycling.

Niko Lukač Ph.D.

In GeMMA:
Since 2011

In 2003 and 2007, Niko Lukač completed elementary school in Lenart and Technical Gymnasium in Maribor, respectively. In 2007 he enrolled at UM-FERI in order to study computer science. He completed B.Sc. and M.Sc. degrees at the given faculty in 2010 and 2012, respectively. His first employment begun in 2011 as a technical assistant in GeMMA. In 2012 he started his Ph.D. in computer science, while also being employed as a young researcher in GeMMA. He successfully defended his Ph.D. thesis in May 2016. He was also a guest researcher at DLR (German Aerospace Center) near Munich in October 2014, and at University of Heidelberg, Germany in March 2016. He has collaborated in several bilateral, industrial, and research projects, as well as provided teaching assistance for undergraduate computer science courses. Moreover, he is one of the founders of the first ACM (Association for Computing Machinery) student chapter in Slovenia, namely ACM Maribor, where he has also served as a vice chair in 2015. His main research is focused on simulations and modelling using remote sensing data, general-purpose computing on graphics processing units, and renewable energy resource assessment. His main hobby is amateur astronomy.

Domen Mongus Ph.D.

In GeMMA:
Since 2008

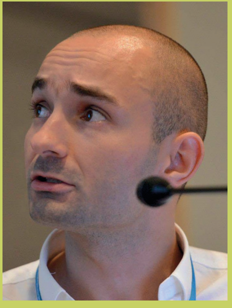
Domen Mongus was born in Slovenj Gradec in 1982. He spent his youth in a small village behind the Carinthian Mountains, by the name of Podgorje. After the elementary and secondary schools he left for Maribor to study computer science at UM-FERI. In 2007 he started to work in GeMMA. He defended his diploma thesis in 2008 and started working as a Young Researcher, funded by the Slovenian Research Agency. He concentrated his work on the fields of geometric pattern recognition, Earth observation data, and geographic information systems. In 2012 he completed his Ph.D. and became an assistant professor at UM-FERI. In the same year, he received an award for research excellence at UM-FERI. In 2013, he receive an award for pedagogic excellence at UM-FERI, while the Slovenian Research Agency awarded him for Exceptional Achievement in Science in 2014. In 2015, Slovenian National Radio and Television, Val 202, named him as "The Name of the Week". In the same year, he received the highest award in the field of Information Society in Slovenia for ongoing work. He was also named as Young Scientist of Danube region by Danube Region and Central Europe and Austrian Federal Ministry for Science, Research and Economy. From 2008 to 2012, Domen Mongus was a member of the Executive Committee of ACM Slovenia. From 2013 to present, he is a member of the Executive Committee of European Umbrella Organization for Geographic Information (EUROGI).

Andrej Nerat

In GeMMA:
Since 2016

Andrej Nerat was born on 6th October 1980 in Maribor. Since early childhood he developed interest in computers, first an old ZX Spectrum, later PCs. After he finished primary school in Ceršak and later Šentilj v Slovenskih goricah in 1995, he continued his education at SERŠ in Maribor. In 1999 he first entered UM-FERI, where he has been since then. He spent the first five years there as an undergraduate student in computer science. After graduation in 2004 he joined the CGAI lab. He has worked there as a technical assistant. In 2016 he joined GeMMA to continue working at the same position.

Sašo Pečnik



In GeMMA:
Since 2008

Sašo Pečnik was born in Maribor in 1985. He spent his childhood in a small village named Miklavž near Maribor where he finished the local primary school in 2000. Four years later he finished SERŠ in Maribor as a Computer Technician. In the same year, he entered UM-FERI. In year 2007, he graduated in Computer Science (professional study program Computer and Information Science) as the best of his class. He continued studying and two years later he received his Honors Bachelor of Computer Science (Academic study program Computer Science and Informatics). While studying in 2008, he was noticed by his professor and mentor Borut Žalik who gave him his first employment in GeMMA. He entered a Ph.D. study program of Computer Science and was promoted to researcher position in 2010. In 2014, he became a teaching assistant at UM-FERI. Between 2014 and 2015, he worked as part-time researcher at the Civil Engineering Company Lineal d.o.o. in Maribor. Along with the Lineal team, he was awarded at CITA Smart Collaboration Challenge 2014 in Dublin with the 1st place for the project RO3D-SMART. His main research interests are processing and visualization of LiDAR data in Civil Engineering along with computer geometry, computer graphics, CAD and cloud computing, while his hobbies are running, football and travelling.

Amadej Pevec

Amadej Pevec finished the primary school in Rogaška Slatina in 2006. Four years later, he finished the Secondary School of Gymnasium Rogaška Slatina. He then entered UM-FERI and received his bachelor's degree in 2013. He started his first employment in February 2015 as a technical assistant at UM-FERI. During his studies at secondary school and university he was a recipient of the Zois Scholarship for gifted students. His main research interests are GIS, while his hobbies are running and playing computer games.

In GeMMA:
Since 2015

David Podgorelec Ph.D.

David Podgorelec finished the primary school Maks Durjava in Maribor in 1982. Four years later, he finished the Secondary School of Natural Sciences and Mathematics Miloš Zidanšek (the present-day Second Gymnasium Maribor). After military service, he entered the Technical Faculty (TF) of the University of Maribor (UM) in 1987 and graduated in computer science in 1993. Already in his student days, he started to work as a programmer in MIPS d.o.o. in Maribor, where he also found his first employment from January 1994 to February 1995. In autumn 1995, he entered the M.Sc. studying programme of computer science and got a position of young researcher at UM-FERI, former department of TF. He became a teaching assistant at UM-FERI in the beginning of 1996. He obtained M.Sc. and Ph.D. in computer science from UM in 2000 and 2002, respectively. In 2005, he has been elected as an assistant professor of computer science. In subsequent 10 years, he taught 15 courses (6-8 each year) at different-level studying courses of computer science, media communication, educational computer science and bioinformatics at 3 different faculties of UM. During 2004-2005, he spent 7 months at the University of Luton (current University of Bedfordshire) in the United Kingdom as a research fellow. Between 2008 and 2012, he also operated as a president of the Slovene National Committee for the Matura Examinations of Computer Science. Between April 2012 and February 2015, he was a head of the Media Communication Institute at UM-FERI. In October 2015, he completed his assistant professor career, but he returned to GeMMA in March 2016 as a researcher. His main research interests are spatial data processing and multimedia data compression algorithms, while his hobbies include mountain climbing, cycling and football.

In GeMMA:
From 2000 to October 2015 and since March 2016

Blaž Repnik

In GeMMA:
Since 2006

Blaž Repnik finished the primary school Črešnjevec in 1998. Four years later he finished SERŠ in Maribor. In 2002 he entered UM-FERI where he got the bachelor degree in 2007. He started working in GeMMA in 2006 as a technical assistant. He entered the Ph.D. study programme of Computer Science and was promoted to researcher position in 2013. His main research interests are GIS, dynamic systems and 3D graphics.

Damjan Strnad Ph.D.

In GeMMA:
Since 2016

Damjan Strnad graduated from computer science and informatics at UM-FERI in 1998. He upgraded his education through the M.Sc. in 2000 and Ph.D. in computer science and informatics in 2006. For his study excellence he received the university chancellor's award. In 1997 he was employed as a technical assistant in the CGAI lab. He continued working in CGAI as an assistant during 1998-2007. Since becoming the assistant professor in 2007 and the associate professor in 2012, he is giving lectures in the field of computer science, particularly computer graphics and artificial intelligence. The latter is also his main research interest. He has been working as a supervisor for several diploma candidates and is currently mentoring a Ph.D. candidate. He joined GeMMA at the start of 2016.

Denis Špelič Ph.D.

In GeMMA:
Since 2004

Denis Špelič was born on 9th of July 1980 in Maribor. During his childhood, he visited primary schools in Slovenska Bistrica, Slovenske Konjice and finished primary education in Maribor in the year of 1994. During primary school years, he started competing in computer science and achieved third place in Slovenian national competition in 1989. In 1999 he finished SERŠ in Maribor. During secondary school, he achieved third place in Slovenian national competition in programming and earned two awards for a young researcher for developing computer game ARES, assembler and disassembler for Intel microprocessor and development of a micro operating system for PC. He entered UM-FERI and received the bachelor degree in 2006. The same year he and his team compete in ImagineCup competition and won Slovenian then Central and Eastern Europe finals and achieved the seventh place at world finals in India. After the bachelor degree, he got a position of a young researcher at FERI and obtained his Ph.D. in computer science in 2011. His work career started in 2004 when he joined GeMMA. He was the leader of several industrial R&D projects while his research interests are data compression, signal and image processing, parallel processing, scientific visualization, and GIS. He is a promoter of ImagineCup competition on FERI and has been a mentor of teams that achieved two second places in Slovenia finals and a team that won Slovenian finals and was placed fourth in world finals in St. Petersburg. Since 2010, he is a member of ACM competition for development of web application for high schools in Slovenia. His hobbies include football, golf, books and movies.

Denis Žganec

In GeMMA:
Since 2008

Denis Žganec finished his primary school in Štrigova. From 1999 to 2003 he attended the secondary school of Technical School in Čakovec, where he graduated as a computer technician. In 2005, he was accepted to UM-FERI in order to study computer science. He obtained bachelor's degree in 2012, and he is currently finishing his master's. From 2008 he is also employed in GeMMA, where he works as a technical associate. His work is mainly concentrated on development of GIS.

Danijel Žlaus

In GeMMA:
Since 2011

He joined the 5 billion strong human population on the 26th of November 1988. After surviving his early childhood he went on to tackle his education. He finished elementary education in 2003, attending schools in Nova Cerkev and later on Vojnik, where he developed an interest in computers and programming. For high school he attended Šolski Center Celje, which he finished with the title Computer Engineer in 2007. He was active during high school and attended various competitions in computer programming and mathematics. For achieving the 1st place in national mathematical competition, he was awarded the generous Zois scholarship. He continued his pursuit of computer science at University of Maribor, where he finished his bachelor degree in 2011, after which he joined GeMMA as a technical assistant. Hobbies include, but are not limited to, drinking tea, bicycling, tinkering with electronics and occasionally gardening.

Roman Čuk

Roman finished the primary school in Črni Vrh and the Computer engineering secondary school in Nova Gorica. In 1995 he entered UM-FERI and graduated in 1998 on lower degree and in 2004 on higher degree. From 2002 to 2008 he was working as a chief technology officer in Hidria d.d and in spare time attended post graduate lessons. From 2009 to 2012 he was a teaching professor at the Technical centre in Nova Gorica. In 2013 he joined GeMMA and worked on advanced Delaunay triangulation algorithms. From 2015 onward he works at Arnes on various national wide projects. In free time his main interests are dedicated to parallel algorithms and high-performance computing.

In GeMMA:
2013

Vid Domiter Ph.D.

Vid Domiter was born on 02/02/1979 in Ptuj. After finishing elementary school in Rače in 1994, he attended Prva gimnazija Maribor. Vid started programming early in the elementary school. In highschool he joined the project "Young researchers for Maribor", where he built his first arcade game. After the highschool he went to study computer science at UM-FERI. During his study he anticipated in the program Socrates-Erasmus by spending 6 months at the Unversity of Paderborn, Germany. In the last year of his study, Vid became a junior member of GeMMA laboratory, where he started to explore computational geometry, especially triangulations.

In GeMMA:
From 2004 to 2011

He graduated with a diploma work entitled Ultrasound medical imaging in 2004. Afterwards he applied for the young researcher scholarship and became a fully-employed GeMMA member and a Ph.D. student. During that time he dug himself deeper in solving geometrical problems and also started teaching as an assistant in the Media Communications study programme, where he became involved with 2D and 3D computer graphics, geometric modelling and animation.He presented his Ph.D. work entitled Triangulation algorithms using sweeping paradigm in 2009 and became a teaching assistant for many subjects.

He left the faculty in 2011 and started working as a freelancer, researching and developing web applications. After a two year-period he was employed at LECIP-ITS, an IT development company for a major Japanese traffic group, where he expanded his knowledge in web applications. He left the company in 2014 and joined a team of young enthusiasts at GameART, a casino gaming startup, and has been involved with slot video games development.

Matej Gomboši Ph.D.

In GeMMA:
From 2000 to 2006;
Part-time from
2006 to 2014

Matej Gomboši graduated UM-FERI in 1999. After military service, he finished his M.Sc. in 2002 and his Ph.D. in Computer Science in 2005 at the same faculty in Maribor. His main research areas were smart algorithms in computational geometry and GIS.

Already in his student time in 1998 he started his career at the faculty. He worked as an assistant and researcher up to 2006 and after that as a part-time researcher until 2014. From 2005 to 2013 he was also a part-time lecturer at the Higher Professional School for Informatics in Murska Sobota. In 2007 he moved to business sector becoming IT analyst and later deputy director for IT at Elektro-Slovenija. In 2010 he took on another challenge after being elected as mayor of Municipality Beltinci. From 2013 to 2014 he was also the president of the Pomurje Region. In 2012 he was elected as a member of Congress of Local and Regional Authorities in the Council of Europe in Strasbourg. After taking part in many international cooperation projects and election observation missions, the Council of Europe selected him as an international expert for cooperation activities. Besides cooperation, he is currently also involved in international election observation activities for organisations like EU and the Council of Europe, while still continuing to be active in IT management.

Gregor Klajnšek Ph.D.

Gregor Klajnšek finished primary school Prežihov Voranc Maribor in 1991. Four years later he finished the First Gymnasium in Maribor and enrolled into UM-FERI. In 2001 he successfully graduated with a degree in computer science and he started with his Ph.D. study. During his undergraduate studies he already started to collaborate with GeMMA, and he got his first employment as a young researcher in this laboratory. He obtained a Ph.D. in computer science from UM-FERI in 2005. He continued to work at UM-FERI until September 2008 as part time teaching assistant and part time researcher. In October 2008 he joined University of Bedfordshire, Luton, UK, as a research fellow, where he stayed until March 2009. In July 2009 he returned to UM-FERI for another stint as a researcher. In 2010 he was elected as an assistant professor of computer Science, but in the same year he decided to end his full time employment at UM-FERI and finally focus on his passion for development of video games. Nevertheless he continued the cooperation with UM-FERI teaching one course per year as external collaborator until September 2014. From May 2011 till July 2014 he worked at a company Sproing Interactive Media Gmbh located in Vienna, Austria, at first as a programmer and later as a senior programmer. During this time he worked on three commercial video games developed for various platforms and also held a position of lead gameplay programmer for one of these games. Since July 2014 he works as a senior programmer for company GTECH Austria Gmbh, Graz, Austria, and since January 2015 he is additionally helping a small Slovenian start-up company called Interak d.o.o. as external consultant. His research interests include compression algorithms and visualization, but his biggest passion still remains development of and research related to video games. His hobbies include playing basketball, hiking and reading about history of computer science.

In GeMMA:
From 2001 to
September 2008;
From July 2009
to 2010

Sebastian Krivograd Ph.D.

In GeMMA:
From 2000 to 2009

Sebastian Krivograd finished the primary school Prežihov Voranc in Ravne na Koroškem in 1990. Four years later, he finished the secondary school in Gymnasium Ravne and then entered UM-FERI. He graduated in computer science in 1999 and continued with his studies as Ph.D. student on same faculty. During his Ph.D. studies he spent 6 months at the University in Paderborn in Germany. When he returned he got a position of young researcher at UM-FERI (November 2001). In October 2003 he obtained Ph.D. in computer science and after that became an assistant on UM-FERI. In 2004 he was elected as an assistant professor of computer science and continued his employment as senior researcher in UM-FERI till 2006. In 2006 he again got employment as assistant till 2009 when he finished his career in research. In October 2009 he became Head of the Department of Informatics and Telecommunications on Police Directorate Slovenj Gradec. From 2011 he is Head of the Department of Informatics and Telecommunications on Police Directorate Celje. In 2010 he also opened a company NuFiRa, where he tries to use his knowledge in some projects. His hobbies are diving and archery.

Renato Mikša

In GeMMA:
From 2009 to 2010

Renato Mikša was born in Velenje in 1985 where he spent his childhood and finished the local primary school in 2000. Four years later, in 2004 he finished the Middle school for electrical and computer engineering in Velenje (PTERŠ Velenje). Same year he enrolled at UM-FERI where he graduated in 2008 (professional study programme Computer and Information Science). He continued with his studies at UM-FERI and graduated in 2010 as Bachelor of Computer Science (academic study programme Computer Science and Informatics). He started working in GeMMA while still studying in 2009 and left the faculty at the end of December 2010. He is now working at the national health insurance institut of Slovenia in a R&D department.

Denis Obrul

Denis Obrul finished primary school in Ljubljana in 1999. He attended the Secondary School for Computers and Electrotechnics Vegova in Ljubljana, which he completed in 2004. Then he enrolled at UM-FERI. In 2007, he finished his higher education computer science studies, followed by Bs.C. in Computer Science and Informatics in 2010 and is currently completing his Ph.D studies. He began working in GeMMA at the end of 2006, first as a technical assistant, then as a teaching assistant and finally as a researcher until 2015. His research topics included medical imaging (DICOM) compression, public traffic predictions and GPS data compression. He also worked on a number of research and commercial projects. In 2014 he started the UM-FERI board games club. His hobbies include aviation, photography and pizza.

In GeMMA:
From 2006 to 2015

Boštjan Pivec

Boštjan Pivec graduated in Computer Science at UM-FERI in 2006. Since 2004 he was employed at the same faculty as a memeber of GeMMA. At first he started as a technical assistant and later he became a teaching assistant. During this time he taught 7 courses of computer science at UM-FERI and a course of bioinformatics algorithms at UM, Faculty Of Health Sciences. In the first quarter of the year 2015, he finished his career at UM and started working for the company GameART as a programmer and web developer.

In GeMMA:
From 2004 to 2015

Damjan Roškar

In GeMMA:
From 2014 to 2015

Damjan Roškar, born on the 24th of November 1991, finished his primary school education in the year 2006 in Gornja Radgona. In 2011 he finished his education at a Gymnasium in Maribor and in the same year applied as a student at UM-FERI. He graduated in computer science in 2015. His interests in programming started to develop in primary school where he attended a programming course for children and entered several competitions in the scope of it. In high school he started developing simple games and applications. A year before finishing his diploma at UM-FERI, he was employed in GeMMA as a technical assistant. In 2016 he became a system analyst at Infonova in Graz, Austria.

Bojan Rupnik

In GeMMA:
From 2006 to 2013

Bojan Rupnik finished the primary school Prežihov Voranc in Maribor. From 1994 to 1998 he attended SERŠ in Maribor where he graduated as a computer technician. In 1998 he enrolled at UM-FERI where he graduated in 2006. In the same year he was employed at UM-FERI where he worked in GeMMA as a technical assistant, and later as a researcher and teaching assistant. In 2013 he became a teaching assistant at the Faculty of Logistics of University of Maribor in Celje.

Mirko Zadravec Ph.D.

In GeMMA:
From 2001 to 2008

Mirko Zadravec finished the primary school in Stročja vas in 1990 and SERŠ in Maribor in 1994. The same year, he entered UM-FERI and graduated in computer science and informatics in 2001. He obtained Ph.D. in Computer Science at the same faculty in 2006.

As a student, he was included in the research work at UM-FERI since 1998. In 2001, he got an employment as a researcher in GeMMA. He has mostly developed computational geometry algorithms, especially those for the nearest point problem and Delaunay triangulation. His research interests also included geometric modelling, CAD, GIS, web and multimedia applications. He presented his work An almost distribution independent incremental Delaunay triangulation algorithm at the university University of Vaasa, Finland, during a bilateral project in 2004. They were impressed and invited him to spend two months there in 2005. The results of the cooperation were published in the Pattern Recognition journal and also included in his doctor thesis.

From 2008 to 2010, he worked at TU Graz in Austria as a researcher within the project Computing Multilayer Freeform Surfaces. The project has been funded by the Österreichische Forschungsförderungsgesellschaft (FFG) on the occasion of a Visual Computing call, and was conducted in cooperation with TU Wien and Waagner-Biro. The results were published in the Computer Graphics Forum journal.

He has worked at Bentley Systems GmbH in Graz since 1st April 2010. Bentley Systems has software developers in more than 50 countries and is a global leader dedicated to providing architects, engineers, geospatial professionals, constructors, and owner-operators with comprehensive software solutions for sustaining infrastructure. Mirko is a senior software engineer working on RM Bridge, the leading bridge design, analysis, and construction software for the largest bridges. Mirko is responsible for advanced computational geometry algorithms, graphics and user interface, and is additionally leading a team of developers for a new MicroStation-based results presentation application named RM Bridge View.

ACTIVITIES

- Remote Sensing
- Computational Geometry
- Geometric Modelling and Visualization
- Geographic Information Systems
- Data Compression
- Medicine
- Miscellaneous

Remote Sensing

Processing of Massive Geometric LiDAR Data

Financed by: ARRS (L2-3650); DAT-CON d.o.o; IGEA d.o.o; X-Lab d.o.o; Geoin d.o.o

Duration: 1 May 2010 to 1 May 2013

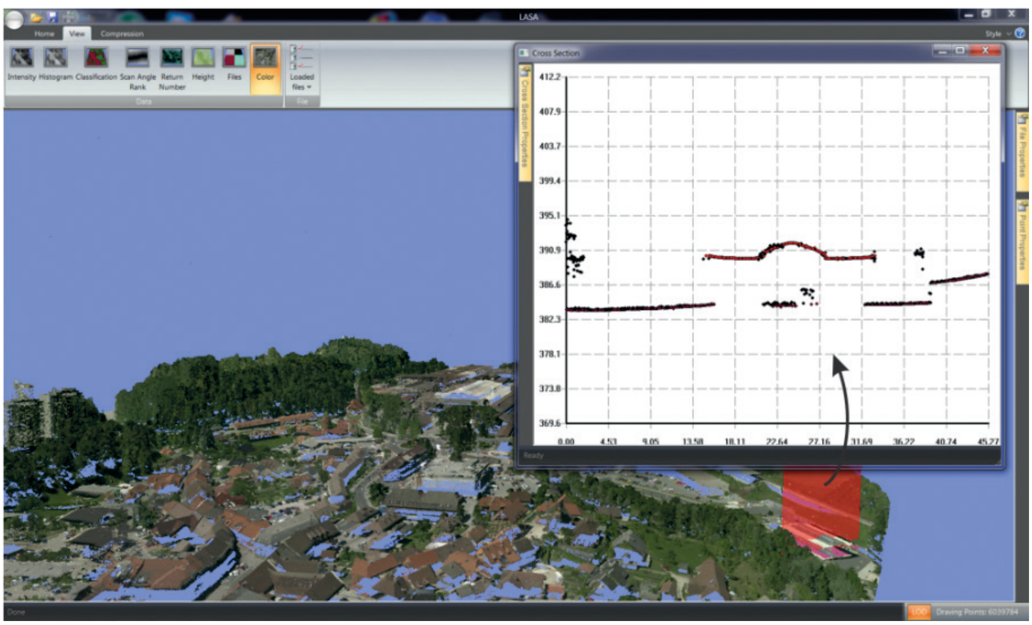
Partners: Jožef Stefan Institute; Primorska Institute of Science and Technology; IGEA, d.o.o; X-Lab d.o.o

The overall goal of the project was to develop advanced methods for processing large datasets acquired by remote sensing tevhnology of **light detection and ranging (LiDAR).** With sampling above 200,000 Hz, airborne LiDAR scanners acquire huge unstructured 3D point-clouds with several tens of points per m^2 of Earth surface. Our research was focused on three closely related objectives.

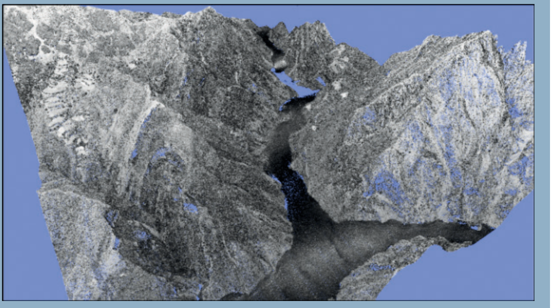
Compression: LiDAR data are commonly stored in the LAS format reaching up to 0.5 TB per km^2. Such storage is expensive; data is hardly deliverable; distribution over the internet is slow or even impracticable.

- Our original lossless compression of LAS files reaches on average 12 % of the original size. It integrates predictive, variable-length and arithmetic coding. It used to be the most efficient known algorithm for LAS files compression, and is about to obtain the US patent in 2016.
- We have also presented a progressive lossless compression and a nearly-lossless hierarchical approach both supporting web-based progressive LiDAR data visualization.

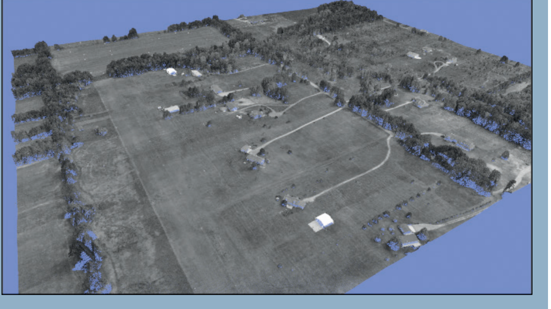
LiDAR LiVE Visualization interactive tool allows real time rendering of large LiDAR



LiDAR LiVE Visualization tool – perspective view and supplementary cross section view.



Mountains and valleys covered with low vegetation are hardly compressible. Anyway, we are four times more efficient than commonly used algorithms. We compress 929,688 kB to 128,053 kB at compression ratio 13.8 %.



Vegetation, buildings, rivers and lakes on flat terrain can be highly efficiently compressed. 531,200 kB (over 30 million points) are compressed to 49,053 kB at ratio 9.2 %.

Vegetation, buildings, rivers and lakes on flat terrain can be highly efficiently compressed. 531,200 kB (over 30 million points) are compressed to 49,053 kB at ratio 9.2 %.

datasets by an efficient out-of-core level-of-details control.

- It utilizes hybridization of point-based and triangle-based rendering.
- High resolution data can be viewed even on average computer systems.
- Supporting tools (e.g. cross section) allow close examination of details.

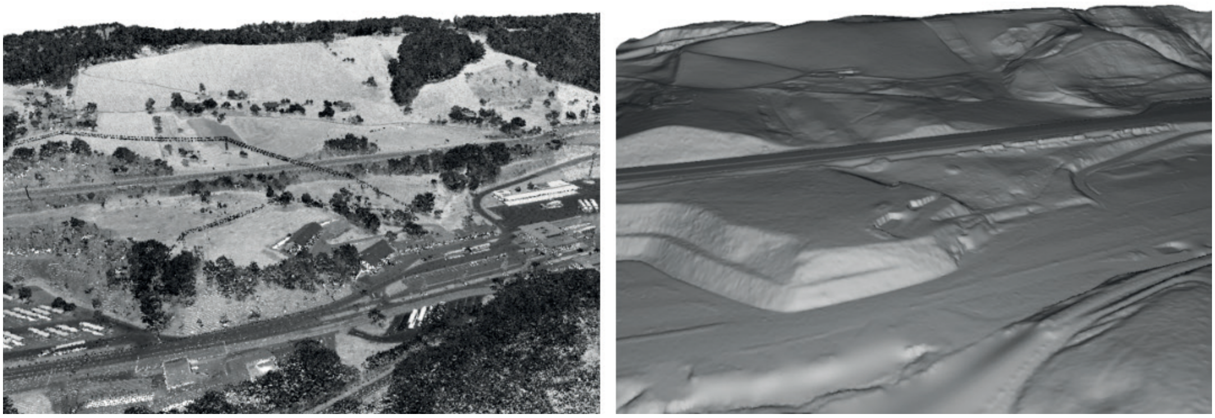
LiDAR data classification means determination of the appropriate class (for example, terrain, building, low, medium or high vegetation) for each individual point. It was the greatest challenge of this project, leading to remarkable breakthroughs by skillfully using the methods of mathematical morphology.

- Among the main advantages of LiDAR is its capability to penetrate even through dense vegetation and gather some points from the terrain beneath it. Thus, a key step in every classification process is the classification of ground points.
- We have developed the first algorithm for ground point filtering and digital terrain model (DTM) world-wide that offers accurate results without any user intervention. It successfully solves even such difficult cases as bridges or hillside structures.
- We have, furthermore, improved the performance of the method by using connected operators, and extended it for successful building recognition, reaching top scores on ISPRS (International Society for Photogrammetry and Remote Sensing) comparison tests. The expected accuracy of ground point determination on those datasets commonly used in practice today is over 96%, while the average total error produced on the ISPRS benchmark dataset is under 6%.

Applications:

- LAS data compression found practical use at the Surveying and Mapping Authority of the Republic of Slovenia where over 40 TB of LAS files have been efficiently compressed.

- The developed software for DTM generation has been used by the Geodetic Institute of Slovenia, leading the Slovenian national project of LiDAR data acquisition.
- The terrain filtering and DTM generation were also applied by the Slovenia Forest Service for planning skid trails at annual tree cuttings in the Karavanke Mountains.
- The classified LiDAR data have been used in a practical GIS application for estimation and display of solar potential for buildings' rooftops in the Municipality of Beltinci.



Visualized LiDAR dataset (left) and the corresponding DTM (right) [3].

Additional reading and resources:

[1] Mongus, D., B. Žalik. A method and apparatus for LiDAR data compression and decompression: U. S. Patent and trademark office, U. S. Department of commerce, Appl. no.: 61410522, EFS ID: 8778528, confirmation number: 7349, 2010, 37 pages.

[2] Mongus, D., B. Žalik. Efficient method for lossless LIDAR data compression. International journal of remote sensing 32 (2011) 2507-2518.

[3] Mongus, D., B. Žalik. Parameter-free ground filtering of LiDAR data for automatic DTM generation. ISPRS journal of photogrammetry and remote sensing 67 (2012) 1-12.

[4] Mongus, D., M. Triglav, B. Žalik. Analiza samodejne metode za generiranje digitalnih modelov reliefa iz podatkov lidar na območju Slovenije (The analysis of an automatic method for digital terrain model generation from lidar data on Slovenian test cases). Geodetski vestnik 57 (2013) 245-258.

[5] Mongus, D., B. Žalik. Computationally efficient method for the generation of a digital terrain model from airborne LiDAR data using connected operators. IEEE journal of selected topics in applied earth observations and remote sensing 7 (2014) 340-351.

[6] Lipuš, B., B. Žalik. Lossy LAS file compression using uniform space division. Electronics letters 48 (2012) 1278-1279.

[7] Mongus, D. Brezparametrični algoritem gradnje digitalnega modela reliefa iz podatkov LiDAR (Parameter-free algorithm for digital terrain model generation from LiDAR data): Ph.D. thesis, UM-FERI, Maribor, 2012, 90 pages.

[8] Mongus, D., B. Žalik. Postopek stiskanja podatkov, pridobljenih s tehnologijo prostorskega laserskega prebiranja (An algorithm for compression of data captured by the spatial laser scanning technology): patent application, Appl. no.: P-200900105, Urad RS za intelektualno lastnino (The Slovenian Intellectual Property Office), Ljubljana, 2009, 11 pages.

[9] http://solarenergo.beltinci.si/

Morphological Operators for Pattern Recognition in Large Point Clouds

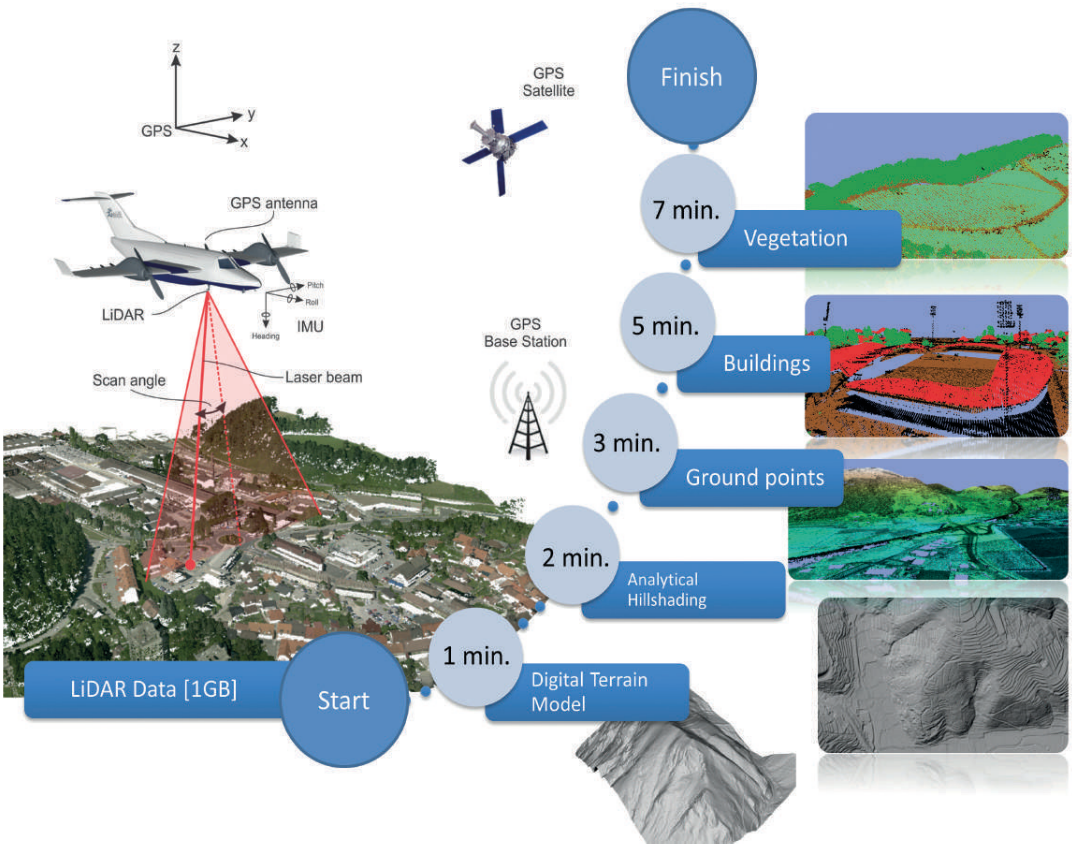
Financed by: ARRS (contract J2-5479)

Duration: 1 August 2013 to 31 July 2016

Partner: Geodetic Institute of Slovenia

This ongoing research project advances on results of our previous LiDAR-related project (*Processing of massive geometric LiDAR data*). This time we face the challenge of building a new methodology for recognizing 3D geometric patterns in vast unstructured clouds of irregularly distributed points, monitoring their dynamics, and detecting events within large point clouds by applying contemporary findings of **mathematical morphology**. The results include official digital terrain model (DTM) of Slovenia, 3D geometrically characterized objects and vegetation as well as point cloud of ground points and analytic shading of the whole country.

We have integrated the proposed methodology into a complete software tool **gLiDAR**. It provides the essential steps in preparation of content for geographic information systems and geospatial analysis of large geographical

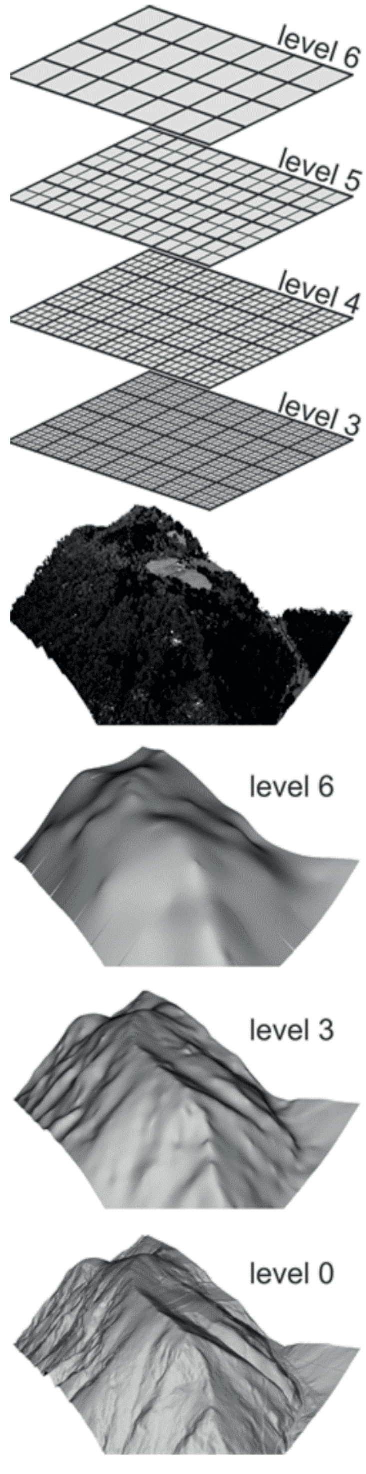


A complete pipeline processing in gLiDAR requires less than 7 minutes per 1 GB data on a regular PC.

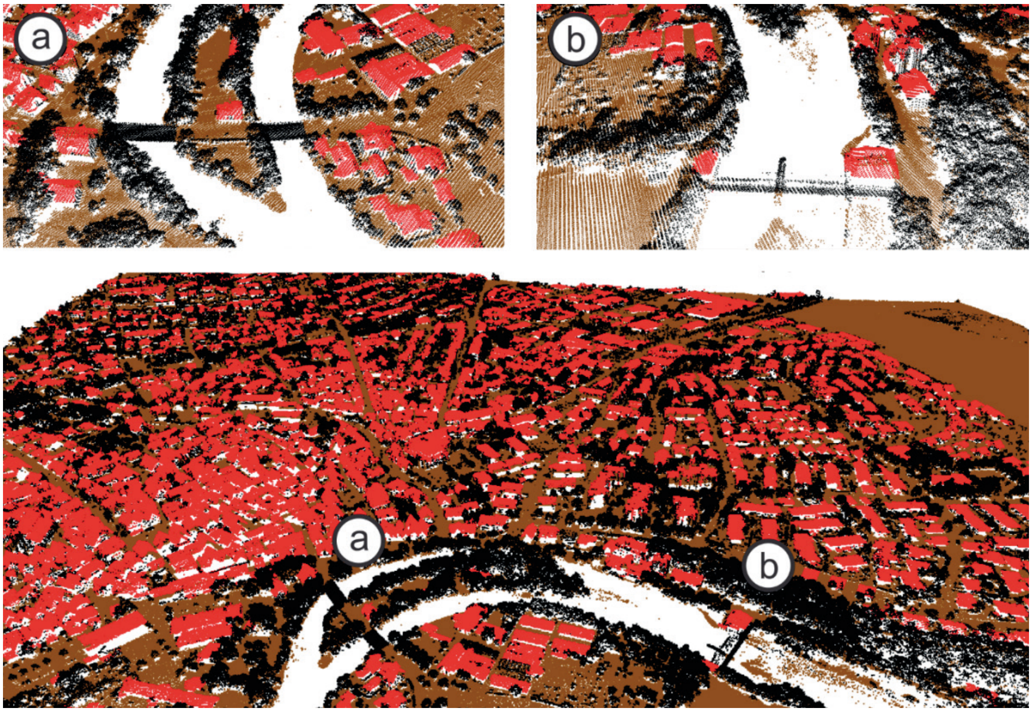
areas with extremely high accuracy. The developed modules are highly computationally efficient due to their parallel implementation, user-friendly and only exceptionally do they require additional user interaction. Thus, a complete pipeline, from raw LiDAR data to the final products, requires less than 7 minutes (for 1 GB) on a regular PC. Based on these merits, gLiDAR was recently awarded by the Information Society (IS) Award for Ongoing Work, while its methodology for ground and buildings extraction is currently recognized as the most accurate one according to the ISPRS evaluation. Its advantages are particularly evident in difficult circumstances when the geometries of buildings are obstructed by vegetation or noisy points within them (e.g. because of glass roofs).

DTM construction, ground and building extraction joined within a common framework represent conceptual extension of the approach from the aforementioned predecessor of this project. Streamlined structure of the algorithm is as follows.

1. Firstly, a grid over the LiDAR point cloud is constructed to establish connectivity between points in order to perform multi-scale data decomposition.
2. Rough approximation of the ground surface is then derived, containing only those points representing low frequency terrain undulations.
3. Multi-scale data decomposition using differential morphological profiles (DMPs) is then performed to complete **ground extraction**. Although the ground points are assumed to lie below other features, a threshold function should additionally consider the sizes of these features. Namely, mild responses may be enough to recognise small features as non-ground while larger threshold values should be applied when considering larger features. The **DTM construction** is finalized by interpolating the non-ground points.
4. Estimated geometrical properties of non-ground points are further considered for **building detection** where supplementary surface analysis is achieved by a new algorithm for the estimation of locally fitted surfaces (LoFS).
5. Finally, regional analysis is performed by inspecting the transitions between ground and non-ground regions in order to incorporate contextual information that allows for distinguishing between objects sharing similar geometrical and surface properties, e.g. buildings and bridges.



Effect of multi-scale data decomposition on DTM construction.



3D visualization of extracted buildings (red) and ground points (brown) [1].

Analytical hillshading and 3D visualizations enable a user to preview the results of the intended operation (building or vegetation extraction) considering the given settings. The objects to be extracted by the selected module are emphasized by colour. If filter settings are modified during the preview, the latter is automatically updated, providing a user the ability to tune the filter settings in order to increase the results accuracy. Although the automatic detection of objects is mostly successful, a user also gets a possibility to manually modify the regions to be extracted.

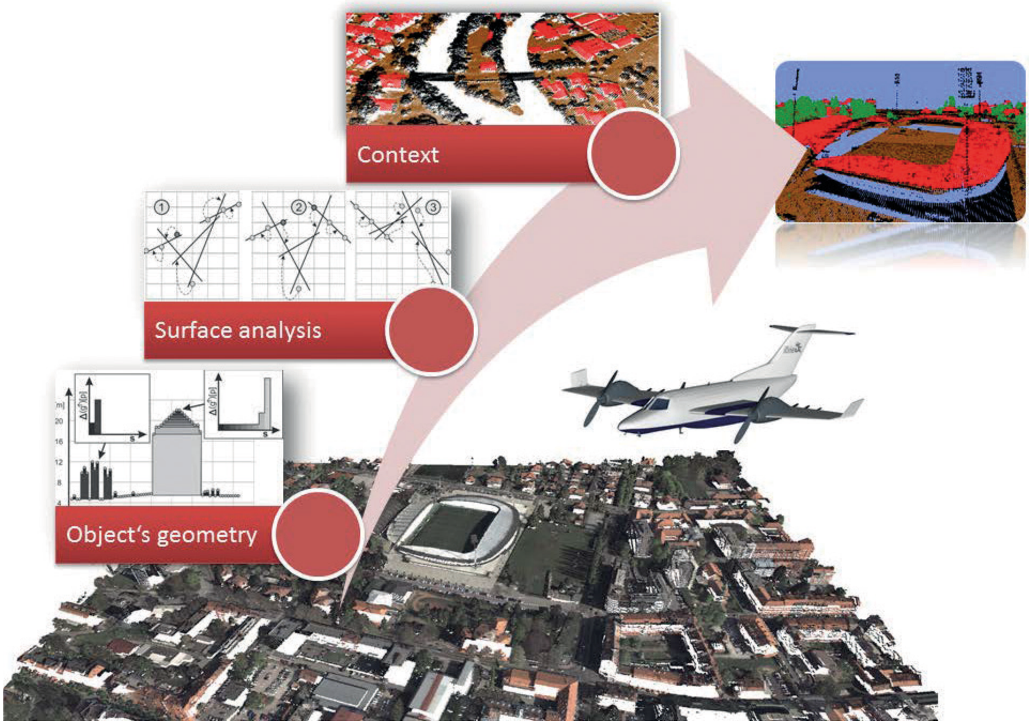
Detection and classification of vegetation is also based on LoFS. If a non-ground point is not mapped to some building, then gLiDAR maps it either to vegetation or to an unknown object (if geometric characteristics of the extracted point set do not fit the criteria for vegetation). The vegetation class is further partitioned into low, middle and high vegetation. The points are clustered for this purpose and the corresponding subclass is attached to each cluster as a whole, with respect to its height. In addition, we have introduced three contextual filters capable of dealing with those exceptions that do not conform with previous interpretations. Namely, they are designed for detecting overgrowing vegetation, small objects attached to the planar surfaces (such as balconies, chimneys, and noise within the buildings) and small objects that do not belong to vegetation (vehicles, statues, fences). A logical next step in processing of vegetation points is recognition of single trees within the detected vegetation regions (see the project *Algorithms of ecosystems dynamics modelling with methods of mathematical morphology and lattice theory*).

The efficiency of the developed methodology is being evaluated in **two validation scenarios:**

1. recognition of geomorphological process kinematics and
2. monitoring tree development in Slovenia.

Let us recall that the methodology is not only aimed to consider feature extraction, but also to **monitor the dynamics of extracted features, and to detect events** within large point clouds.

Therefore, a special attention is being paid to increasing the accuracy of developed modules, which is crucial in tracking small changes in DTMs of a given area through time. The accuracy is further supported by carefully designed **transformations between geographic coordinate systems**, and a rich collection of **analytical tools for assessing the accuracy of the data and the end-user products.**



Feature extraction considers candidate features geometry (height, area, volume, their ratios…), surface analysis (distances of a point to the surface locally fitted to its surroundings) and context (e.g. bridge is not a house).

Additional reading and resources:

[1] Mongus, D., N. Lukač, B. Žalik. Ground and building extraction from LiDAR data based on differential morphological profiles and locally fitted surfaces. ISPRS journal of photogrammetry and remote sensing, 2014, vol. 93, pp. 145-156.

[2] Mongus, D., D. Horvat, Glidar: napredno orodje za obdelavo lidarskih podatkov (Glidar: advanced tool for Lidar data processing). Geodetski vestnik, 2015, vol. 59, no. 1, pp. 153-158.

[3] Mongus, D., B. Žalik. Detection of ground in point-clouds generated from stereo-pair images. Informatica 39 (2015) 271-275.

[4] Rupnik, B., D. Mongus, B. Žalik. Point density evaluation of airborne LiDAR datasets. Journal for universal computer science, 2015, vol. 21, no. 4, pp. 587-603.

[5] Horvat, D., B. Žalik, D. Mongus. Context-dependent detection of non-linearly distributed points for vegetation classification in airborne LiDAR. ISPRS journal of photogrammetry and remote sensing, 2016, vol. 116, pp. 1-14.

Algorithms of Ecosystems Dynamics Modelling with Methods of Mathematical Morphology and Lattice Theory

Financed by: ARRS (contract J2-6764)

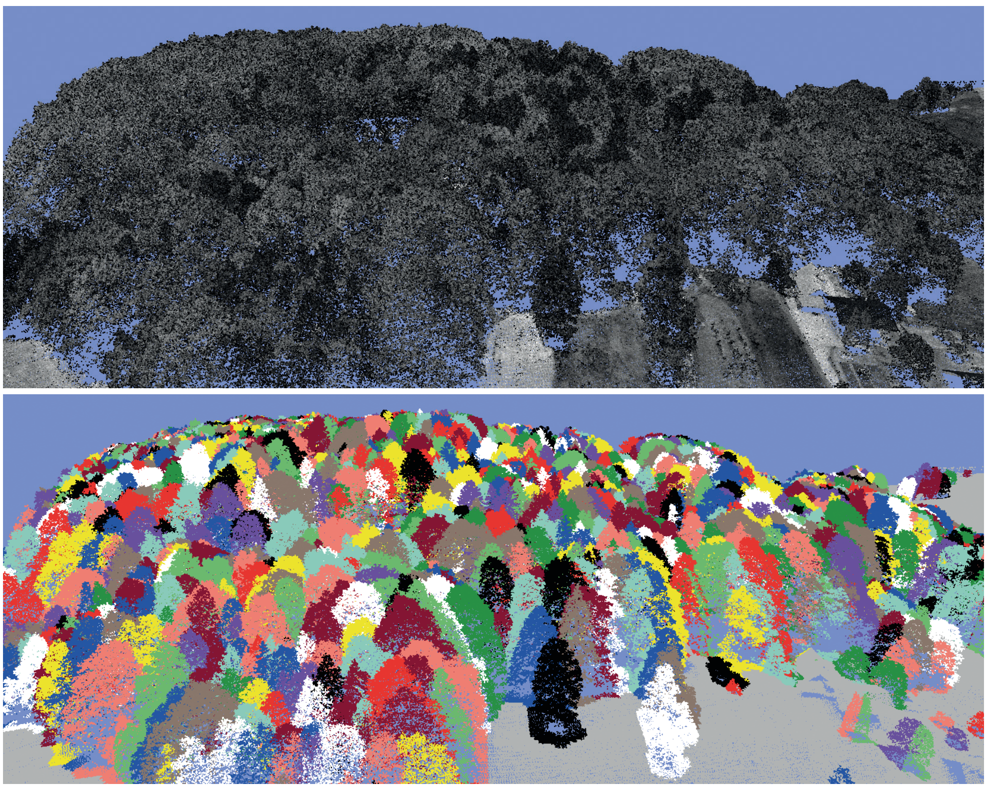
Duration: 1 July 2014 to 30 June 2017

Partner: Slovenian Forestry Institute

The overall objective of this ongoing project is to develop a methodology for analyzing large ecosystems and modelling the dynamics of interactions between their basic elements derived from Earth observation data. The key theoretical emphasis is focused on lattice theory and mathematical morphology (MM). The above key objective will be accomplished by confirming the three hypotheses H1, H2 and H3 in a runtime environment of the prototype application for systematic monitoring and modelling the **dynamics of large forest areas.**

H1: *Advanced concepts of the mathematical morphology and the lattice theory allow, together with the state-of-the-art approaches to image and signal processing, an efficient decomposition of heterogeneous Earth-observation data into their basic elements.*

- We have developed the data decomposition methodology based on locally fitted surfaces (LoFS). Significant progress has already been made in another ongoing project (*Morphological operators for pattern recognition in large point clouds*) where we



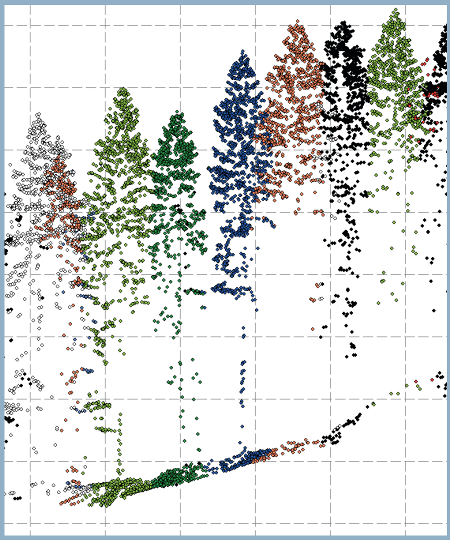
Visualized LiDAR dataset of a forest area (top) and the corresponding decomposition to single trees (bottom).

introduced classification of LiDAR data into the ground, buildings and low, middle and high vegetation classes (plus the unknown objects' points).

- Here we make a step forward by **extracting single trees**. Treetops are firstly identified by detecting concave neighbourhoods within the canopy height model using LoFS. These serve as markers for watershed segmentation of the canopy layer. Additional tree crowns are delineated from mid- and understorey layers based on a tree trunk detection.
  - The methodology has been tested by an international group of experts on a unique dataset originating from different and versatile regions of the Alps. An approximately 6% increase in the efficiency of our treetop definition based on LoFS in comparison with the traditionally used model has been achieved. In addition, 4% increase in the efficiency has been achieved by the proposed tree trunk detection.
- In a separate chapter, the **extraction of electric power lines** from LiDAR data is presented as another example of the developed data decomposition methodology.
- All together, we may conclude that H1 has already been completely confirmed.

H2: *The basic elements of the Earth-observation data can be efficiently merged based on their geometric, textural and shape attributes and, furthermore, integrated in the complex network representing possible interaction between them.*

- Although the LiDAR data enables us to acquire the majority of key information in a concrete case of a forest ecosystem modelling, the geometric relations (e.g. tree height, area, canopy height and volume, shape compactness, social status) between fundamental primitives are not sufficient for complete description of an ecosystem.
- Environmental factors, e.g. soil structure, humidity and insolation, urgently require an appropriate integration model for heterogeneous environmental data.



The cross-section view reveals that the points beneath the tree canopies are also mapped onto single trees.

- The integration model has been designed as a spatially embedded graph i.e. complex network. Graph nodes may be considered as a definition space of discrete weight functions assuring us both, applying all well-known concepts of MM and development of new efficient methodologies.
- A novel methodology for **construction of a complex network** provides **functional definition of graph edges** by examining impacts of non-topological features of nodes. A two-level evolutionary algorithm (EA) is used, where the search for the optimal function type is carried out at level 1, while precise function fitting is achieved at level 2.
- The methodology has been evaluated on several scenarios, e.g. competition between trees, communication between biological cells and relations between buildings in a city. It has proven more efficient than comparable configurations of EAs and traditional methods of machine learning (e.g. neural networks, decision trees, support vector machines).
- We may consider H2 practically confirmed.

H3: *By the development of the new mathematical morphology methods, lattice theory, and statistical analytics of the complex networks, new methods for recognizing interactions between basic elements can be designed for modelling the dynamics of large ecosystems.*

- Our future work shall focus on testing and proving H3. A methodological support for these research activities is ready. Namely, analysis of complex networks with functionally defined edges may offer a key knowledge on ecosystem operation. Currently, we are still collecting the testing data which shall enable extraction of all key dynamic variables for a comprehensive description of large forest ecosystem dynamics.
- We estimate from the up-to-now progressing of the project that H3 will be successfully confirmed before its termination.

Visualization of a spatially embedded complex network.

Additional reading and resources:

[1] Mongus, D., B. Žalik. An efficient approach to 3D single tree-crown delineation in LiDAR data. ISPRS journal of photogrammetry and remote sensing, 2015, vol. 108, pp. 219-233.

[2] Eysn, L., M. Hollaus, E. Lindberg, F. Berger, J.-M. Monnet, M. Dalponte, M. Kobal, M. Pellegrini, E. Lingua, D. Mongus, N. Pfeifer. A benchmark of lidar-based single tree detection methods using heterogeneous forest data from the alpine space. Forests, 2015, vol. 6, iss. 5, pp. 1721-1747.

Photovoltaic Potential Estimation Using LiDAR Data

Financed by: ARRS (grants 1000-13-0552, J2-5479, P2-0041, L2-5489, L2-4114, P2-0115); The Municipality of Beltinci

Duration: since 2012

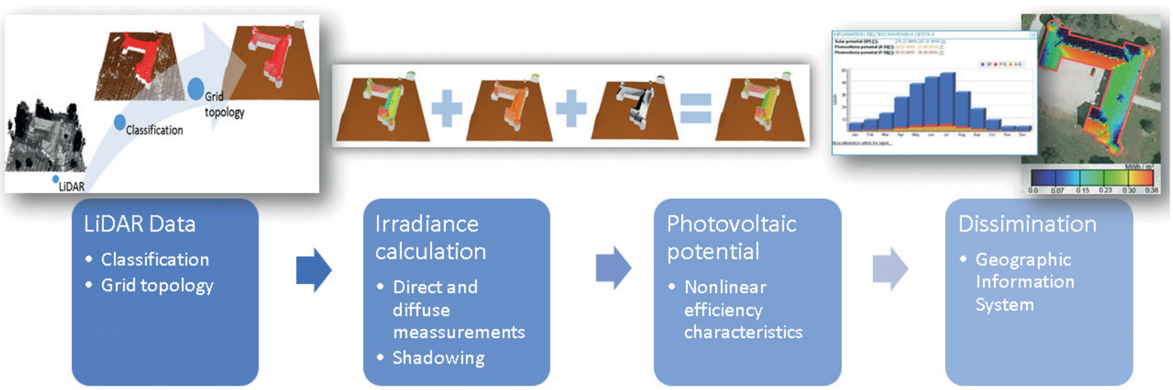
Partner: Power Engineering Laboratory at UM-FERI

Renewable energies are becoming extremely important due to the depletion of the fossil fuels. Over the recent years solar energy has attracted a lot of investors, especially because more efficient solar technology is being developed. One of the most critical problems is the automatic search for suitable buildings' roofs surfaces, in order to maximize solar energy utilization. Solar potential represents one of the most accurate metrics to solve this problem, where solar irradiance (i.e. the power of solar radiation per unit area incident on a surface) plays a key role. Many factors affect the solar irradiance: surface topography, geographical location, self-shadowing and shadowing from the environment, the impacts of atmospheric attenuation by molecular absorption and scattering, and cloud cover.

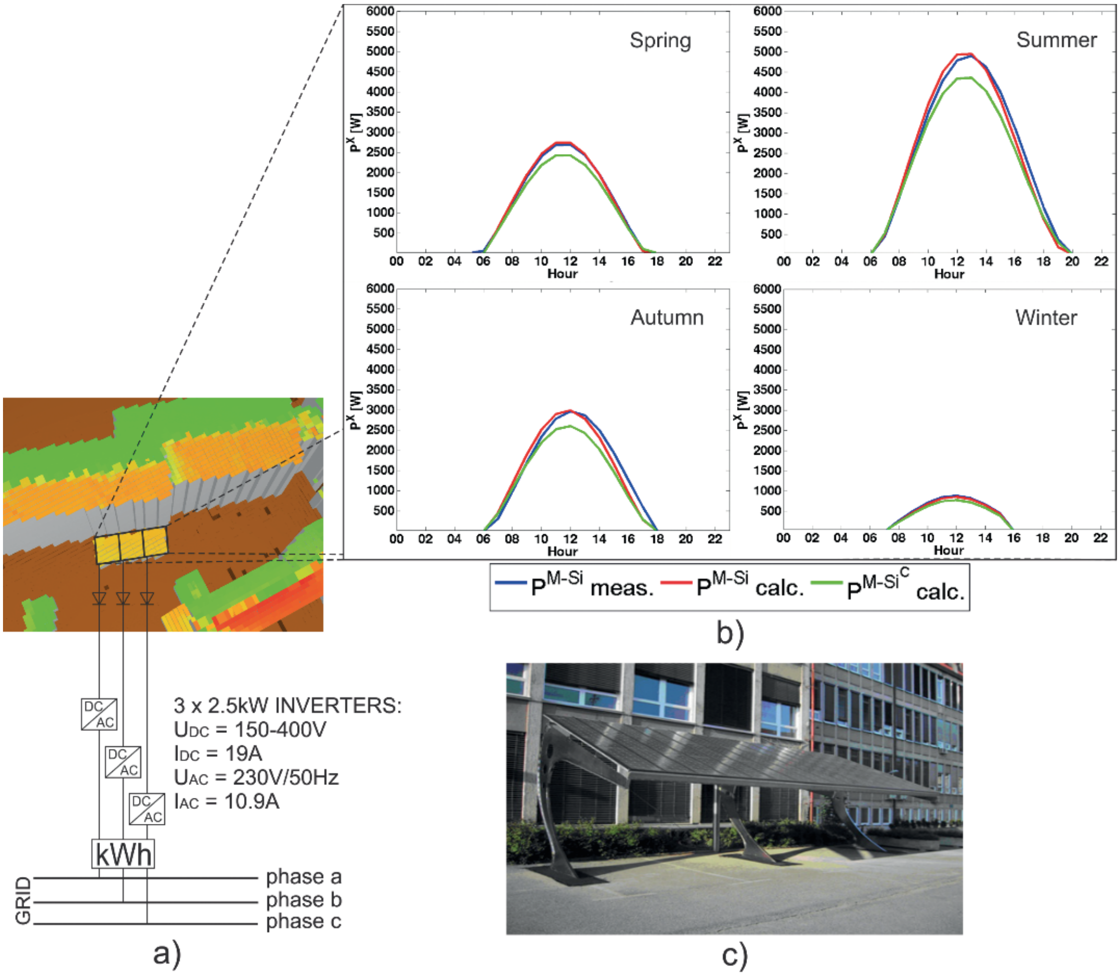
In collaboration with the Power Engineering Laboratory at UM-FERI, we have developed a novel method for estimating spatiotemporal photovoltaic potential for buildings' rooftops by using classified LiDAR data. Local topographic properties are also accurately obtained from the same LiDAR data.

The method was validated by comparing results to the photovoltaic plant at UM-FERI. Highly accurate estimation was achieved by considering the following factors:

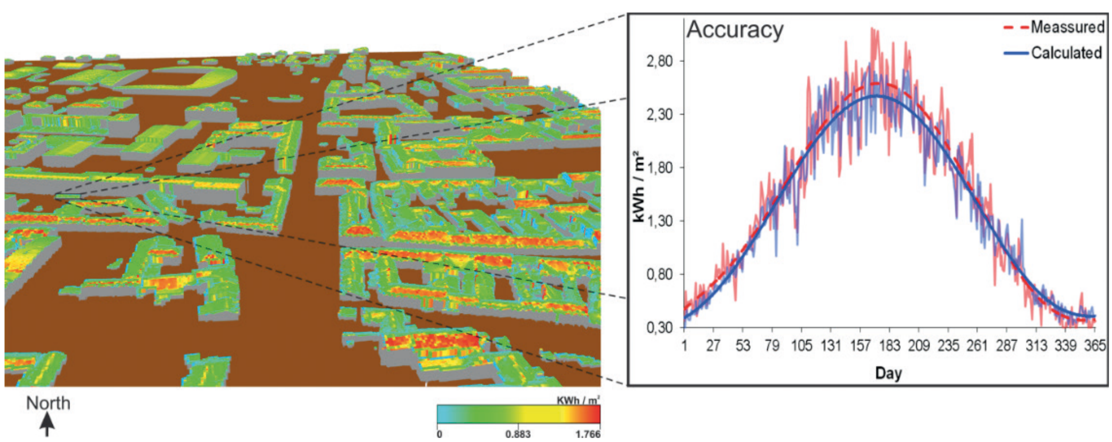
- Long-term measurements of the direct and diffuse irradiance by pyranometer, which captures the site-specific climate conditions.
- Self-shadowing and shadowing from surrounding obstacles (e.g. buildings and terrain).
- Variable shadowing from vegetation throughout the year by using satellite-based Leaf Area Index data.
- Time-based integration of calculated irradiance, where the final production is estimated by considering nonlinear efficiency



From LiDAR data to photovoltaic potential estimation and visualization.



(a) Visualization of the FERI power plant within considered LiDAR data, and the inverters schematic structure; (b) Comparison between the onsite measurements at the power plant and estimated electrical power production of for four extreme days; (c) The considered power plant.

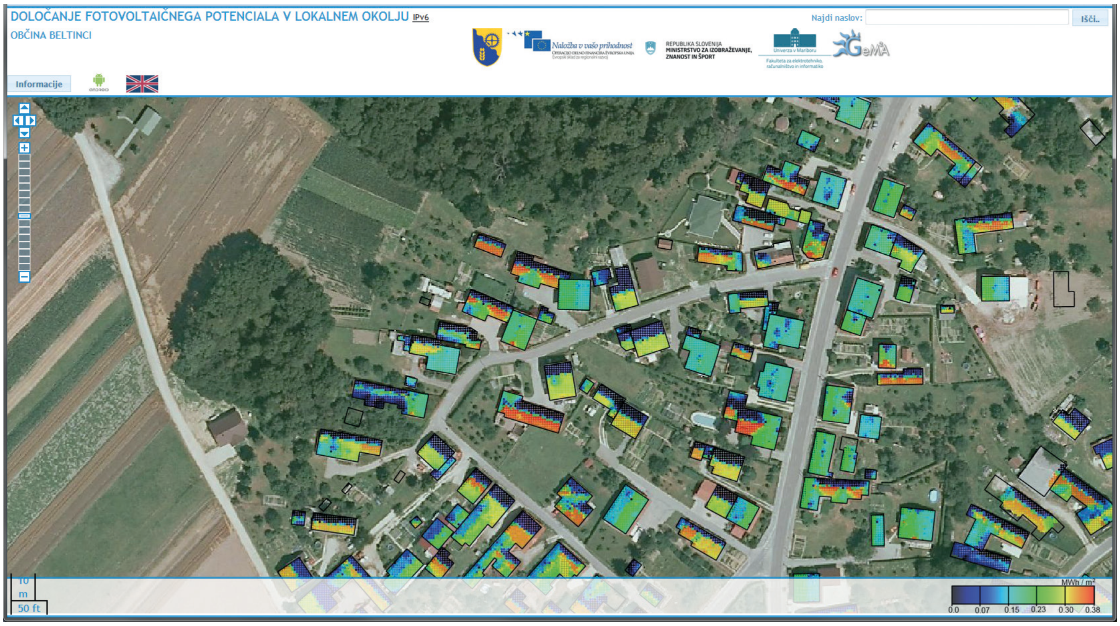


Visualization of the estimated solar potential for part of Maribor (left), and comparison of the simulated and measured ten-year averages (right), where over 97% correlation is achieved.

characteristics for each instantaneous irradiance.

- Nonlinear efficiency characteristics are considered for both the photovoltaic module and solar micro inverter, which were modelled by nonlinear regression over local measurements.

The results of this research have been used in a practical GIS application for the Municipality of Beltinci.



GIS application developed for the Municipality of Beltinci.

Additional reading and resources:

[1] Lukač, N., D. Žlaus, S. Seme, B. Žalik, G. Štumberger. Rating of roofs' surfaces regarding their solar potential and suitability for PV systems, based on LiDAR data. Applied energy 102 (2013) 803-812.

[2] Lukač, N., B. Žalik. GPU-based roofs' solar potential estimation using LiDAR data. Computers & Geosciences 52 (2013) 23-41.

[3] Lukač, N., S. Seme, D. Žlaus, G. Štumberger, B. Žalik. Buildings roofs photovoltaic potential assessment based on LiDAR (light detection and ranging) data. Energy 66 (2014) 598-609.

[4] Lukač, N., S. Seme, K. Dežan, B. Žalik, G. Štumberger, Economic and environmental assessment of rooftops regarding suitability for photovoltaic systems installation based on remote sensing data. Energy 107 (2016) 854-865.

[5] Brumen, M., N. Lukač, B. Žalik, GIS application for solar potential estimation on buildings roofs. WEB 2014: The Second International Conference on Building and Exploring Web Based Environments, April 20-24, 2014, Chamonix, France.

[6] http://solarenergo.beltinci.si/

Optimization of Buildings' Design Regarding Solar Potential

Financed by: ARRS (grants P2-0041, 1000-13-0552, J2-6764)

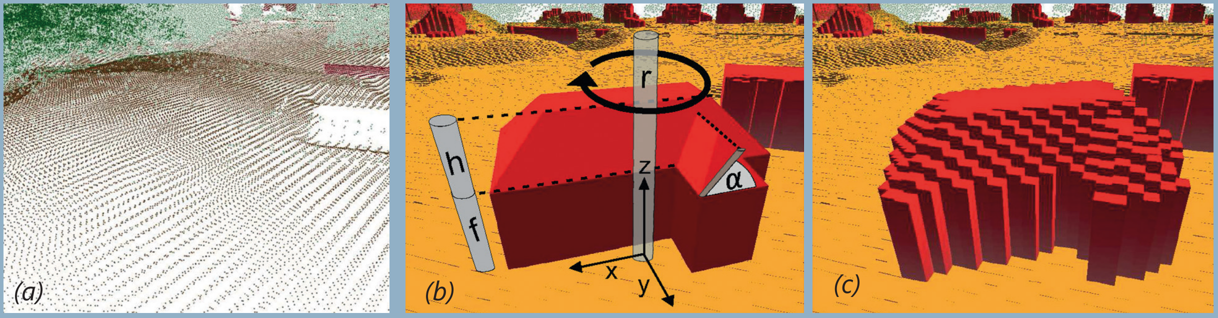
Duration: since 2014

Although solar energy represents one of the most available renewable and clean types of energy, its potential for electrical energy generation remains widely unutilized. In order to develop low-energy buildings for self-sustainable cities, reduce carbon missions or maximize passive solar heating, it is vital to increase solar energy utilization. The solar energy is normally actively converted into electricity using photovoltaic (PV) systems. They are commonly installed on buildings' roofs, where it is generally considered that a surface oriented towards the equator with a tilt angle equal to a location's latitude is optimal. However, this is often not the case due to local climatic conditions and influence of shadowing from terrain and man-made objects. Therefore, the optimal slope and orientation of a PV system attached onto a building's surface presents an optimization issue for investors, as well as for architects, urban planners and civil engineers.

In the presented research, a novel method for searching optimal solar building models within urban areas is proposed. The method's input is the georeferenced LiDAR point cloud, where each point is classified as either building, terrain or vegetation. This cloud is then arranged into a regular 2.5D grid. In order to improve the accuracy of the solar potential estimation, the empty cells are interpolated.

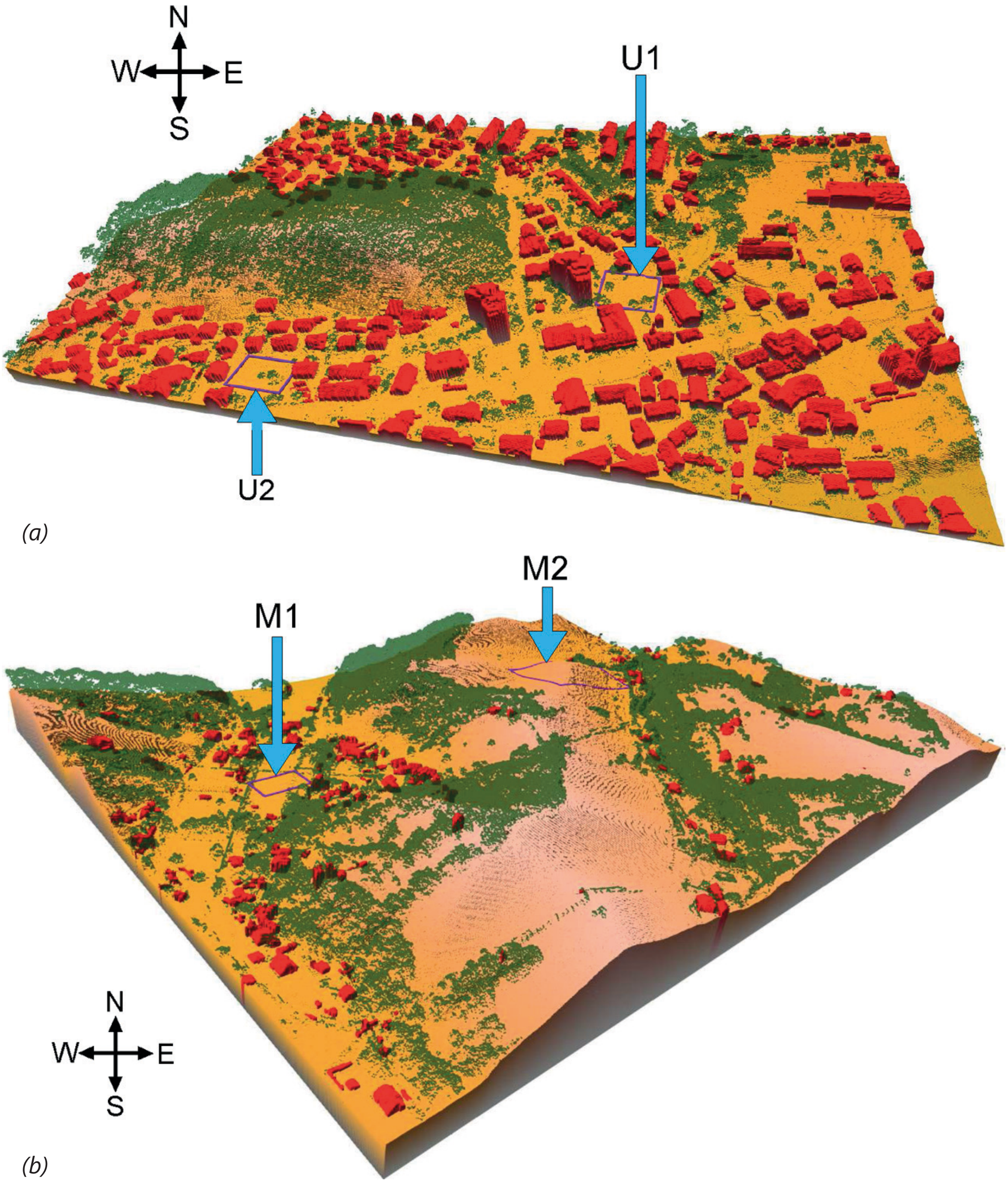
The method considers self-adaptive differential evolution (DE) for solving the constrained optimization problem. In the experiments, various strategies were tested and the best performer turned out to be the DE/best/1/bin strategy. For every candidate, a building was modelled on the grid and evaluated regarding solar potential by considering shadowing from real topographic data and local climate conditions. Rectangular, T and L-shaped buildings were considered with several design parameters, including position, building rotation, facades' height, roof's height and slope, but the method is easily extensible to handle more building design parameters as well.

The experiments confirmed that the method can efficiently find the solar building design with maximum solar potential within constrained optimisation space. To our knowledge, this is the

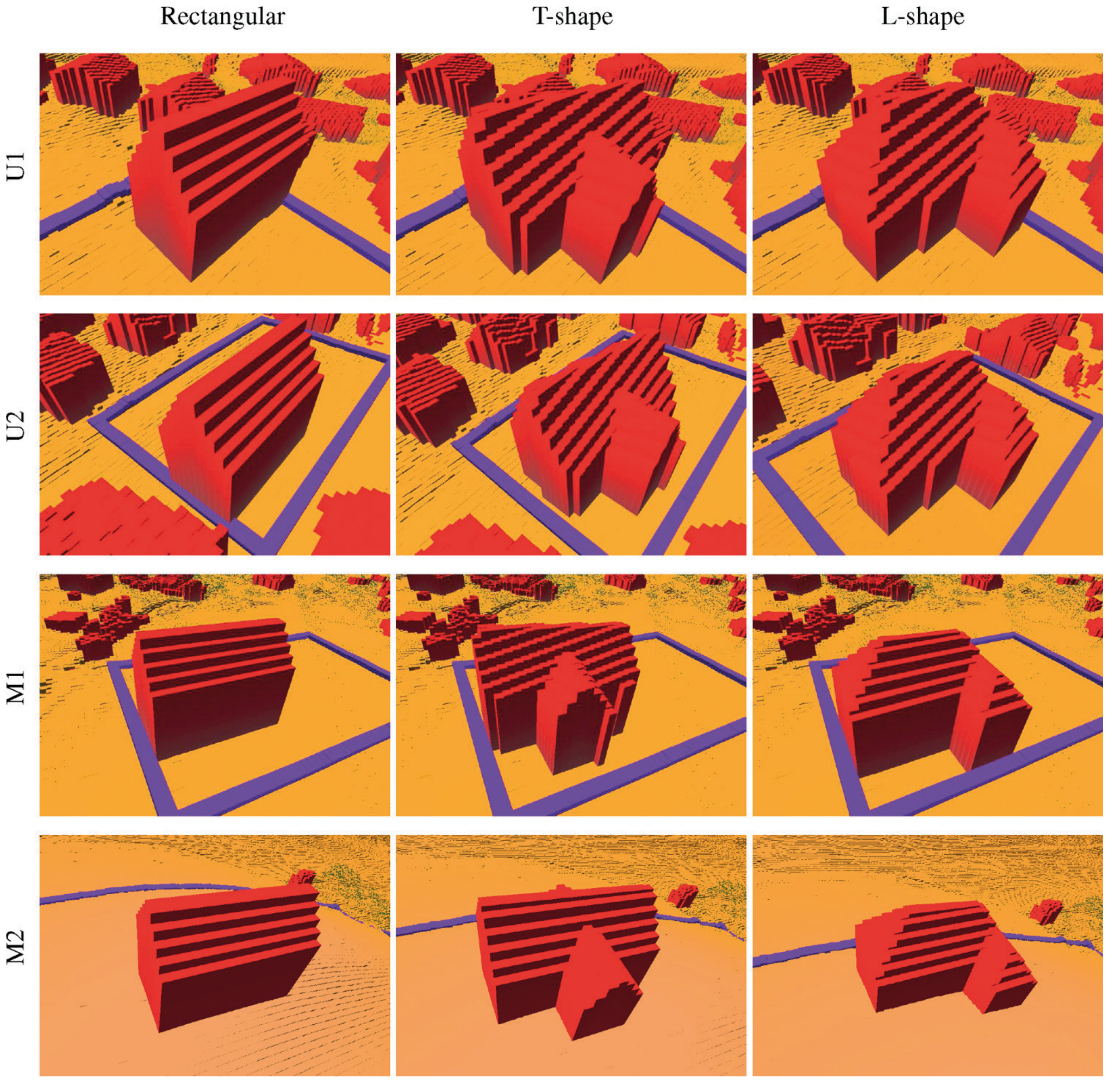


(a) Classified LiDAR data; (b) Building model on the 2.5D grid of classified LiDAR data, where the following building design parameters are considered: r – rotation axis, f – facades' height, h – roof's height and α – roof's slope; (c) Building's cells within the 2.5D grid [1].

first attempt to use LiDAR data in order to find the most efficient building design regarding the solar potential.



LiDAR datasets representing: (a) an urban area with designated testing locations U1 and U2, and (b) a mountainous area with designated locations M1 and M2. A part of M2 location is concealed by the hill [1].



Optimal building models rasterized into the 2.5D grid [1].

Additional reading and resources:

[1] Bizjak, M., B. Žalik, N. Lukač. Evolutionary-driven search for solar building models using LiDAR data. Energy and buildings 92 (2015) 195-203.

Segmentation of a Point Cloud Using Locally Fitted Surfaces

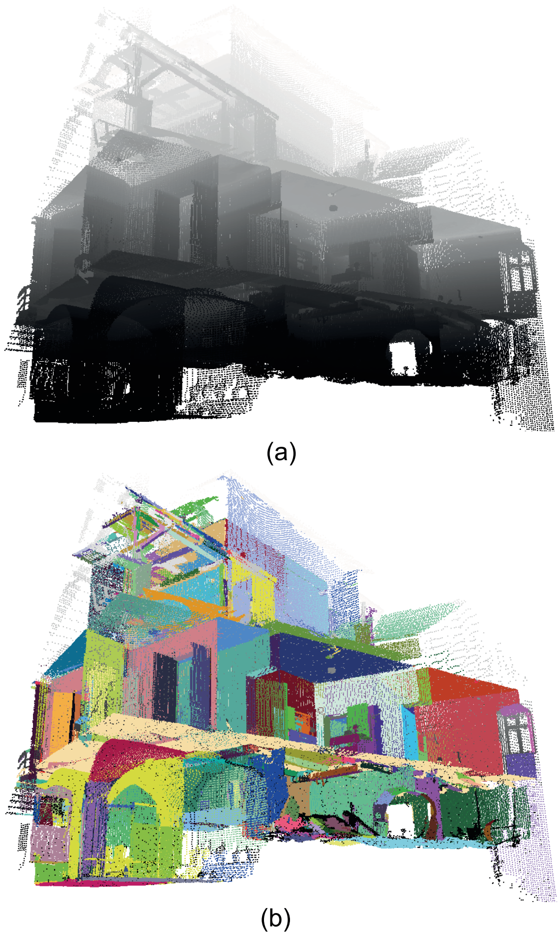
Financed by: ARRS (research programme P2-0041)

Duration: 2014 to 2015

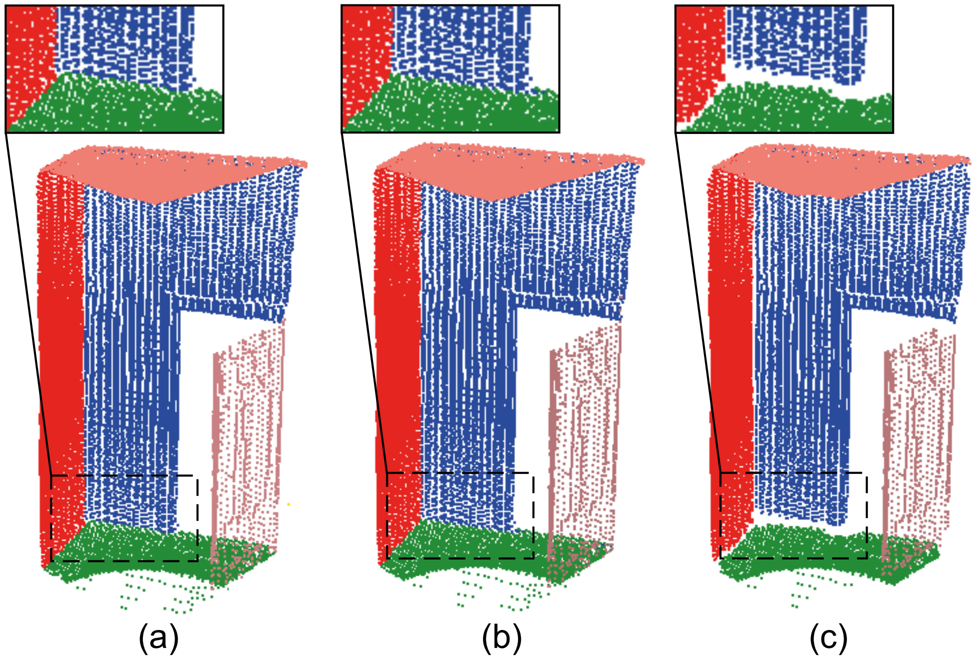
Data provider: Geofoto d. o. o.

Over recent years we have observed a significant increase of the digitalization of real objects. 3D models of buildings are particularly important as they are becoming a crucial part of numerous applications, such as 3D geographic information systems for urban planning, digitalization of cultural heritage, tourism, augmented reality, etc. The digitalization of buildings is usually performed with remote sensing systems, mostly with terrestrial LiDAR which utilizes laser light to acquire the geometry of points on objects' faces. The result of such scanning is an unstructured and noisy point cloud (it may contain over 100 million points) of high resolution (a few thousand points per square meter). Segmentation of the scanned point cloud into subsets of points that describe individual faces is usually required in 3D modelling of buildings and, therefore, significant research efforts are directed towards the development of efficient algorithms for this segmentation.

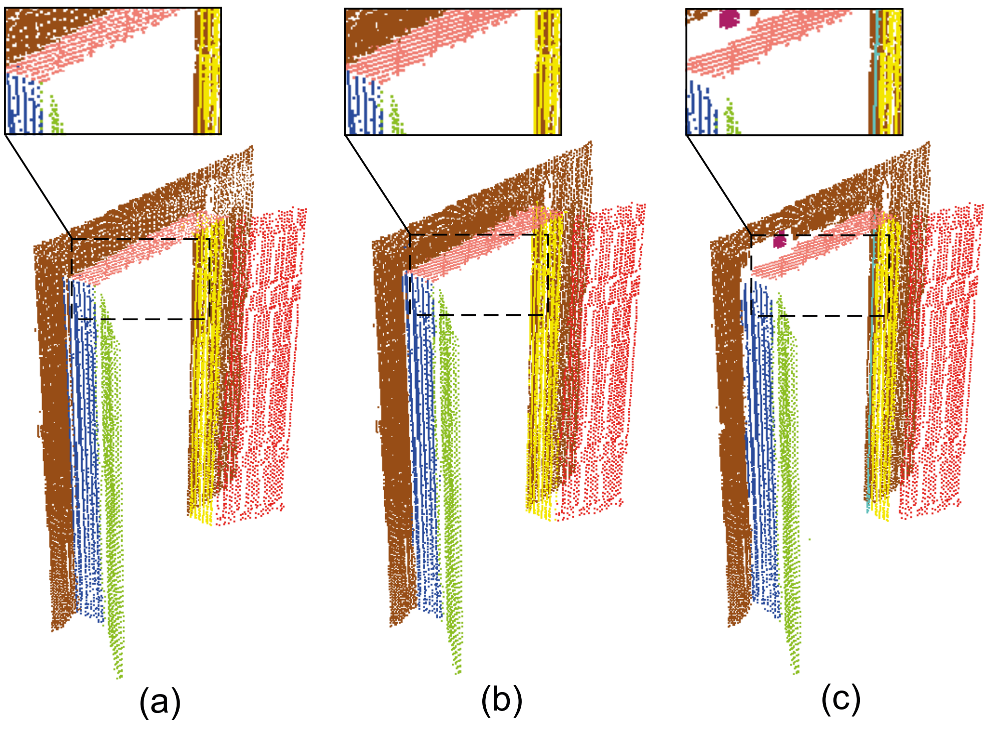
In this research, we have developed a new segmentation method that is based on the locally fitted surfaces (LoFS) and achieves an accurate definition of objects' faces. The method was tested using the terrestrial LiDAR data of a real object and benchmarked against a widely used related method from the Point Cloud Library (PCL). The results show that our method successfully segments point clouds, even at junctions between the object's faces. This holds as long as the density of points at a face is high enough. LoFS have proved as an accurate and robust way for estimating the local curvature. The results show that our method allows us to achieve over 5% higher precision than the current state-of-the-art.



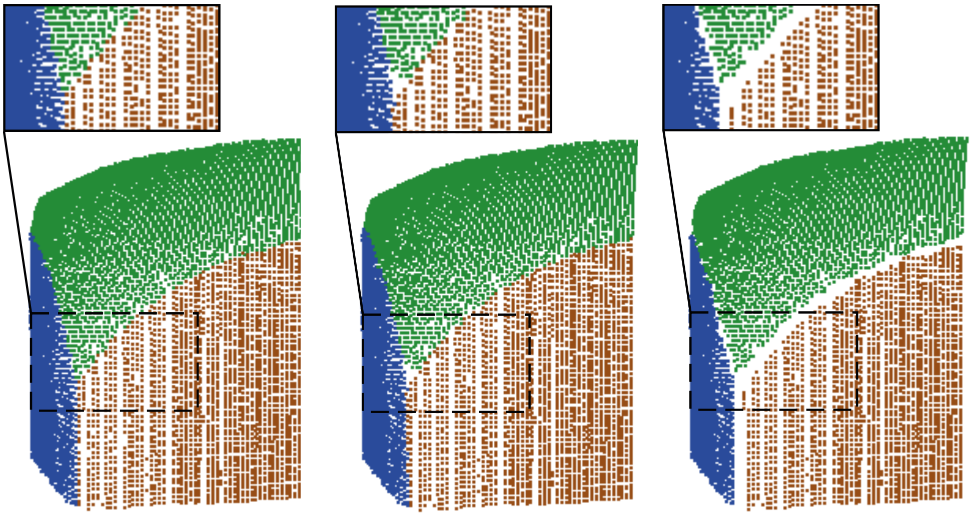
(a) Unsegmented point cloud and (b) the segmented point cloud. Points before the segmentation are colored by height, whereas segmented points regarding the face membership [1].



Segmented room corner with an open door where (a) is the ground truth data, (b) is our result with precision of 99.35%, and (c) is the result of the PCL method with 93.00% precision [1].



Segmented open double door where (a) is the ground truth data, (b) is our result with precision of 96.41%, and (c) is the result of the PCL method with 90:09% precision [1].



Segmented corner of a room with a curved ceiling where (a) is the ground truth data, (b) is our result with precision of 98.94%, and (c) is the result of the PCL method with 95.82% precision [1].

Additional reading and resources:

[1] Bizjak, M. The segmentation of a point cloud using locally fitted surfaces. In: 18th Mediterranean Electrotechnical Conference – Melecon 2016, Limassol, Cyprus, 2016, 6 pages.

GeMMA Photogrammetry Suite

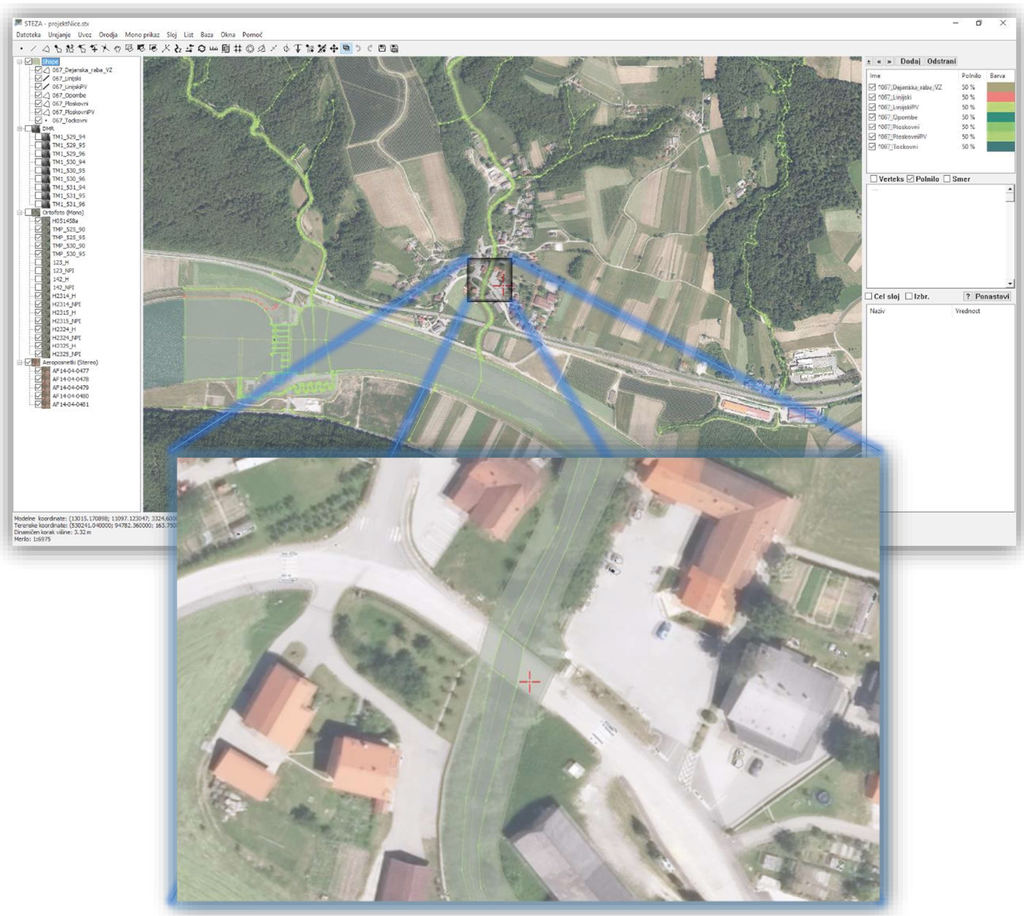
Financed by: Geodetic Institute of Slovenia

Duration: 2015 to 2016

Partners: Geodetic Institute of Slovenia; Geodetski zavod Celje

Gemma Photogrammetry Suite is an advanced software tool designed and optimized for 3D mapping of georeferenced vector objects by using multimodal remote sensing data. It was developed in collaboration with the Geodetic Institute of Slovenia and Geodetski zavod Celje. It found practical application in mapping the entire hydrography of Slovenia. Its main functionalities are as listed below.

- Supporting multimodal geo-referenced remote sensing data: aerial & satellite stereo or mono imagery (i.e. orthophoto), DTM and classified LiDAR data. For each type of dataset a pyramidal hierarchical decomposition is performed, in order to enable real-time user-interactivity.

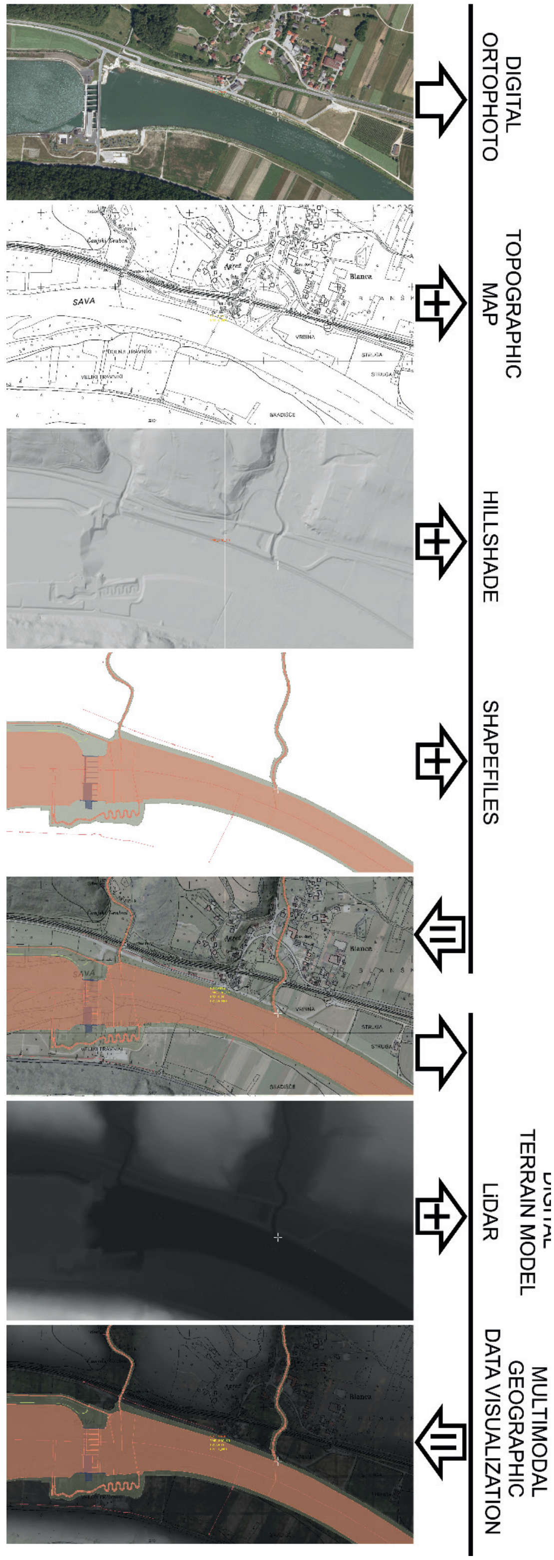


2D orthophoto of the hydroelectric power station near Blanca on the Sava River and a stereo image of a zoomed detail suitable for stereo visualization. The Shapefile-based vector layer of hydrographic objects is displayed with light green color.

- Relational database support: Shapefile-based objects can be uploaded to remote relational database with geographic objects support (e.g. PostgreSQL supported with PostGIS). The database is supported with multi-level user management: inner control, outer control, operators and admin. The inner control provides feedback to the assigned regions that are mapped by specific operators. The outer control provides the general feedback over geometry or attribute mistakes.
- Manipulation and mapping of Shapefile-based objects: ESRI-based vector format Shapefile is well supported and all its object types together with assigned attributes.

Additional reading and resources:

[1] Lukač, N., B. Žalik, GPU-based rectification of high-resolution remote sensing stereo images. High-Performance Computing in Remote Sensing IV, September 22, 2014, Amsterdam, Netherlands.

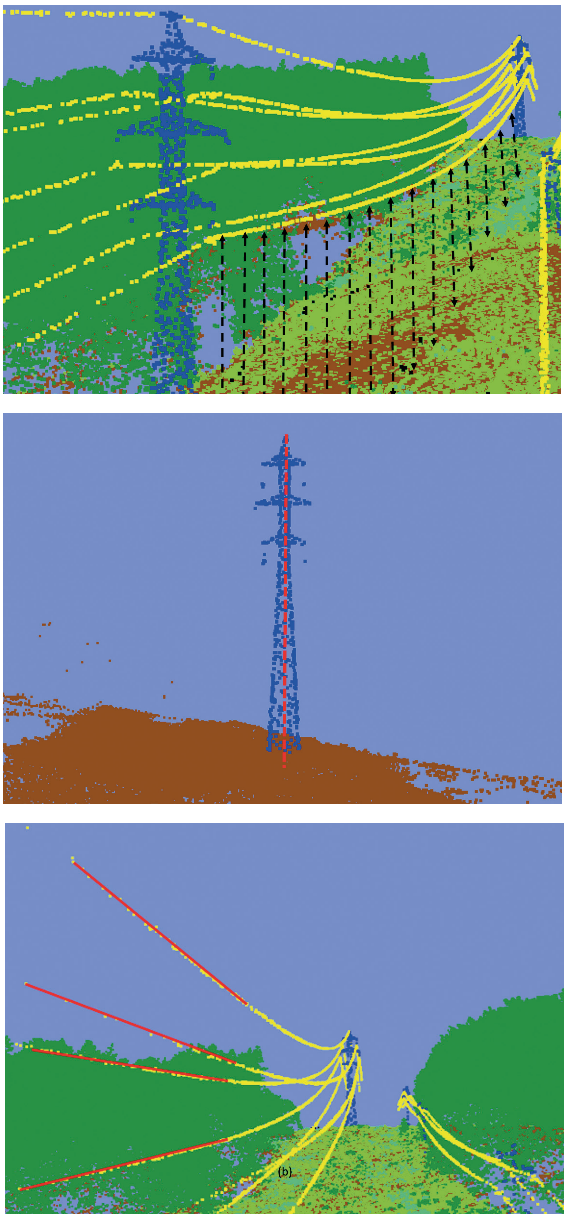


Multiple input layers and visualization possibilities in GeMMA photogrammetry suite.

Detection of Power Transmission Lines in LiDAR Data

Internal project

Duration: 2015



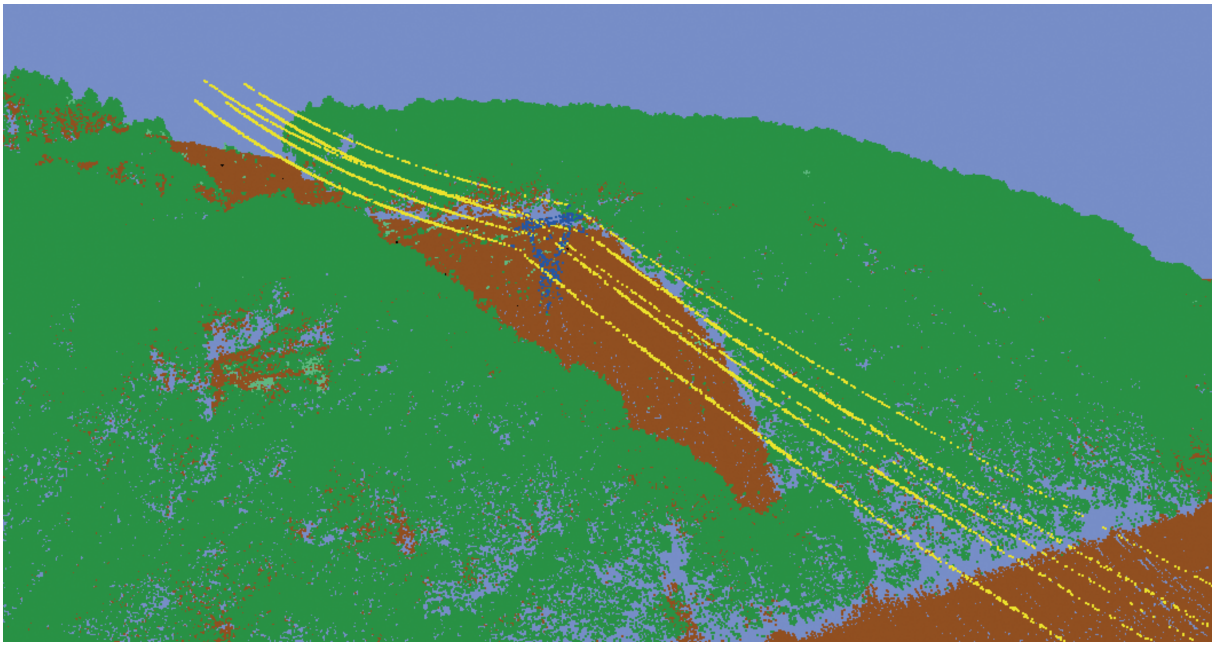
Detection of power transmission lines (top), towers (middle) and conductors.

The detection of power transmission lines is important for the electrical engineering society for assessing of the current situation of transmission lines and for further analysis (e.g. calculating electromagnetic field in nearby areas). In this research, we have developed a new method for detecting power transmission lines in a LiDAR dataset. As they are represented by linearly distributed sets of points above the ground, we detect areas on which they are located using the top-hat transformation based on the morphological opening. Thresholding is then applied in order to extract areas with high responses. Here, locally fitted surfaces are used twice. First they serve to extract power transmission lines, and then for identifying points representing a single conductor. In the last step the detection of the transmission towers is achieved. The proposed method is reliable and considerably fast as it can process 5 million points in less than 40 sec on an average PC.

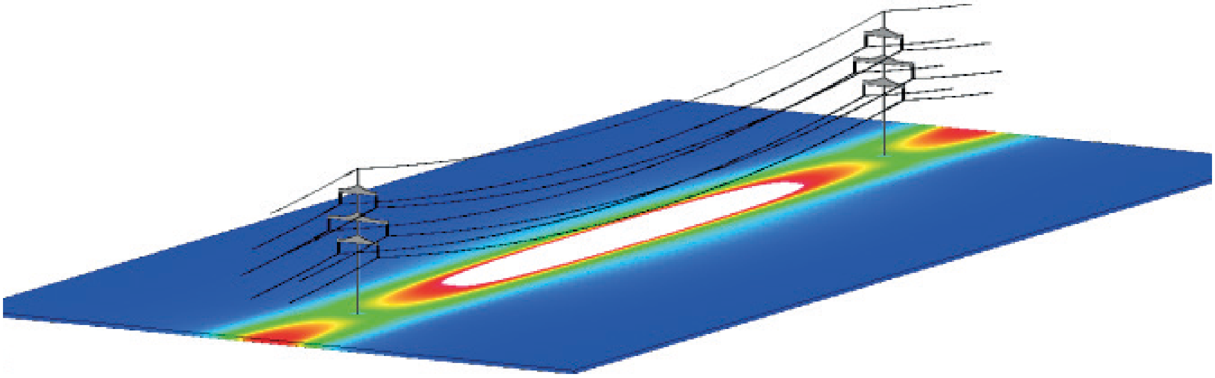
The detected power transmission lines may be utilized for versatile domain-specific tasks, including computation and visualization of electromagnetic field below the conductors and assessment of various geometric characteristics as, for example, lowering of a particular conductor, height of a conductor above the ground, distances between the conductors forming a power transmission line, vicinity of vegetation in transverse direction and vertical distance of tree tops to the conductors.

Besides these monitoring activities, planning of the power transmission lines can also be importantly facilitated by LiDAR-based DTMs and extracted vegetation and buildings.

Estimation of electromagnetic field along the modelled corridors and assessment of other environmental impacts e.g the number and volume of trees to be cut, are of particular public interest.



Detected power transmission lines in LiDAR data.



Electromagnetic field below the power transmission line

Additional reading and resources:

[1] Cvirn, R. (2015). Zaznava daljnovodov v podatkih LiDAR (Detection of power transmission lines in LiDAR data). Master thesis. UM-FERI, Maribor, 2015, 36 pages.

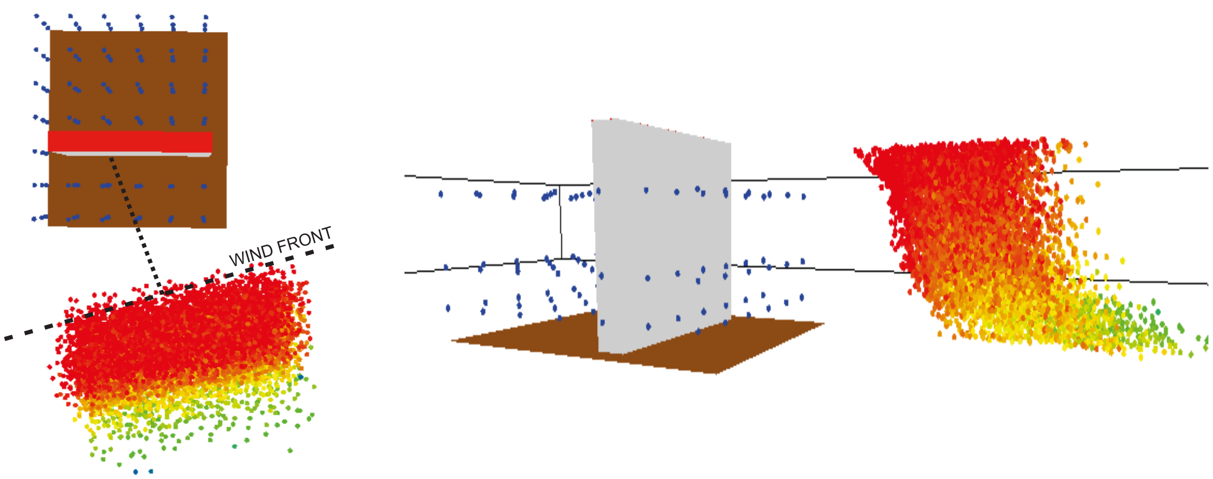
Wind Potential Estimation Using LiDAR Data and Computational Fluid Dynamics

Financed by: ARRS (grants 1000-13-0552, P2-0041)

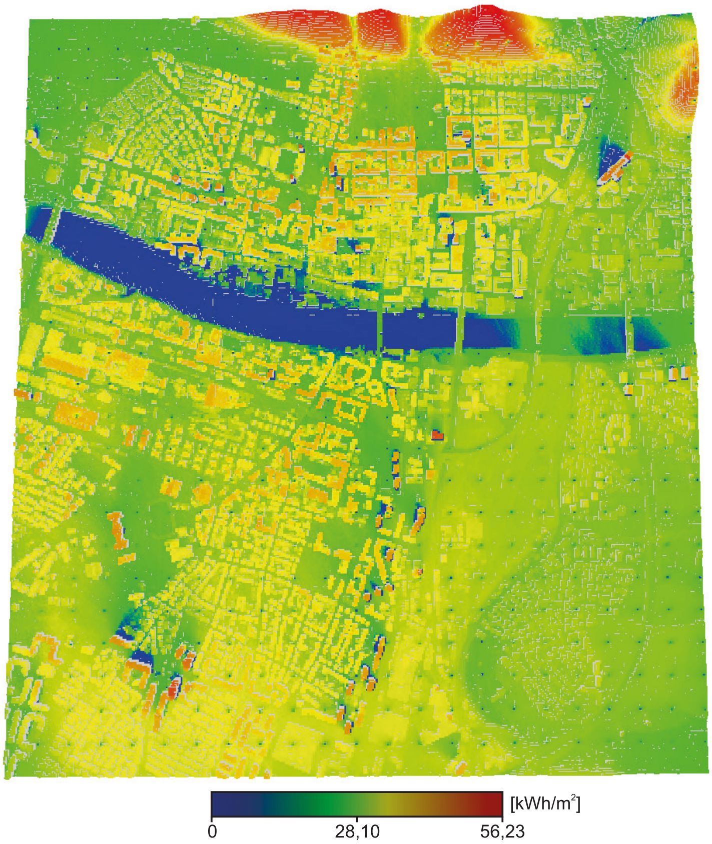
Duration: since 2015

Accurate wind potential assessment is nowadays vital for finding the most suitable locations for wind power plants. Moreover, knowledge of wind flow has numerous applications in environmental modelling (e.g. air pollution dispersion, transportation of snow and dust, etc.) and urban planning. Extended information about the surface and the local microclimate is required, in order to accurately estimate the wind potential at a given location. As the remote sensing technologies such as LiDAR have increased immensely within the past few years, new datasets are available which describe the surfaces in high detail.

We have developed a new wind potential estimation method using classified LiDAR data, where the wind flow is simulated with smoothed particle hydrodynamics, which is a well-established Lagrangian method in computational fluid dynamics. The classified LiDAR point cloud is pre-processed into 2.5D grid, in order to establish topological relations. The wind is initialized as a wind-front and then simulated for each time-step (e.g. hourly), as shown in the below figure. The air particles are initialized using the logarithmic wind profile of the lower atmospheric boundary layer, where the reference velocities are obtained from long-term meteorological data. The wind potential is then estimated by also incorporating the wind power curve of a given wind system, in order to predict average yearly electricity production. The figure below shows the resulting wind potential between the heights of 10 m and 20 m above the surface for the 10 km2 urban area of Maribor city, Slovenia. In the analysis, a micro wind system with a nominal output power of 250W was considered.



Wind-front initialization over sample 2.5D grid.



Wind potential estimation over Maribor city.

Additional reading and resources:

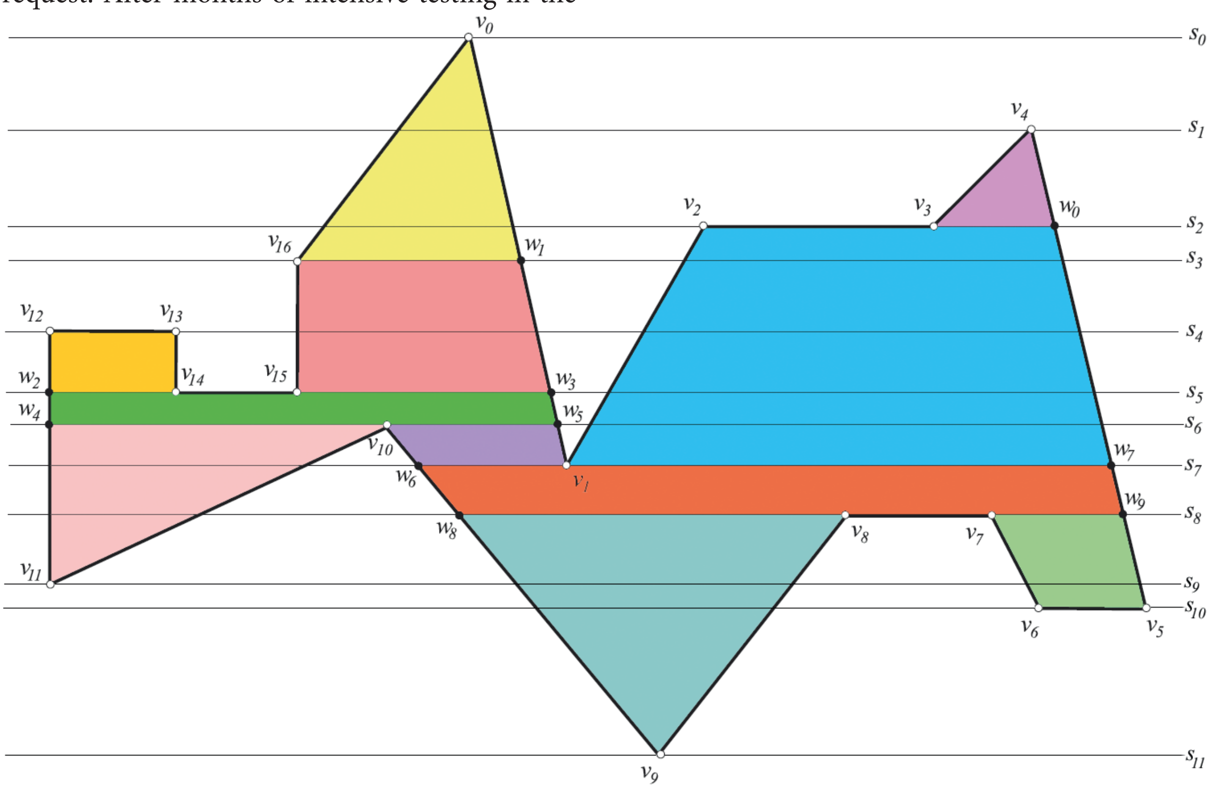
[1] Lukač, N. Algorithm for the determination of photovoltaic and wind potential over large geographic areas, Ph.D. dissertation, UM-FERI, 2016.

Robust Implementation of Simple Polygon Trapezoidation and Triangulation Algorithms

Financed by: AUTODESK GmbH, Germany

Duration: 2000

The first industrial project of GeMMA was aimed to provide two robust dynamic link libraries for the German branch of the renowned engineering software producer. We have developed a novel polygon trapezoidation algorithm and adapted an existing polygon triangulation algorithm. Both of them are based on a sweep-line paradigm. They can handle simple (non-self-intersecting) polygons with or without holes. The latter may be separately trapezoidated/ triangulated on a request. After months of intensive testing in the AUTODESK's testing department, our solutions were accepted for incorporation in a worldwide used commercial software product, while GeMMA was honoured with the AUTODESK's certificate of quality. Besides the feasibility, correctness and speed, we also had to achieve high level of numerical robustness by avoiding all arithmetical operations that could produce inexact results: floating point divisions, triangular functions and square root calculations.

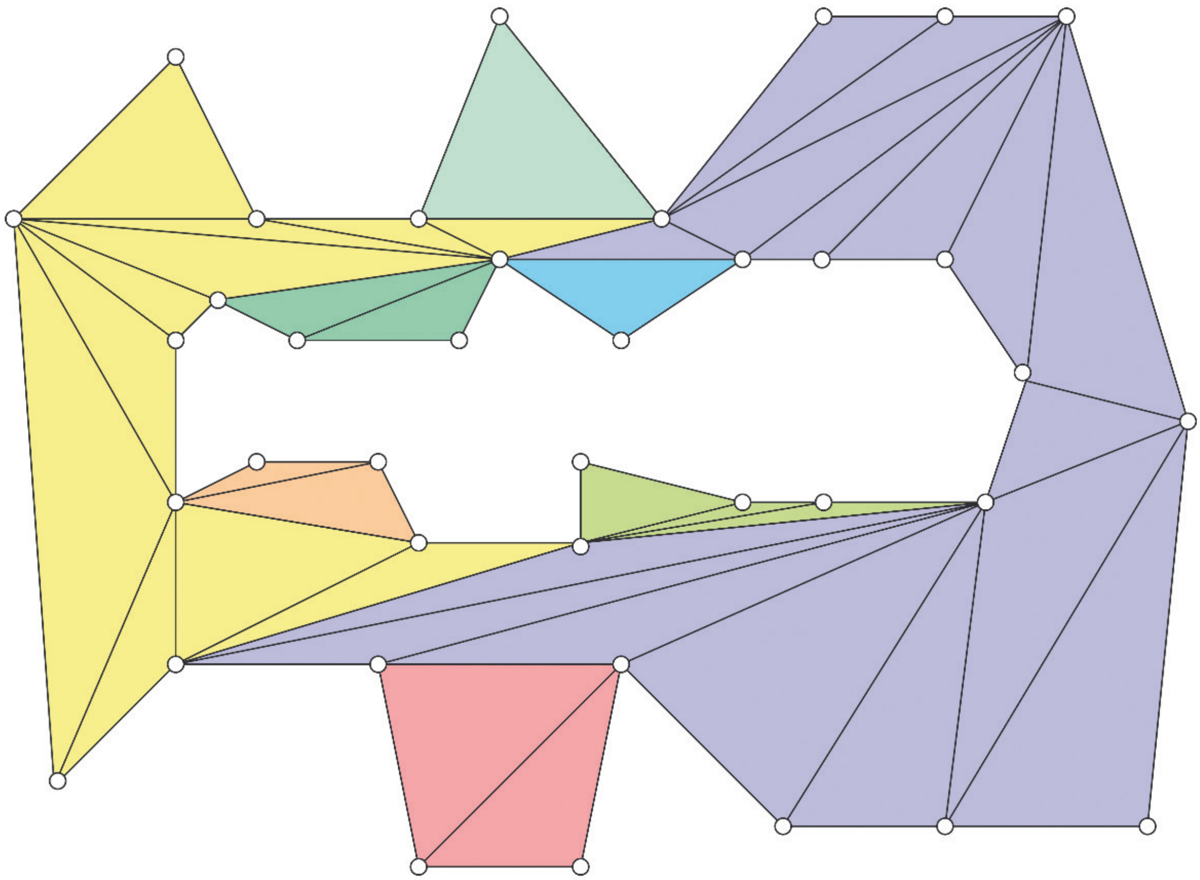


A trapezoidated concave polygon. Vertices v0 to v16 are original polygon's vertices while w0 to w9 are added by the trapezoidation algorithm.

The proposed **polygon trapezoidation** algorithm represents an original approach. As the sweep-line glides over the plane, a set of so-called open trapezoids is generated and maintained. An actual trapezoid is cut from the open one by adding a horizontal side in accordance with the context of a processed vertex. In this manner, a simple polygon is partitioned into a set of trapezoids with horizontal parallel sides. These may be limited either with original or with newly added vertices. Some trapezoids may also be degenerated into triangles. In comparison to the fastest Seidel's method at the time, our algorithm revealed 30 to 100% faster performance, although both methods require O(n log n) time with respect to the number of vertices n.

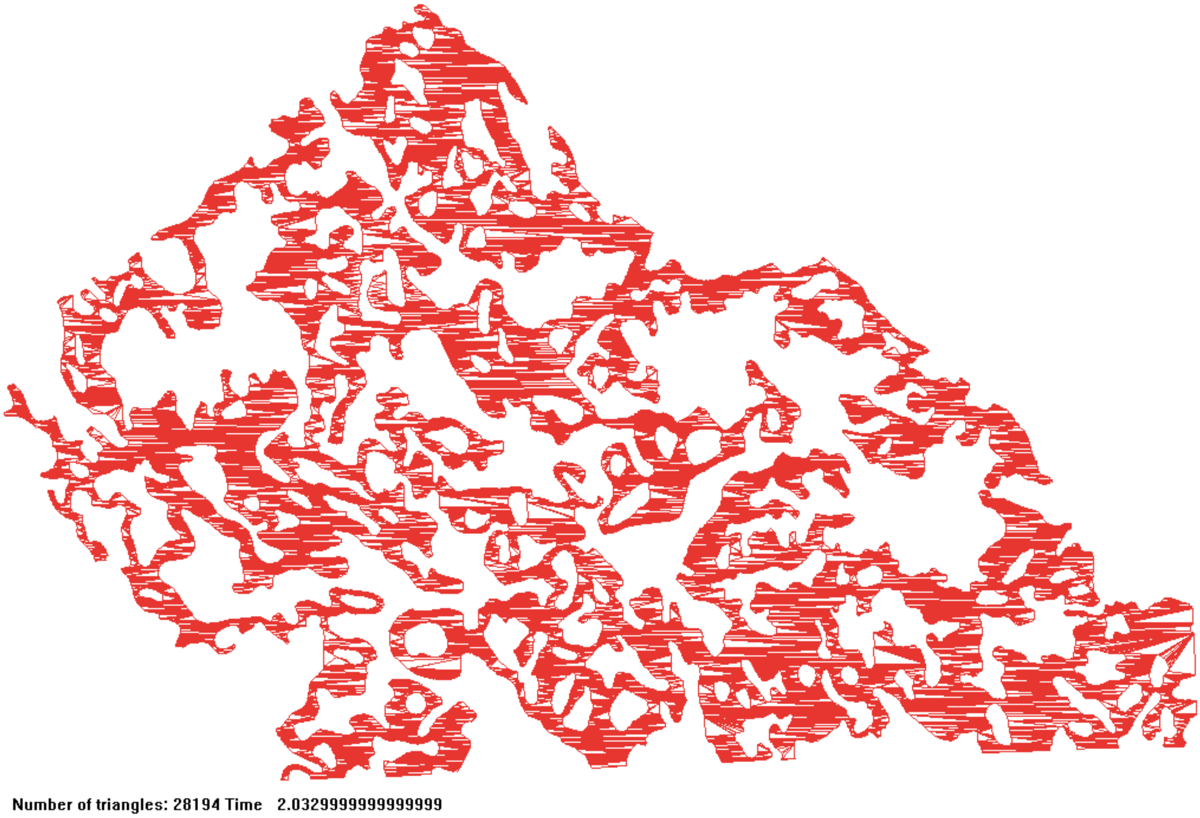
Another problem considered in the project was the **polygon triangulation**. One could use the trapezoidation and then partition each trapezoid into two triangles, but our costomers preferred the solution without additional vertices that would typically appear during the trapezoidation. We have utilized quite traditional two-step approach which firstly decomposes the input polygon into the so-called y-monotone pieces as proposed by Garey, Johnson, Preparata and Tarjan (1978), and then separately triangulates each separate y-monotone polygon with the method introduced by Lee and Preparata (1977). To achieve the required speed, we have slightly adapted the algorithm by utilizing some redundant data structures, particularly the so-called neighbour tree for each vertex.

The theoretical analysis has shown that the first step runs in O(n log NMS), where NMS is the number of monotone pieces, while the triangulation itself



A triangulated concave polygon with a hole. Colours denote 8 y-monotone pieces.

requires linear O(n) time. Since the sweep-line algorithm must be pre-processed by sorting and since a popular quicksort performs best in random case, but appears slow in intuitively the simplest cases (corresponding to polygons with low NMS), this project initiated our increased interest in developing adaptive sorting algorithms. Our original solutions include vertex sort, smart quicksort and finally (still unpublished) smart merge sort.



A triangulated concave polygon with 28,012 vertices and 91 holes.

Additional reading and resources:

[1] Žalik, B., A. Jezernik, K. Rizman Žalik. Polygon trapezoidation by sets of open trapezoids. Computers & Graphics 27 (2003) 791-800.

[2] Podgorelec, D., G. Klajnšek. Acceleration of sweep-line technique by employing smart quicksort. Information Sciences 169 (2005) 383-408.

[3] Žalik, B., D. Podgorelec, R. Starodub. Trapezoidation of concave polygons with nested holes : technical report for AutoDESK, Munchen, Germany. Maribor: UM-FERI, 2000, 22 pages.

[4] Podgorelec, D., B. Žalik. A triangulation algorithm for concave polygons containing holes, (Contributions to geometric modelling and multimedia, Vol. 1, no. 1). Maribor: UM-FERI, GeMMA, 2001, 28 pages.

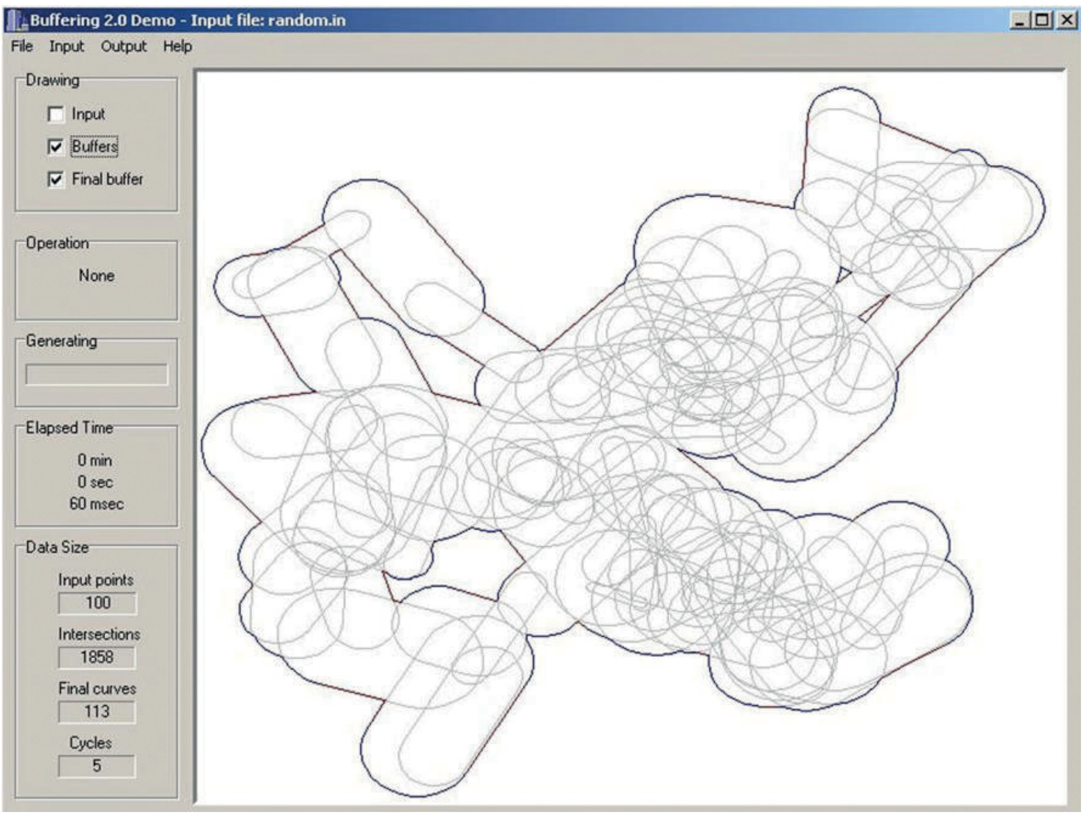
Construction of Geometric Buffers

Financed by: GeoSpatial Technologies, Inc.; The British Council in Slovenia; The Ministry of Science and Technology of the Republic of Slovenia

Duration: January 2000 to September 2003

A basic geometric buffer (BGB) is the border of the area obtained by moving a disk along a vector. If the disk centre is offset from the vector by a fixed distance during the motion, a non-symmetric BGB is obtained. The border of the union of areas surrounded by a set of BGBs is called a geometric buffer. It can also be either symmetric or non-symmetric.

Geometric buffers serve for estimating, modelling and visualization of various phenomena in GIS applications, including polluted, deforested, endangered areas. Construction of geometric buffers has been intensively studied in GeMMA at the beginning of the new millennium, initially as a student research work and later as the lab's internal project which also found partial funding within the British-Slovenian Project Partnerships in Science PSP 13. The resulting software implementation of our original algorithm has been offered to international research community as a shareware downloadable from the GeMMA web page. In 2003, a DLL library was also sold to be integrated into a commercial GIS software



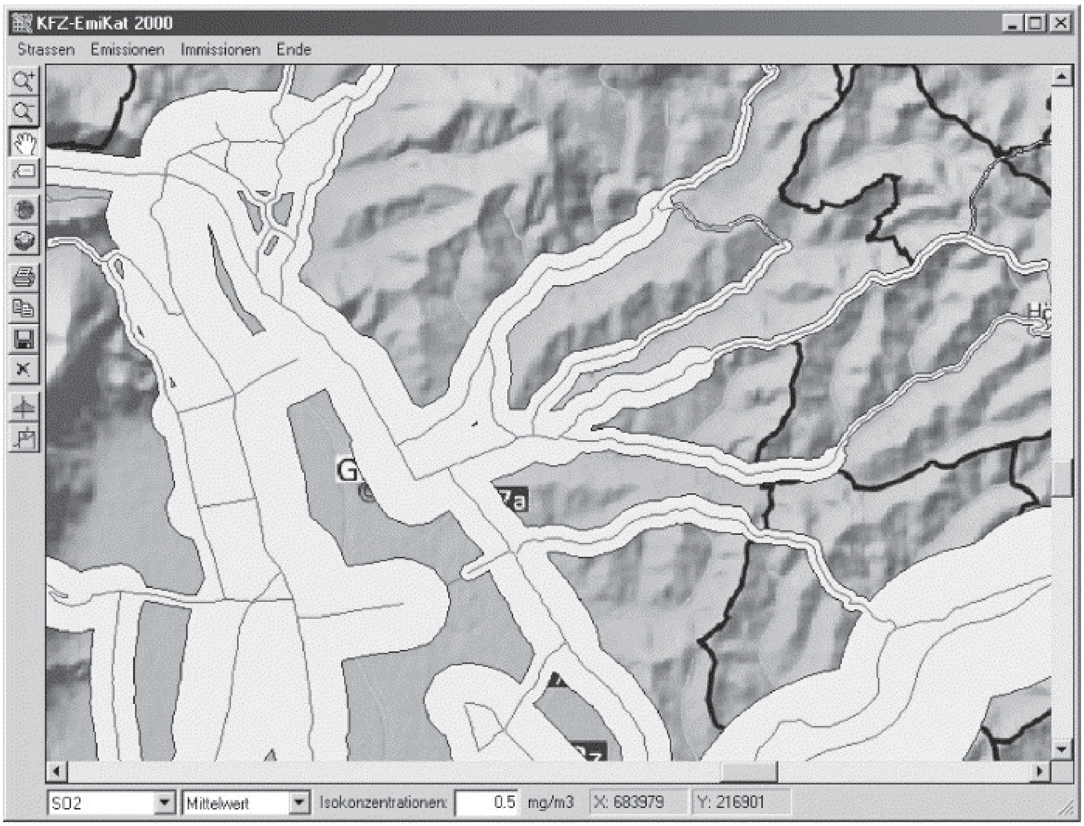
An example of the geometric buffer of a set of line segments and polylines.

developed by the California-based company GeoSpatial Technologies, Inc.

Our algorithm for the construction of geometric buffers works in four steps:

- creation of the basic geometric buffers,
- determining the intersection points between them,
- constructing the cycles, and
- establishing spatial relations among the cycles.

The algorithm is based on the sweep-line technique. A theoretical estimation of the worst time complexity gives O(n2 log n), where n is the number of input vectors. However, the expected time complexity is close to O(n log n), which is confirmed by the experiments. The algorithm proved stable and efficient in practice (also in comparison with the algorithm from the ArcView environment).



Utilization of the algorithm for geometric buffers construction in a GIS application [1].

Additional reading and resources:

[1] Žalik, B., M. Zadravec, G. J. Clapworthy. Construction of a non-symmetric geometric buffer from a set of line segments. Computers & Geosciences 29 (2003) 53-63.

[2] Zadravec, M., B. Žalik, D. Podgorelec. An algorithm for constructing geometric buffers of simple polygons. In: Jelšina, M., Hudák, Š., Kollár, J. (eds.). Proceedings of the fifth international scientific conference Electronic computers and informatics'2002, Košice - Herl'any, Slovakia. Košice: Faculty of electrical engineering and informatics of Technical University, 2002, pp. 328-333.

Compression of Triangular Meshes

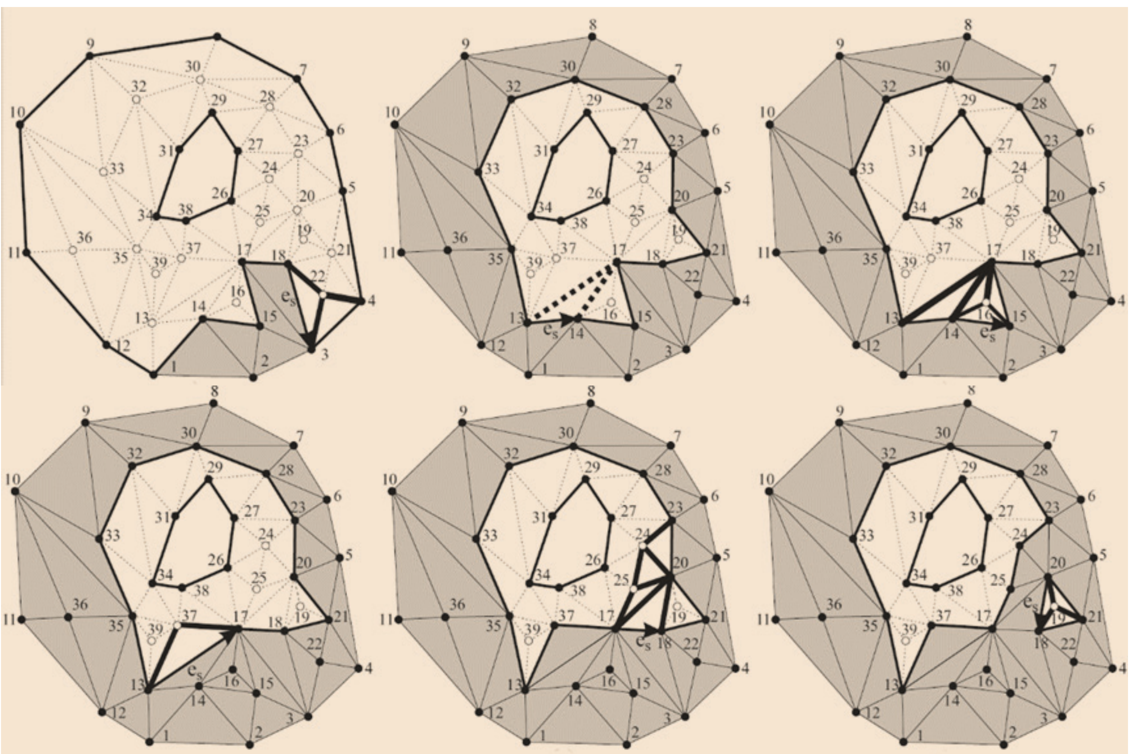
Financed by: ARRS (young researcher fellowship and P2-0041 research programme)

Duration: October 1999 to October 2003

Nowadays, triangular meshes are the most popular representation method for complex 3D shapes produced by CAD systems, terrain generators, 3D scanners etc. Their superiority arises from several factors:

1. excellent support in visualization standards,
2. improved performance of high-resolution 3D scanners and related software, and
3. objects' boundaries are explicitly defined, geometry and topology may be easily manipulated on local level.

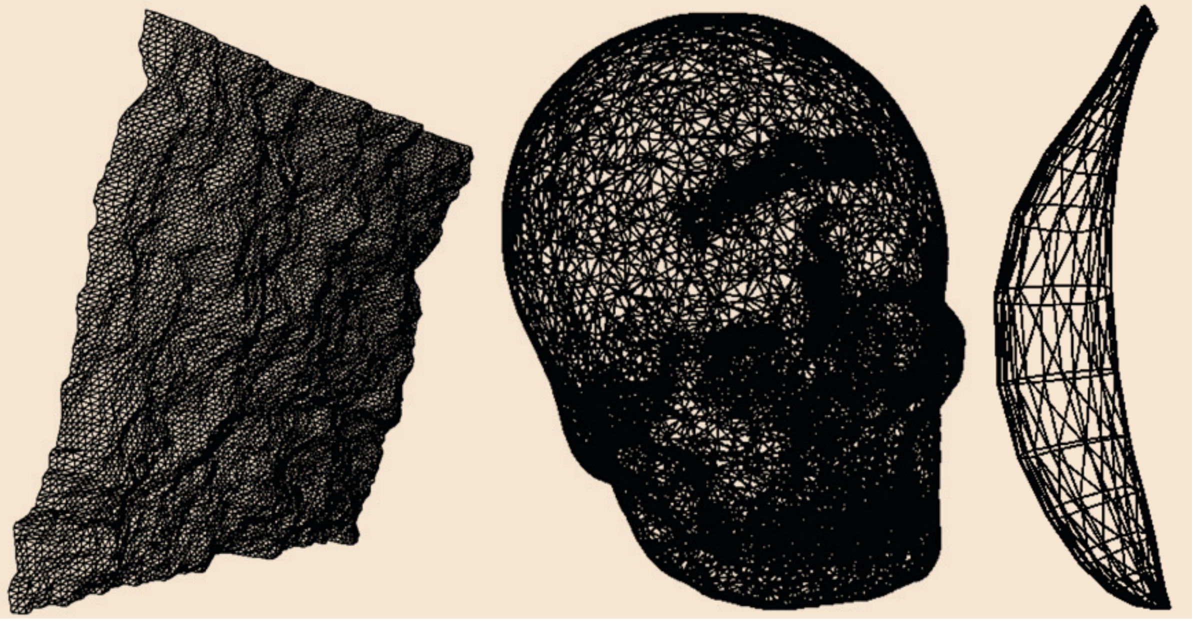
However, a problem appears when a huge number of triangles have to be stored or transferred over the internet. In such case, the data compression has to be applied. Traditional general-purpose methods are impractical since the triangular meshes do not incorporate only geometric (textual) but also the topological (adjacency) information. Specialized approaches may be classified into those based on (i) triangle strips, (ii) spanning trees, (iii) edge-breaker encoding, and (iv) cut-border machines. We have developed an efficient method from the fourth group.



Execution of the algorithm: compressed (dark) triangles and those (light) still waiting to be processed.

The cut-border machine is based on a region growing traversal of the mesh. The methods before ours incrementally considered an edge or two along the (cut-)border of the growing region, and added a new triangle into this region. However, our method compresses two triangles simultaneously. It is based on 8 states, which are described by 4 commands. A comparison with the then most efficient method by Touma and Gotsman has been made using over 150 testing examples. Our approach turned out as more suitable for 2.5D and regular 3D triangular meshes. Anyway, the experiences from this research significantly affected our work in the decade afterwards.

1. No significant progress has been made by simultaneous processing of more than two triangles.
2. We developed new algorithms for compressing hexagonal meshes and FEM (finite element method) quadrilaterals.
3. Several surface reconstruction and mesh decimation approaches were realized.
4. By compressing only topology, neglected possibilities for the compression of geometric and other attribute data were revealed. This inspired our voxel data compression approaches and, finally, culminated in the most efficient and US patent awarded compression of LiDAR point clouds.



Three of 150 testing examples of triangular meshes.

Additional reading and resources:

[1] Krivograd, S., M. Trlep, B. Žalik. A compression method for engineering data represented by triangular meshes. WSEAS transactions on mathematics 4 (2005) 266-272.

[2] Krivograd, S., M. Trlep, B. Žalik. Compression of triangular meshes by simultaneously processing pairs of triangles. In: Jüttler, B. (ed.). Spring conference on computer graphics SCCG 2005 in cooperation with ACM SIGGRAPH and Eurographics, Budmerice, May 2005: conference proceedings. Bratislava: Comenius University, 2005, pp. 103-108.

[3] Krivograd, S. Stiskanje trikotniških mrež s sočasnim procesiranjem parov trikotnikov (Compression of triangular meshes by simultaneously processing pairs of triangles): Ph.D. thesis. UM-FERI, Maribor, 2003, 139 pages.

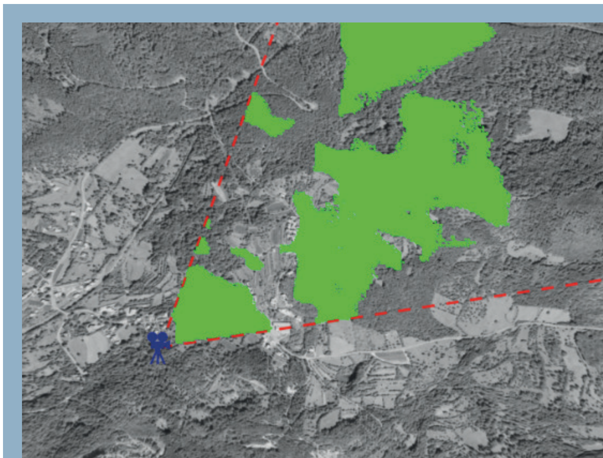
Virtual Sensors

Internal project

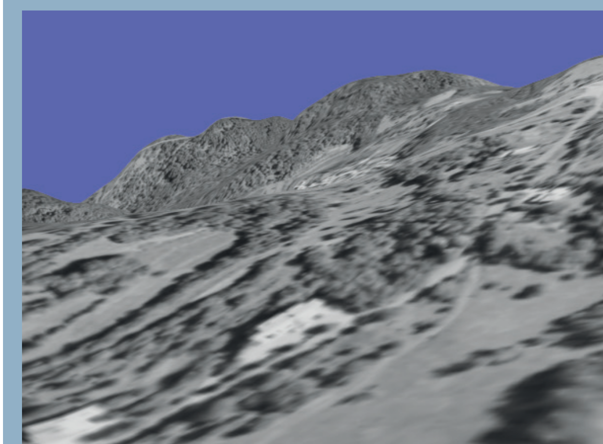
Duration: 2012

This internal project carried out for experimentation and presentation purposes only resulted in a conceptually simple and user-friendly online or desktop application which allows a user to define a specific sensor (virtual camera) with its geographic (longitude, latitude, altitude) and optical parameters (lens and field-of-view or FOV attributes), and then place it on top of a digitized terrain model (DTM) with or without orthophoto image(s) projected onto it. Then the user can change the camera's parameters (including location) and observe the modified results in real-time. Thus, the goal of this experimentation was to compute the visibility problem solution from a given point of view (POV) of a specified camera in real-time by taking into consideration various obstacles in a high-resolution DTM. The application offers a top-down view with drown POV, visually constrained FOV and green-coloured visible positions inside it. Another offered possibility is the first-person 3D view from the camera's POV.

In this way, for example, a user can manually locate the position for the security cameras. Furthermore, the decision making support for this and other problems may also be automated, more cameras can be handled (with merged visibility field), they can be either static or dynamic etc.



A top-down view with labelled POV, FOV and visible area.



A perspective view from the POV in the previous image.

Inclusion Test for Polyhedra Using Depth Value Comparisons on the GPU

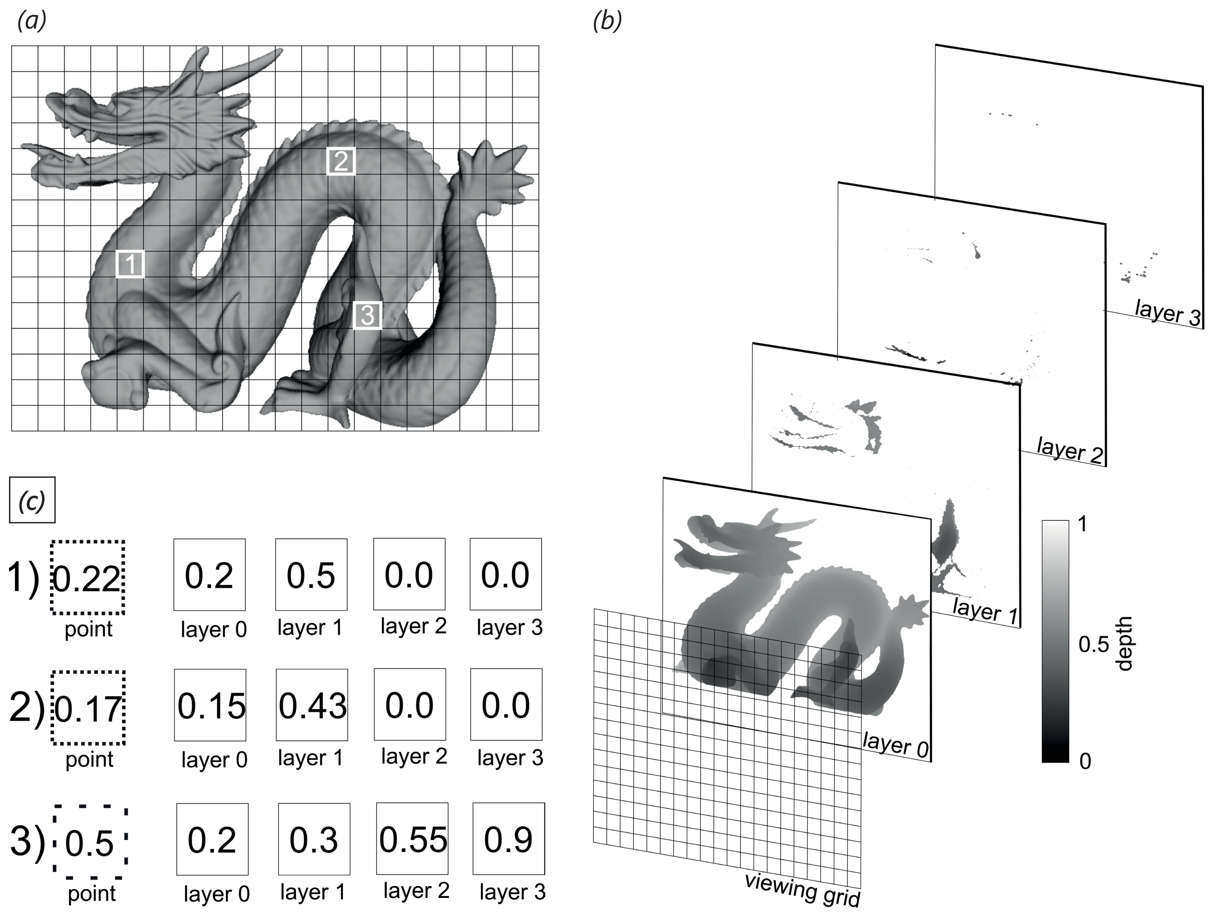
Financed by: ARRS (grants P2-0041, J2-6764)

Duration: 2015

The inclusion test (also called the hit test or containment test) is one of the basic operations in computational geometry. It checks, whether the considered point is located within the boundaries of a given geometric object. Being an elemental operation, it is usually used in conjunction with more complex tasks and can, therefore, be found in various fields such as physics simulations, artificial intelligence, computer graphics, or object modelling. Given that the problem is long-established, many different solutions have already been presented. However, new approaches still appear in scientific publications which solve the problem more efficiently.

In this research, we proposed a novel approximation method for testing of inclusion in 3D scenes i.e. between points from a given set and the boundary representation of polyhedrons. The tested geometry is required to be manifold and watertight, but not necessarily limited to triangle meshes. The method is executed almost completely on the GPU and is most closely related to the approach that uses layered depth images (LDI). LDI can be used to establish the inclusion status of a point, based on the Jordan Curve Theorem. The layered structure of LDI, however, is not very memory efficient as the layers can contain many empty allocated values that are not needed to perform the inclusion test. Additionally, multiple geometry passes are required for the construction of LDI, which can represent a problem for objects containing many triangles or dynamic scenes with changing geometry where LDI is constantly recalculated. Motivated by these shortcomings, the following contributions of the proposed method can be outlined:

- **Memory efficiency:** Only a list of point depths and their index map is required, thus making the method very memory efficient.
- **Fast execution:** The method is almost completely executed within the rendering pipeline of the GPU. This enables real-time detection of inclusions on geometrically arbitrary or deformable objects.
- **High integrability:** If used in the right order, most of the code for inclusion can be executed along drawings of objects, which makes the method applicable in computer graphics or in various simulations.



(a) A testing 3D model for our inclusion test with labeled demonstration cases. (b) The constructed set of depth layers. (c) Demonstration of two cases (1 and 2) where the point lies inside the model and a case (3) where the point is outside [1].

Additional reading and resources:

[1] Horvat, D., B. Žalik. Inclusion test for polyhedra using depth value comparisons on the GPU: lecture at 8th International conference on computer science and information technology, ICCSIT 2015, Amsterdam, The Netherlands, 11 December 2015.

VHCE – Virtual Heart of Central Europe

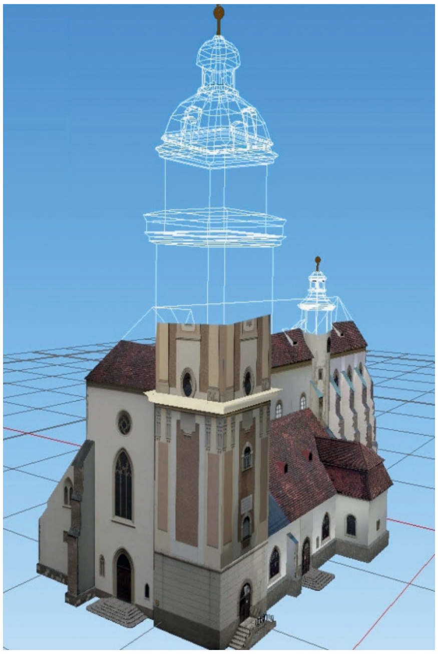
Financed by: European Union

Duration: April 2003 to April 2004

Partners: Comenius University Bratislava (coordinator); Czech Technical University Prague; Graz University of Technology

As a part of the European Union's Culture 2000 programme, VHCE was aimed to protect outstanding universal values of the European cultural heritage, to promote cultural understanding throughout the world and, in this manner, to enable Europeans to be consciously proud of their contribution to World Cultural Heritage. This was achieved by the digital reconstruction of selected significant objects of cultural heritage in four European cities Prague, Bratislava, Maribor and Graz, and creation of a public digital archive for future use of the digitalized artefacts. The partners focused on architectural verticals of the cities and, therefore, subtitled the project as Towers and Wells. Each object was presented by a set of photographs, text and audio commentary, 3D animation mixed with real video, Quick Time VR panorama and interactive VRML walkthroughs. The presented jewels of Maribor comprise the oldest living vine (400 years), the Water Tower, the plague monument, the castle in the centre of the city, the Slomšek square with the cathedral of St. John the Baptist, the Franciscan church, the synagogue, and the Town Hall.

The Water tower in the VRML environment




3D model of the cathedral of Maribor.

3D model of the Town Hall in Maribor.

Additional reading and resources:

[1] http://www.vhce.info

Development of a System for Visualization of Realistic Terrain Required for Training Battle Crews

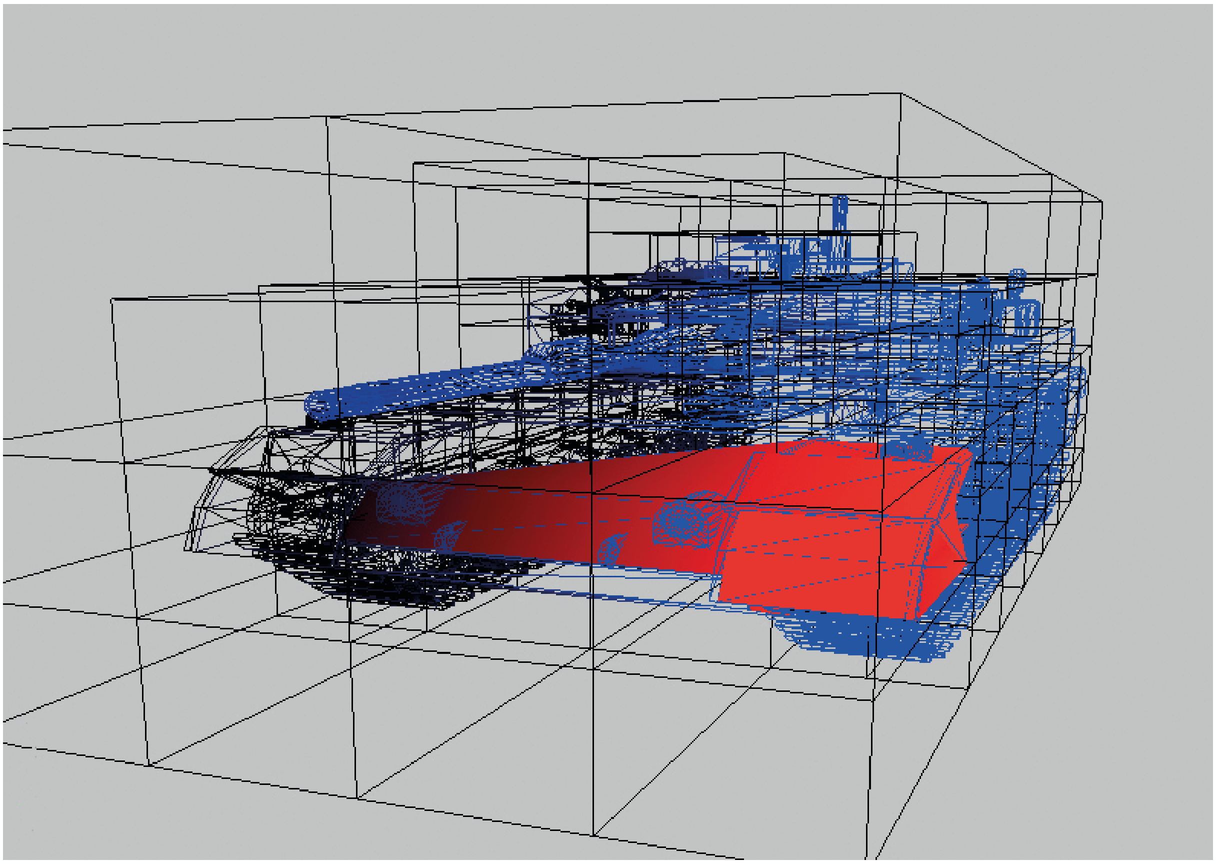
Financed by: ARRS; Ministry of Defence of Republic of Slovenia (contract M2-0141)

Duration: 1 June 2006 to 31 May 2008

Partner: EM. Tronic d.o.o.

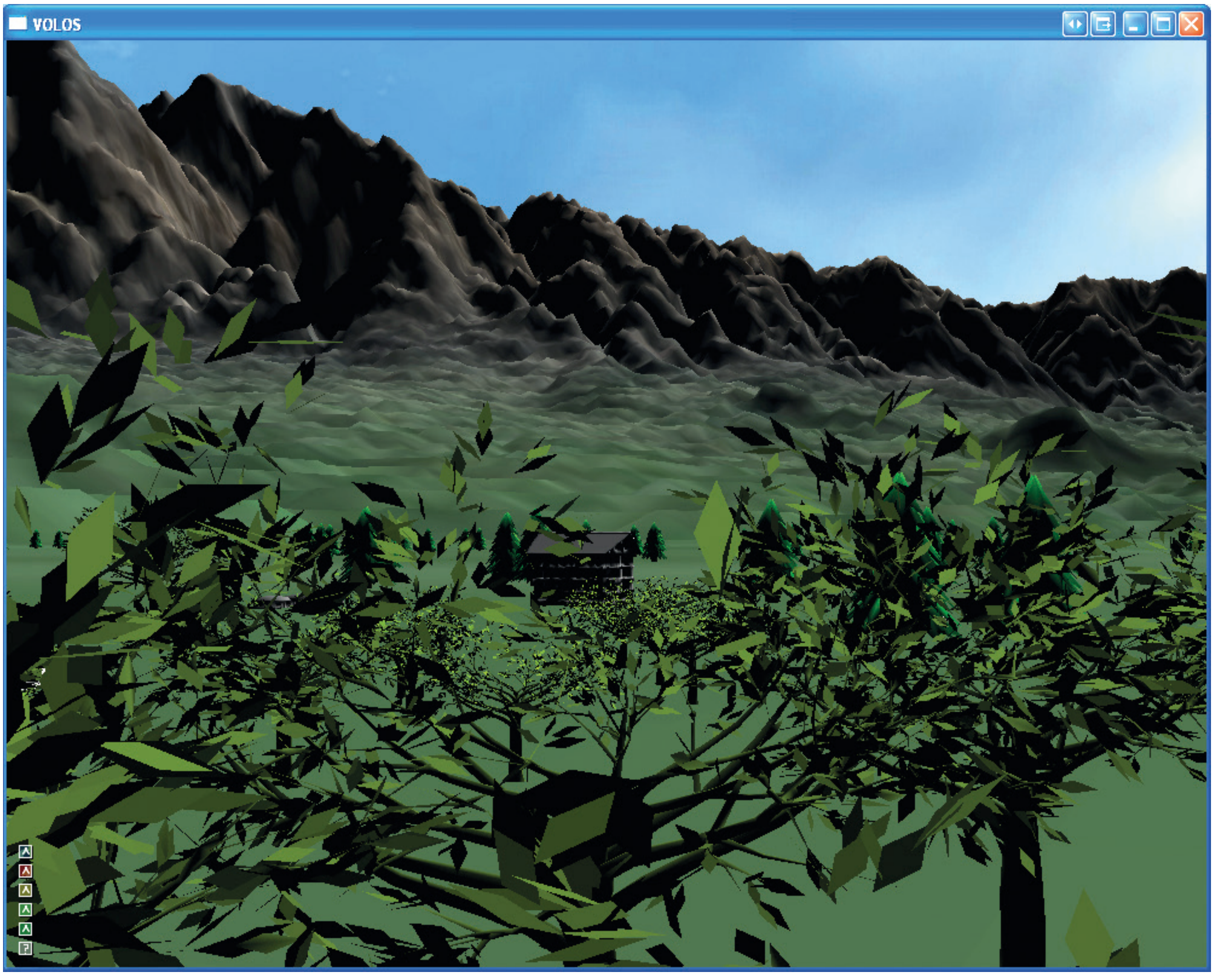
The aim of the project was to support efficient tactical training of battle crews through an interactive virtual reality environment, utilizing the existing hardware in the middle price range only. The main goal of the project was to create a software system that would support a terrain representation in as realistic manner as possible. The model of the terrain is built upon a chosen part of the real-world digital relief model, but a user can also change geometry of the terrain through an interactive scene editor. This external application also supports insertion and deletion of additional objects, either static (trees, houses, electrical wiring…) or dynamic ones (targets) that can be typically found on a real training polygon. The objects' properties (textures, geometry) are also editable.

To offer truly efficient support to tactical training, the system is able to perform visualization



A tank – example of an additional dynamic object.

of the training polygon from different angles simultaneously and offer the possibility of simulating the interaction with some specific battle devices through special user interfaces. Besides the advanced visualization system, the simulated dynamic events required an efficient, stable and precise physics engine which represented one of the main challenges in the project development.



A terrain model for interactive tactical training of battle crews.

Additional reading and resources:

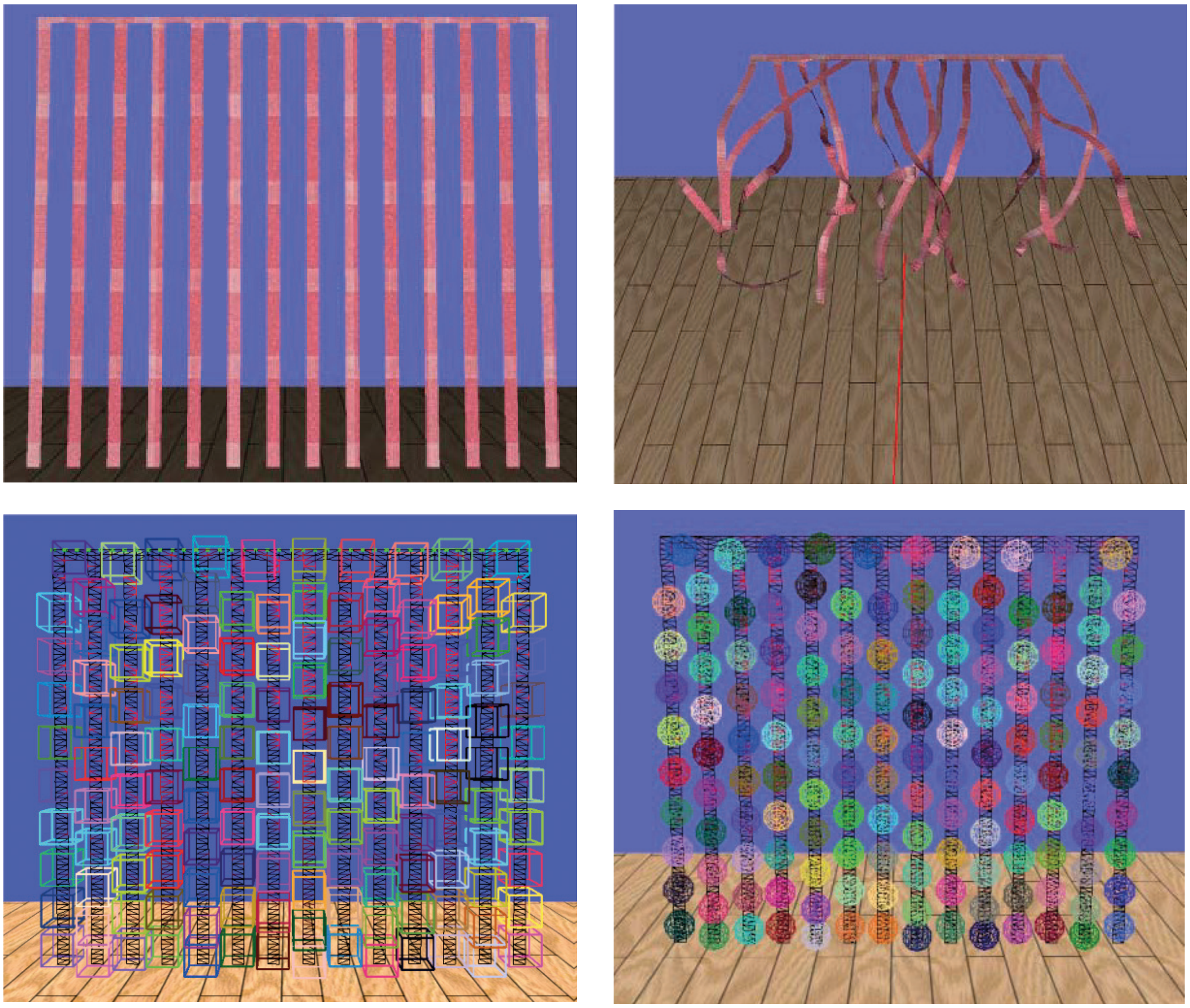
[1] Klajnšek, G., B. Rupnik. Development of a system for visualization of realistic terrain required for training battle crews (Razvoj sistema za simuliranje realistične pokrajine za bojno usposabljanje posadk): final report of the research project M2-0141 in the framework of the Target Research Programme "Knowledge for Safety and Peace 2006-2010", for Ministry of Defence of Republic of Slovenia. Maribor: Faculty of electrical engineering and computer science, 2008, 90 pages.

Mass-Spring Particle System for Cloth Simulation

Internal project

Duration: January 2006 to December 2007

Contemporary methods for realistic cloth simulation are typically based on mass-spring particle systems. Here particles are considered as small pieces of material connected by springs. Conceptually, the particles represent the crossing points between warp and weft threads, and are arranged within a grid in order to mimic the textile's structure. By adjusting the stiffness of the springs, characteristics of the simulation model (e.g. stretching, bending, and shearing) can be controlled. We use the optimized Verlet integration which is amongst the most efficient methods to formally describe particle systems.



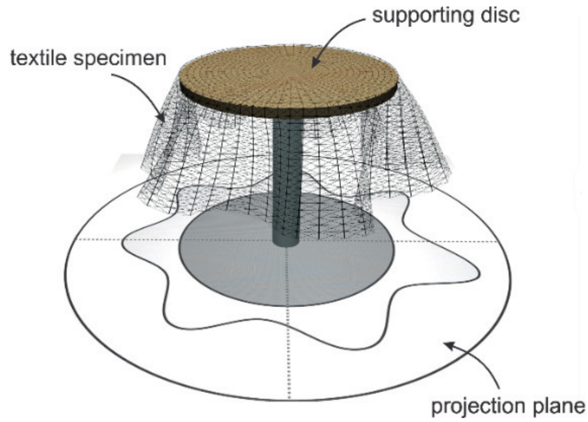
Case study of curtain strips: model during the stable phase (top left), model with applied wind effect (top right), axis-aligned bounding boxes (bottom left) and spheres (bottom right).

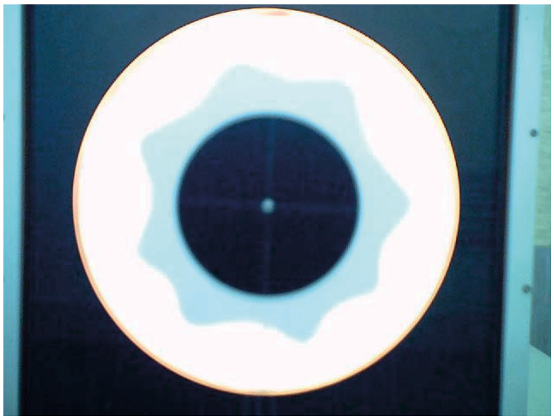
Collision detection is one of the sub-problems that particularly attracted our attention. We looked for a method capable of treating static and dynamic meshes and also addressing the self-collision detection problem. Hence we studied two basic acceleration techniques: axis aligned bounding boxes and bounding spheres.

Tests confirmed that both methods enabled smooth real time simulation of nearly 10,000 triangles even on an ordinary PC.

Tuning a cloth-simulation model was our main research challenge. Since there is no explicit correlation between the physical characteristics of textiles and stiffness of model's springs, mapping the physical characteristics to the simulation parameters is an extremely complex task. We have proposed a **hybrid evolutionary algorithm** (EA) which, to the best of our knowledge, represented the first EA-based approach to solve this problem. This was achieved by the following two features.

1. The initial genes represent parameters of predefined textile types. Industry acknowledges the drape as a crucial property. It describes the extent to which a textile deforms when allowed to hang under its own weight, and is usually measured using a drapemeter. The obtained drape curves are compared against the computer generated one. The parameters of the latter are then calibrated by the EA.
2. Our primary goal to improve the convergence in comparison to the initial simple EA was achieved by performing the local search only within the neighbourhood of the best individual in the population, by limiting the search-space with the heuristic elimination of springs, and by decreasing the mutation step over generations.





Drape curve acquisition (left) [1]; image of fabrics drape created by digital drapemeter (right).

Additional reading and resources:

[1] Mongus, D., B. Repnik, M. Mernik, B. Žalik. A hybrid evolutionary algorithm for tuning a cloth-simulation model. Applied soft computing 12 (2012) 266-273.

[2] Repnik, B., B. Žalik, Z. Stjepanović. Simulating the dynamic behaviour of textile fabrics. In: 8th AUTEX Conference, Biella, Italy, 2008, 8 pages.

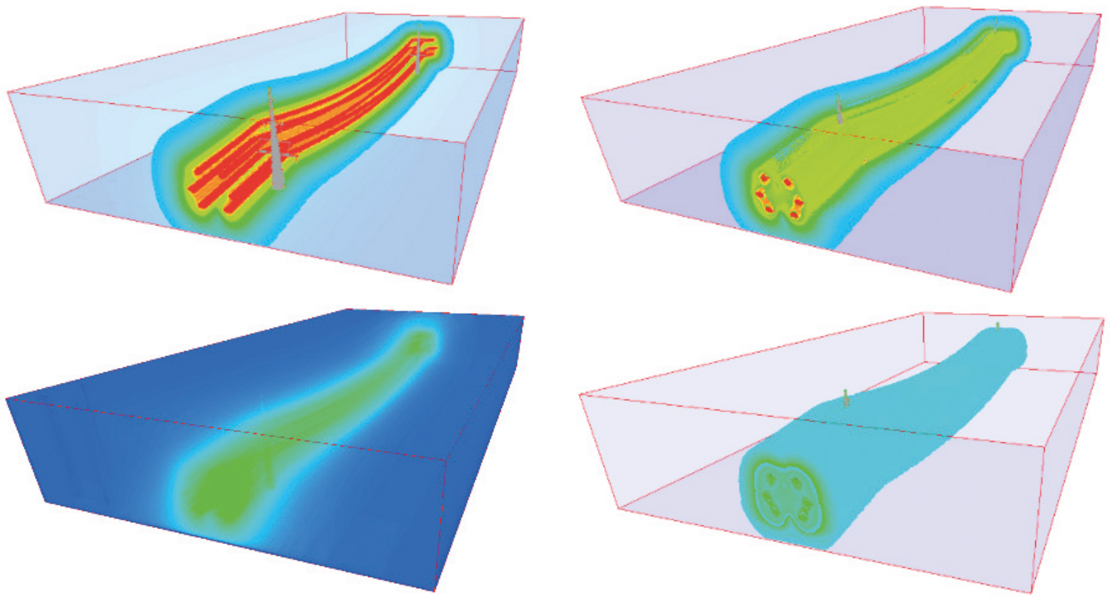
Volume Rendering of Electromagnetic Field

Internal project

Duration: 2014

Partners: Laboratory for fundamentals and theory in electrical engineering at UM-FERI; Power engineering laboratory at UM-FERI.

Visualization of the electromagnetic field on the high voltage transmission line is important for the electrical engineering society and also for environmental agencies. The latter do not directly calculate the field values, but need a visual representation for their analysis. The proposed visualization system is based on precise 3D calculations of electromagnetic fields on double circuit 400 kV transmission lines. The volume ray casting visualization technique is employed. The intensity is calculated using local maximum intensity projection, where the first local maxima of the sampled values exceeding the pre-specified threshold are displayed. Finally, a look-up table of the heat map colour scale is used to obtain the final image. The proposed system enables observers to move and observe the electromagnetic radiation within the 3D space. Interactive change of the scale is possible for the influential areas. Voxel representation of electromagnetic field is created as a graphical application and enables users to display the field independently from the numerical program tools.



Electromagnetic field values along a transmission line, visualized by different ray-casting techniques [1].

Additional reading and resources:

[1] Kitak, P., J. Pihler, A. Glotić. D. Horvat, D. Špelič, B. Žalik, I. Tičar. Pristopi k prostorski upodobitvi elektromagnetnega polja nadzemnih vodov (in Slovene). In: Pihler, J. (ed.). 23rd International Expert Meeting Power Engineering, May 13th to 15th 2014, Maribor, Slovenia. Maribor: UM-FERI, 2014, pp. 1-8.

Development and Integration of a System for Locating Caller in GIS

Financed by: ARRS; Ministry of Defence of Republic of Slovenia (contract M2-0138)

Duration: 1 June 2006 to 30 November 2007

Partners: Faculty of Electrical Engineering, University of Ljubljana; IGEA, d.o.o.

Determination of the caller's location when calling the emergency phone number 112 is of crucial importance for efficiently performing tasks of protection and rescue. Officials and professionals at the Administration of the Republic of Slovenia for Civil Protection and Disaster Relief (URSZR) are well aware of this demand and, therefore, they have established an extensive spatial database and spatial information system GIS_UJME years ago to assist operatives to orient on terrain.

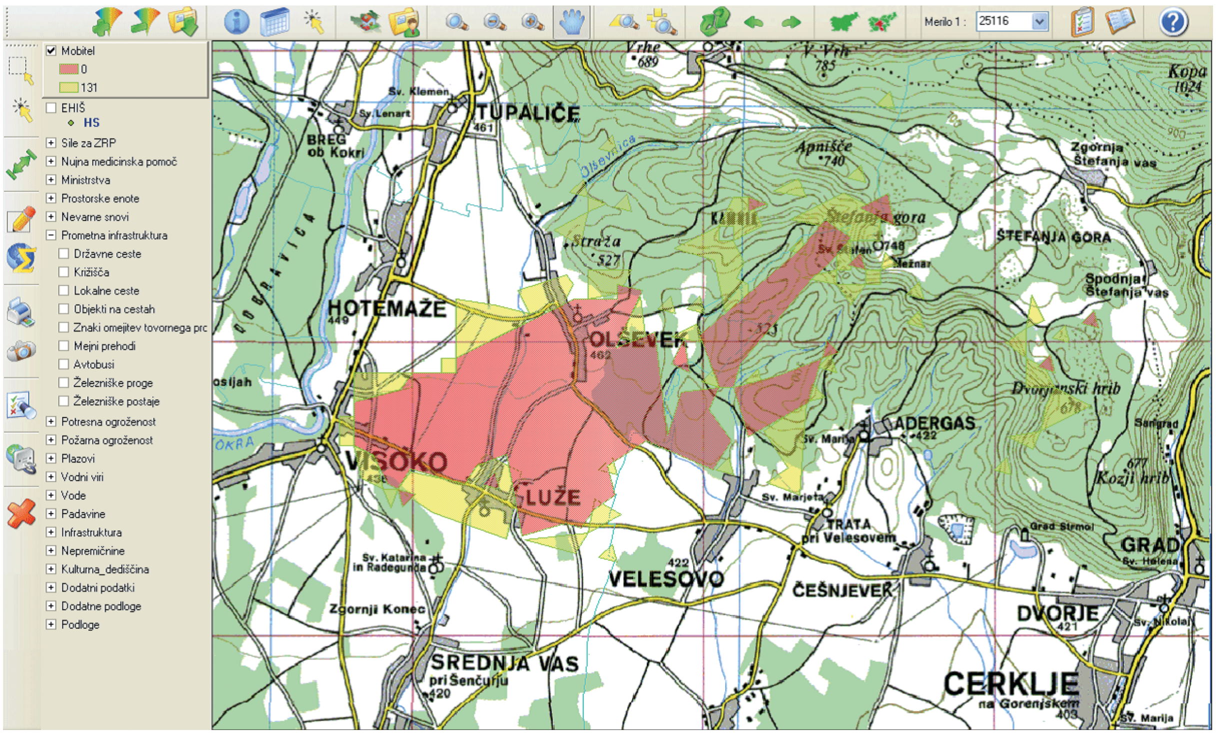
Nowadays, a caller usually calls 112 from the mobile phone directly at the location of the accident or from the nearest stationary or IP phone, but often has difficulties to describe his location. The goals of this project were to investigate (and improve) the possibilities of passing the geolocation of a caller from the stationary, mobile, or IP phone of any provider located in Slovenia to the GIS_UJME and to upgrade the latter with the visualization of the

GIS_UJME: demonstration of the location of a caller from a stationary phone number.

caller's location on the screen. These goals are directly reflected in the project results:

- draft of the agreement with telecommunications service providers on ensuring the data about providing the data on stationary or mobile phone callers' locations for needs of protection, rescue and relief,
- analysis of technological possibilities of data exchange with certain phone operators, and definition of system architecture and algorithms for transferring data about the caller's location, and
- implementation of the service for stationary and mobile telephony, and its integration into the GIS_UJME system. In the case of calling to 112, the GIS_UJME operator receives a graphical demonstration of the caller's location on the screen.

The proposed solution is directly transferable to similar systems, e.g. emergency medical services. Besides this, it can be upgraded to tracking which offers much wider range of applications in civil (location-based services) and military spheres (tracking of military crews and individuals).



GIS_UJME: demonstration of possible locations of a caller using a mobile phone number of the Mobitel operator. Yellow areas have lower probabilities of the caller's occurrence than the red ones.

Additional reading and resources:

[1] Žalik, B., B. Repnik, D. Fajfar, M. Pegan, K. Majcen, G. Küzma, V. Podobnik, D. Bele, B. Ilijevski, A. Štern. Development and integration of a system for locating caller in GIS (Razvoj in integracija prikaza lokacije kličočega v GIS za podporo ukrepanju ob klicu na 112): Target Research Programme "Knowledge for Safety and Peace 2006-2010": final report on the performed work. Ljubljana, 2007, 32 pages.

[2] Fajfar, D., K. Majcen, G. Küzma, B. Žalik. Prikaz lokacije kličočega ob klicu v sili (112). In: Perko, D. (ed.), et al. Geografski informacijski sistemi v Sloveniji 2007-2008 (GIS v Sloveniji, ISSN 1855-4954, 9). Ljubljana: Založba ZRC, 2008, pp. 417-423.

GeoServer Development

Financed by: IGEA d.o.o.

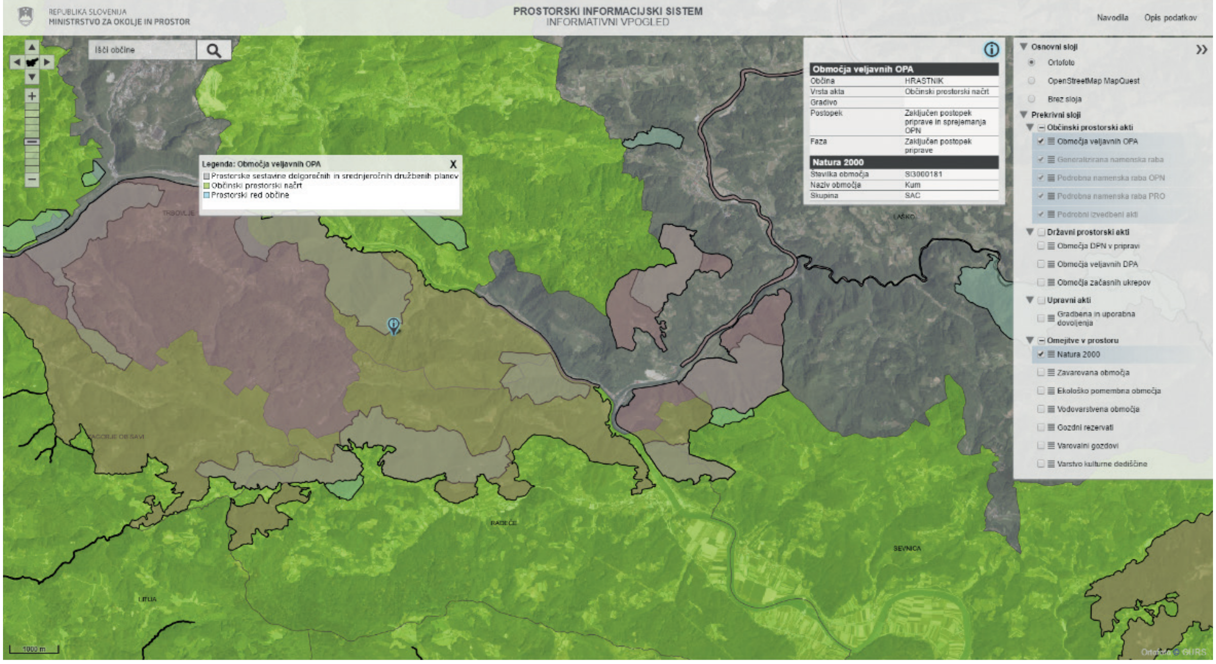
Duration: 2007 to 2010

Partner: IGEA d.o.o.

GeoServer is an OGC (Open Geospatial Consortium) compliant open-source server written in Java, allowing web users to share, process and edit geospatial data. Designed for interoperability, it publishes and enables transparent access to data from any major spatial data source using open standards such as:

- WFS (Web Feature Service): service for handling vector GIS data where results are returned in text (xml/gml/json) form,
- WMS (Web Map Service): service for generating rich georeferenced map images using the SLD standard,
- WCS (Web Coverage Service): service for serving rasters in "original" form (not usable for map clients, but as a raster transfer service),
- WFS-T (Web Feature Service Transactional): service for dynamic data updating, and
- WPS (Web Processing Service): a service with numerous defined functions enabling users to transform and execute all sorts of actions on the input data (using this service we can for example calculate which parcels intersect the buffer of the road segments of specific type).

GeoServer is also fully extendable allowing us to write custom extensions such as services, input formats, output formats, custom WPS functions and so on.



An example of a public GIS application, using GeoServer services for georeferenced map images creation.

As a community-driven project, GeoServer is being developed, tested, and supported by a diverse group of individuals from a number of different organizations around the world. IGEA d.o.o. from Ljubljana as one of the leading Slovene providers of solutions for real estate, infrastructure and space management also found strong interest to base their products on GeoServer and, furthermore, to actively participate to its development. GeMMA approached to this project in a form of a series of smaller subprojects agreed in a form of subcontracts to the principal contract. Our main contributions were:

- authentication for WMS requests and usage of the WFS authentication server,
- translation of the Geoserver source code into Jdeveloper, in order to enable functionality in Oracle IAS environment,
- integration of a security system in Geoserver,
- expansion of MapBuilder functionality,
- integration of data-store for MrSID format into the GeoServer infrastructure and update of data-store for ArcSDE spatial data,
- implementation of WFS-T specifications for spatial data manipulation for usage in Oracle Spatial and ArcSDE,
- the support for EPSG projection for the system of coordinates used in Slovenia, and
- development of tools for state maps and DOF infrastructure for Geoserver.

Additional reading and resources:

[1] Annual Report on Research Activities. Korže, D., B. Žalik (eds.) Maribor: UM-FERI, 2007, 2009, 2010.

[2] http://geoserver.org/

[3] http://boundlessgeo.com/products/opengeo-suite/geoserver/

[4] Mongus, D., B. Repnik, V. Podobnik, M. Pegan, B. Žalik. Zagotavljanje interoperabilnosti v geografskih informacijskih sistemih/ Ensuring interoperability in GIS. In :Interoperabilnost kot izziv informatiki, Zbornik prispevkov, Dnevi slovenske informatike 2008 - DSI, April 9.-11. 2008, Portorož, Slovenia. Slovensko društvo Informatika, 2008, pp. 1-9.

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Bus Arrival Prediction and Monitoring System

Financed by: DAT-CON d.o.o.

Duration: 2013 to 2014

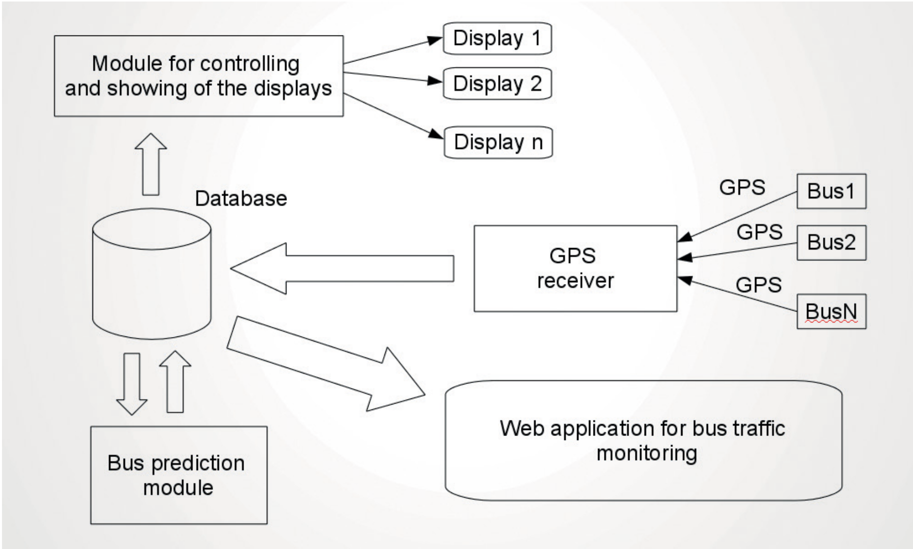
Partner: DAT-CON d.o.o.

The bus tracking and monitoring system was primarily developed for arrival prediction of buses on the bus stops in Maribor. The system predicts arrivals for up to 55 buses (up to 30 active buses in rush hours on working days). There are 29 bus stops included in bus tracking and monitoring system. Information about bus arrivals are shown on 41 displays. The developed software solution consists of several modules and applications.

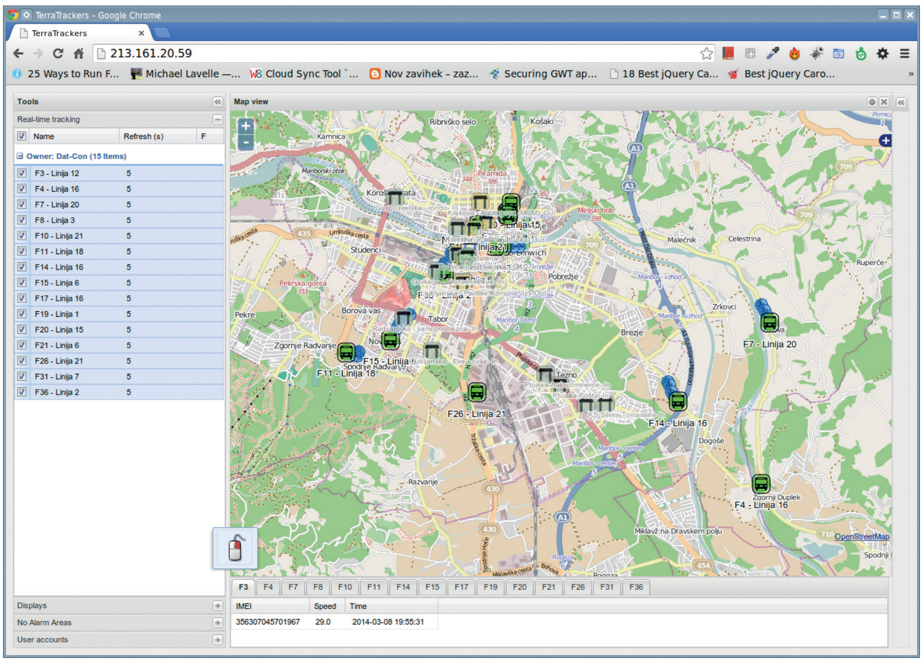
- The GPS receiver gathers GPS tracking information from buses.
- The database stores information (routes, stations, GPS tracking information etc.).
- The module for bus arrival prediction predicts arrivals to different bus stops. This is the most important module.
- The module for controlling the displays shows appropriate information at each display.
- The web application for monitoring the bus traffic is an instance of online GIS for real-time tracking of GPS-enabled objects, named TerraTrackers.

TerraTrackers works with all major web browsers, such as Firefox, Internet Explorer, Chrome, Safari, and Opera. It supports various databases (MySQL,
PostgreSQL and more) and represents a platform for various enduser applications, including road information displays, firefighters support and, of course, the public transportation predictions here discussed.

Displayed predicted bus arrivals times at one of the bus stops in Maribor [1].



Architecture of the bus arrival prediction and monitoring system.



Graphical user interface of web GIS application.

Additional reading and resources:

[1] Obrul, D., B. Žalik. Real-time online tracking platform. In: International Scholarly and Scientific Research & Innovation, (World Academy of Science, Engineering and Technology) 8 (2014), iss. 2, pp. 315-318.

[2] Obrul, D. Aplikacija GIS za sledenje objektom (GIS application for object tracking): diploma work at B.Sc. study programme. UM-FERI, Maribor, 2010, 41 pages.

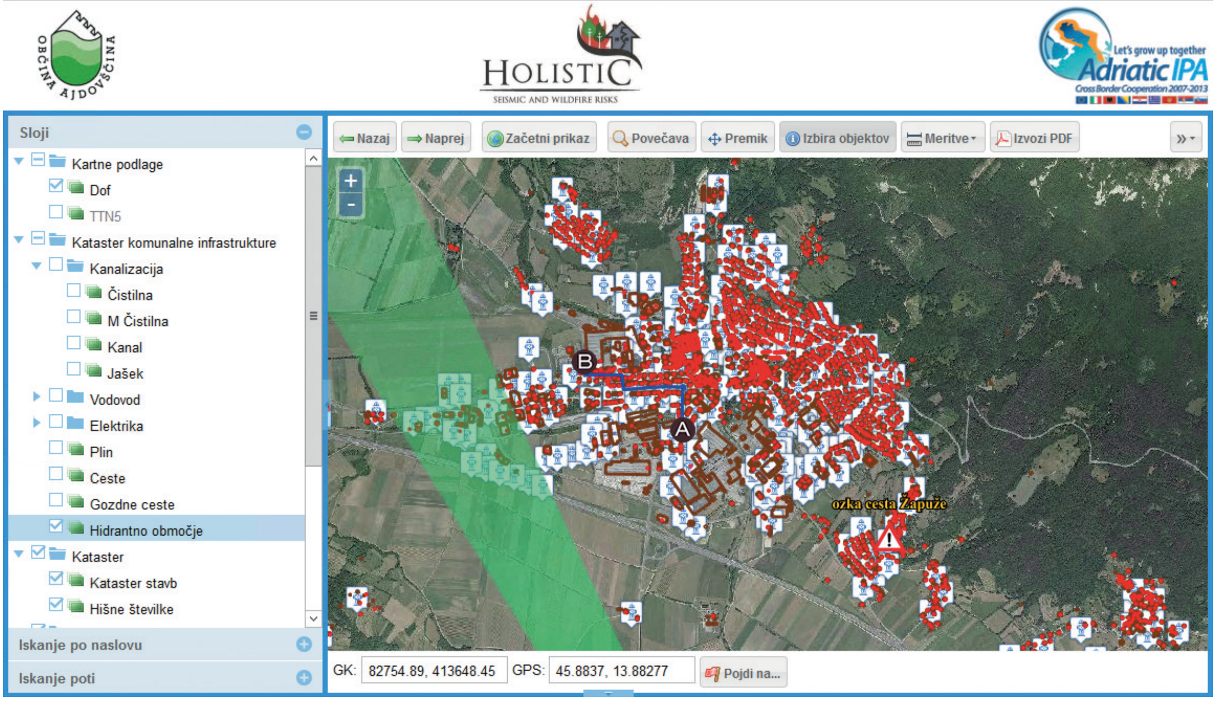
HOLISTIC – Wildfire Monitoring and Management System

Financed by: European Commission

Duration: From June 2014 to June 2016

Partners: Municipality of Ajdovščina; DAT-CON d.o.o; Slovenia Forest Service; 20 partners from Croatia, Bosnia and Herzegovina, Montenegro, Serbia, Albania, Greece and Italy.

HOLISTIC aims at development of comprehensive wildfire monitoring and management system at the Adriatic seacoast. GeMMA provided a group of experts for environmental and Earth Observation data processing for the Municipality of Ajdovščina, where the system is being evaluated in operational environment. An advanced GIS has been developed that provides real-time decision support to fire fighters, civil protection, and other first responders. This GIS allows for integration of real-time video-streams from thermal cameras and supporting information acquired by drones. Integrated analytics tools include navigation support for rescue teams as well as information support for evaluation of burned areas. In addition, the system integrates tracking of units for their improved coordination, supported by automatic routing and mapping of obstacles.



Current thermal camera view (green), densely populated areas (red), and the route of the fire brigade (blue) from its current position (A) to the fire location (B), together with all the layers of critical infrastructure.

Additional reading and resources:

[1] http://www.adriaholistic.eu/

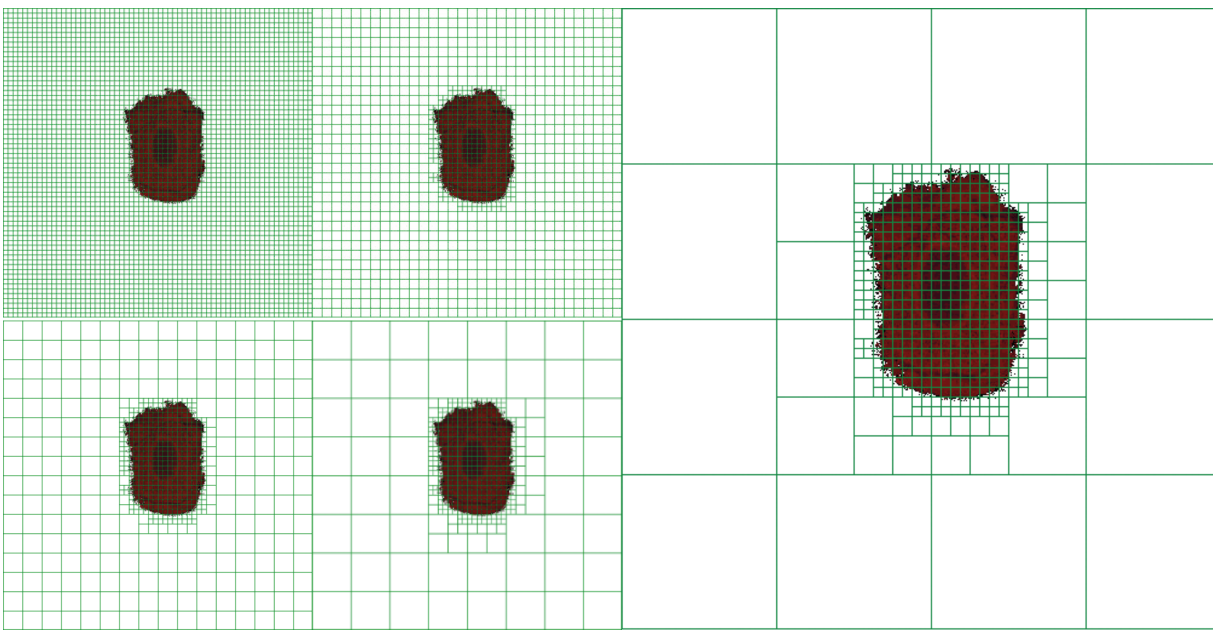
Lossless Compression of Voxel Data

Financed by: ARRS (2 young researchers and P2-0041 programme)

Duration: 2001 to 2011

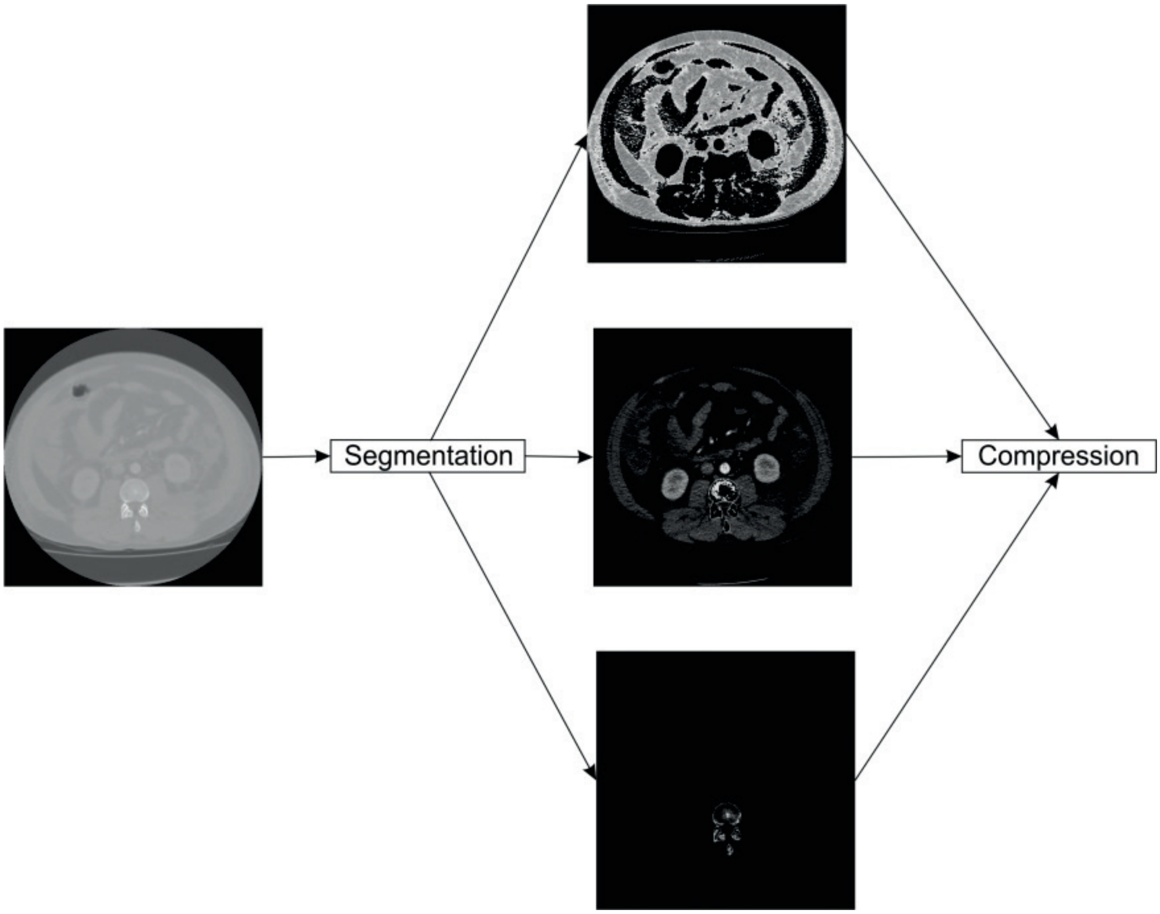
Voxels represent values on a regular grid in 3D space. Voxel or volumetric datasets may therefore be considered as a 3D extension of 2D raster images. They are attractive for many scientific areas, for example, medicine, geology or mechanical engineering. However, voxel datasets processing meets two considerable problems: slow visualization and large file sizes. This second problem has been systematically studied in GeMMA for a decade from 2001 to 2011, resulting in 2 Ph.D. theses, a diploma work and several scientific papers. Three approaches to lossless compression were developed.

1. A **quadtree-based progressive lossless compression** consists of three steps: a division quadtree is first built for each slice. Its smallest unit is called a basic macroblock. A Boolean intersection is then performed on pairs of quadtrees and the differences are stored. In the last phase, variable-length encoding is applied to reduce entropy among the differences. This method achieves, in general, better compression than the popular octree-based method. In addition, it can be realized using small on-board memory.
2. **Dr. DICOM** is a software tool for storing, exchanging and visualizing DICOM medical files over the Internet. More about it can be read in the next chapter.
3. **LoCoVox** is a lossless algorithm for compressing voxel-based 3D medical images. Firstly, data is segmented according



Quadtree-based progressive lossless compression: tree generation with prunning.

to selected ranges of the Hounsfield scale, and then arranged into two streams. The first one identifies positions of data not being segmented. This information is losslessly compressed by the JBIG standard. The second stream contains the exact data values and it is losslessly compressed by our algorithm. LoCoVox gives, in general, better compression results than the general-purpose RAR and our quadtree-based algorithm.



Lossless compression of threshold-segmented medical voxel data.

Additional reading and resources:

[1] Klajnšek, G., B. Žalik, F. Novak, G. Papa. A quadtree-based progressive lossless compression technique for volumetric data sets. Journal of information science and engineering 24 (2008) 1187-1195.

[2] Špelič, D., B. Žalik. Lossless compression of threshold-segmented medical images. Journal of medical systems 36 (2012) 2349-2357.

[3] Klajnšek, G. Postopek brezizgubnega stiskanja vokselskih podatkov s štiriškimi drevesi (An algorithm for lossless compression of voxel data using quadtrees): Ph.D. thesis. UM-FERI, Maribor, 2005, 130 pages.

[4] Špelič, D. Postopek brezizgubnega stiskanja razčlenjenih vokselskih podatkov (Lossless compression of segmented voxel data): Ph.D. thesis. UM-FERI, Maribor, 2011, 111 pages.

PCA-Based Video Compression

Financed by: ARRS (young researcher fellowship and P2-0041 research programme)

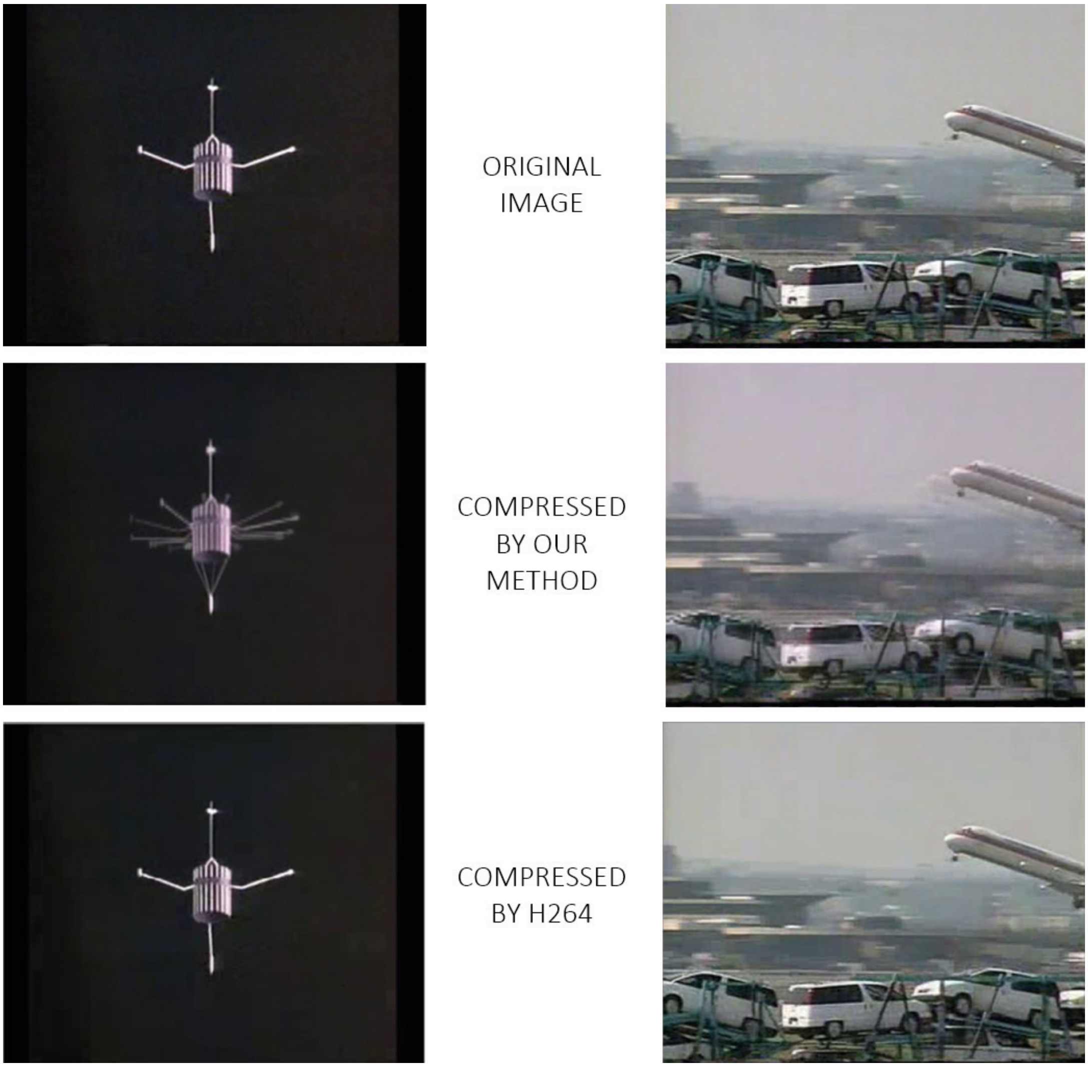
Duration: 2011 to 2014

Video compression has gained importance in recent years, as increasingly more multimedia data are being transferred in digital form for digital television or internet streaming. We have developed a new efficient method for video representation that exploits redundancy in successive images in a completely different manner from the standard contemporary methods. Namely, the latter rely on motion compensation, while our approach uses a special encoding database obtained by the primary components analysis (PCA). This can be either separately constructed for each video or can be general for a bigger collection. In any case, the database can be personalized (i.e. each user can create his own database) and thus, it serves as a protection key, allowing only the owner to decode video information.

In comparison to standard video compression algorithms, the proposed method produces

In slow moving scenes, our method maintains better quality than H264, where the pattern of macroblocks appears with much sharper contrast.

visible errors only when truly fast movements are recorded, making it especially adapted for slow moving scenes. According to the experiments, the achieved compression ratios are comparable to popular MPEG-4 AVC/H264.



In the case of fast motion, our method produces errors in a form of blurred or doubled objects and possible colour changes.

Additional reading and resources:

[1] Gangl, S., D. Mongus, B. Žalik. An efficient eigenspace updating scheme for high-dimensional systems. International journal of applied mathematics and computer science 24 (2014) 123-131.

[2] Gangl, S. Algoritem stiskanja domenskih zaporedij slik s projekcijo v prostor osnovnih komponent (Domain-bound image sequence compression algorithm based on projection to principal component space): Ph.D. thesis. UM-FERI, Maribor, 2014, 111 pages.

Chain Code Representation of Rasterised Shapes

Financed by: ARRS (grants J2-5479, J2-6764, P2-0041, 1000-13-0552); Slovenian–Chinese bilateral project BI-CN/14-15-007; European Regional Development Fund; National Natural Science Foundation of China

Duration: 2004 to now

Partner: Dalian Nationalities University, College of Computer Science and Engineering, China

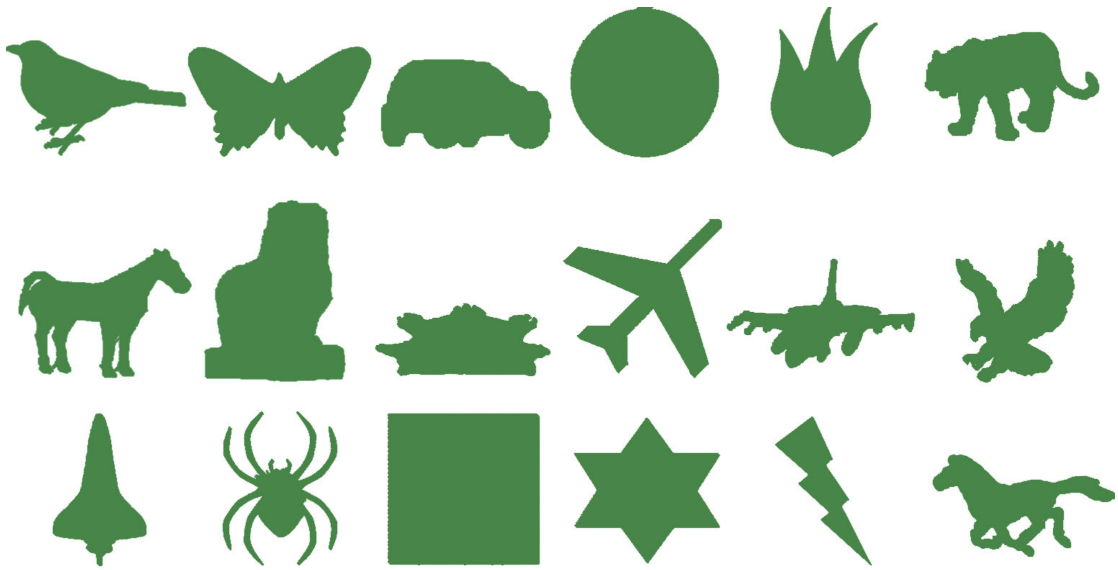
Chain codes compactly represent rasterized curves. Instead of encoding grid coordinates of all curve pixels with for example 2 × 16 bits per pixel, moves between subsequent pixels along a curve are encoded. More than half a century ago, Freeman utilized 8-connectivity pixel paradigm[1] to encode curves with 3 bits per pixel[2]. His idea and the overall concept of chain codes were re-discovered in the 1990s for needs of visualization in (embedded) systems with weak processing power and low memory capacity, and for shape encoding in new video standards. Together with our Chinese colleagues, we didn‘t miss a chance to do some pioneering work in this field as late as in the first decade of the new millennium, and to proceed with more advanced solutions recently. All our lossless compression methods are surveyed below. Each of them achieved better compression rate than the state-of-the-art methods of similar complexity from the same era.

- Directional difference chain codes (**DDCC**) adapt the traditional Freeman's chain-difference coding (CDC) scheme. An averaged statistical model is extracted from over 1000 training discrete objects, and used for Huffman coding of CDC symbols.
- Compressed vertex chain codes (**C_VCC**) extend Bribiesca's vertex chain codes (VCC) with two additional symbols for consecutive pairs (0, 2) and (2, 0). A rasterized curve is encoded by hard-coded averaged Huffman codes.
- Compressed directional difference chain codes (**C_DDCC**) extend the DDCC statistical model by extra codes for pairs (45°, –45°) and (–45°, 45°) and for RLE encoded 0° sequences.
- The chain code compression method based on move-to-front transform and adaptive run-length encoding (**MTFT + ARLE**) introduces an important conceptual novelty by adapting to the characteristics of a particular shape without performing statistical analyses. It firstly utilizes the almost forgotten MTFT to reduce the information entropy in the input sequence of chain codes (VCC, 3OT or newly introduced **NAD**), and the resulting entropy-reduced chain code is then encoded with the variable-length coding ARLE.
- The universal chain code compression (UCCC) first converts the input sequence of chain codes into the binary stream independent of the input chain code representation (F8, F4, VCC, 3OT and NAD were used in tests). Then, the compression is done using three modes:
  - RLE0 to compress runs of 0-bits,
  - LZ770, a simplified version of LZ77, to handle repetitions within the bit stream, and
  - COPY, the escape mode when neither RLE0 nor LZ770 can be efficiently used. In such a case, the input bits are directly copied to the output.

1 The Freeman chain code in eight directions (F8) also has a variant in four directions (F4) which spends only 2 bits per pixel, but the rasterized curve usually consists of significantly more pixels than in F8 representation.

2 The contemporary methods are approaching average compression rate of 1 bit per pixel.

- **String transformation techniques**, including Burrows–Wheeler Transform (BWT), MTFT, and the constant 0-symbol Run-Length Encoding (RLE_0^L), may all reduce the information entropy. The ordered sequence (MTFT, RLE_0^L, BWT) provides the best results for input schemes with short alphabets (VCC, 3OT), while it is more suitable to apply only BWT otherwise (for F8, F4 and NAD). Entropy is coded by a binarization model combined with RLE0. 3OT turns out the most compressible while F8 is the least.
- Unsigned Manhattan Chain code (**UMCC**) considers movement through the shape's boundary pixels by separating x- and y-coordinate directions. UMCC switches between the movement and the sign context and in this way, only 2 symbols {0, 1} are needed.



Different shapes employed for testing our chain code compression techniques.

Additional reading and resources:

[1] Liu, Y., B. Žalik. An efficient chain code with Huffman coding. Pattern recognition 38 (2005) 553-557.

[2] Liu, Y., W. W. Wei, P. J. Wang, B. Žalik. Compressed vertex chain codes. Pattern recognition 40 (2007) 2908-2913.

[3] Liu, Y., B. Žalik, P. J. Wang, D. Podgorelec. Directional difference chain codes with quasi-lossless compression and run-length encoding. Signal processing, Image communication 27 (2012) 973-984.

[4] Žalik, B., N. Lukač. Chain code lossless compression using move-to-front transform and adaptive run-length encoding. Signal processing, Image communication 29 (2014) 96-106.

[5] Žalik, B., D. Mongus, N. Lukač. A universal chain code compression method. J. of visual communication and image representation 29 (2015) 8-15.

[6] Žalik, B., D. Mongus, K. Rizman Žalik, N. Lukač. Chain code compression using string transformation techniques. Digital signal processing 53 (2016) 1-10.

[7] Žalik, B., D. Mongus, Y. Liu, N. Lukač. Unsigned Manhattan Chain Code. Journal of visual communication and image representation 38 (2016) 186-194.

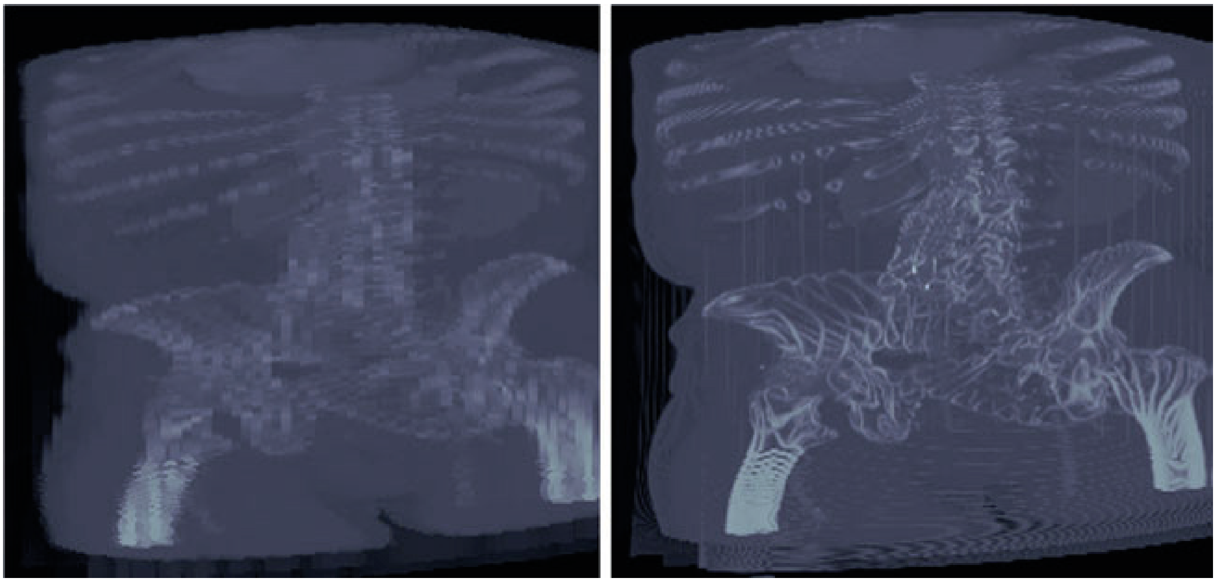
DICOM Compression and Progressive Visualization

Internal project

Duration: January 2006 to December 2007

The Digital Imaging and Communications in Medicine (DICOM) is the most widely used standard for the exchange of medical image data. As a typical study can contain hundreds of files consisting of textual and volumetric data, compression of DICOM files is frequently applied, mostly by using JPEG for the volumetric data within each single file. Here we present Dr. DICOM, an efficient software tool for storing, exchanging and visualizing DICOM files over the Internet. Dr. DICOM consists of a server with stored compressed DICOM studies and a Java applet that performs decompression of volumetric and textual data. The applet offers basic visualization based on ray-casting, selection of colour palettes and basic geometric transformations (zooming and rotating). Three main contributions of Dr. DICOM are as follows.

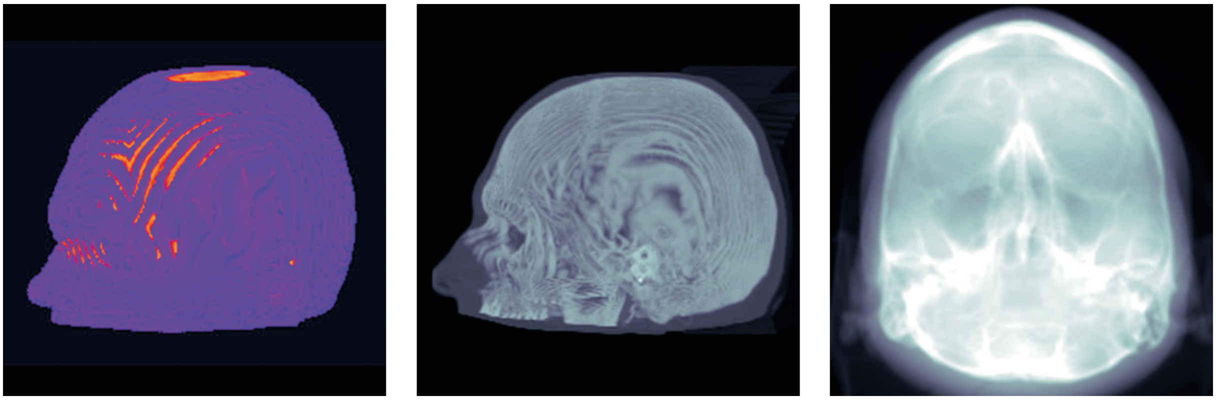
1. **Efficient compression**. Files from the same study are considered as a volumetric object, which is progressively compressed using the lossless quadtree-based method from the previous chapter. The average compression rate is around 65%. The text is losslessly compressed using a predicting scheme.
2. **Quickly identifiable objects during progressive visualization**. Due to the progressively compressed volumetric space, users can quickly determine the content of the data being transferred, progressively decompressed and visualized. Visually useful information is obtained after a few seconds,



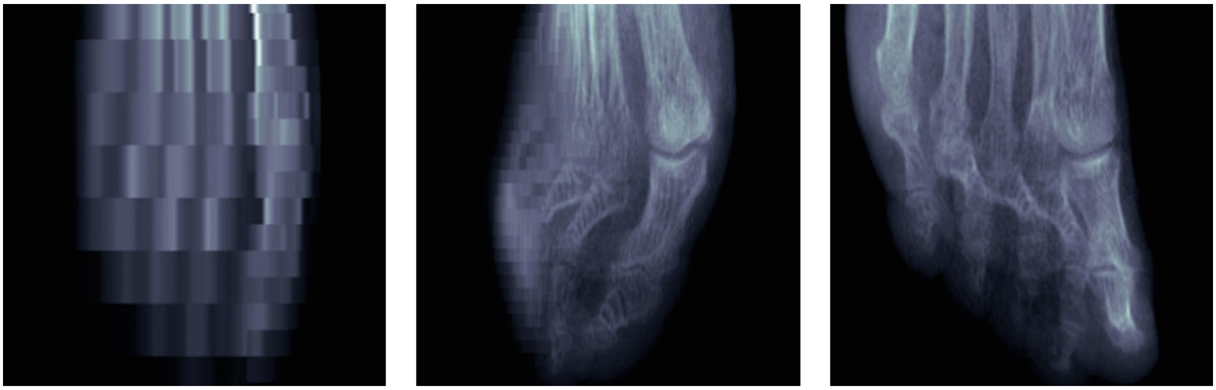
Object quality after 26 s with 3.532 kB downloaded data (left) and after 217 s—complete transfer with 23.740 kB (right). The original dataset size was 89.088 kB in 174 slices.

which is much faster than with classical methods (Zip or Rar), where a complete download is needed before the content can be examined.

3. **Interaction with objects during the progresssive decompression.** A user can manipulate (rotate, scale) the model while the decompression is still taking place. This is possible as the data is hierarchically transferred, not just as single images.



Implemented ray-casting techniques: first hit ray-casting (top), maximum intensity ray-casting (middle), and density integration ray-casting (bottom).



Progressive transfer and visualization of a foot dataset; after 10 kB (left), after 790 kB (centre) and after full (4.639 kB) transfer (right). The scene has been interactively rotated before each screenshot.

Additional reading and resources:

[1] Obrul, D., Y. Liu, B. Žalik. Progressive visualization of losslessly compressed DICOM files over the internet. Journal of medical systems 36 (2012) 1927-1933.

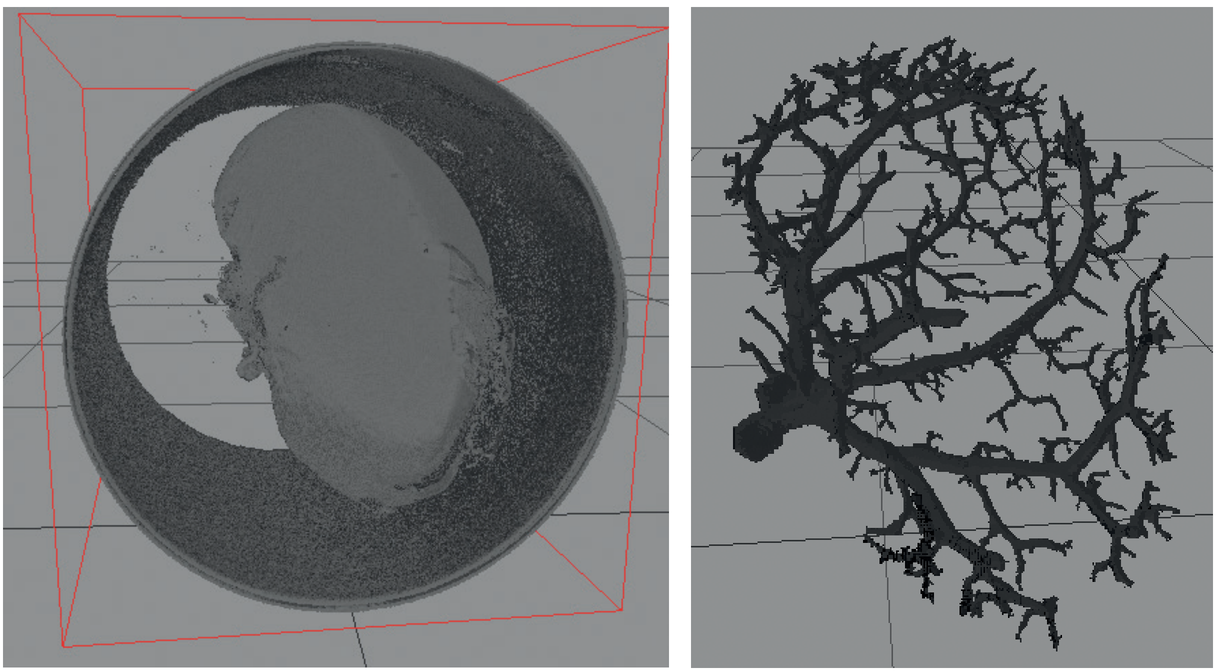
[2] Obrul, D., B. Žalik. Sistem za napredujoč prenos in prikaz stisnjenih podatkov DICOM (System for progressive transfer and visualization of DICOM data). Informatica medica slovenica 15 (2010) 25-26.

[3] Obrul, D. Brezizgubno stiskanje podatkov DICOM (Lossless DICOM data compression): diploma work of professional higher education programme. UM-FERI, Maribor, 2007, 43 pages.

Filtering and Characterization of Vascular Network

	Internal project
Duration:	Since 2015
Partner:	Faculty of Natural Sciences and Mathematics, University of Maribor.

Micro Computed Tomography (micro-CT) has emerged in recent years as the preferred modality for vascular studies, because it provides high-resolution 3D volumetric data suitable for analysis, quantification, validation, and visualization of results, at the level of an organ or set of tissues. This particular study is aimed to screen potential vascular morphogenesis impairment of adult mice in which some of the core PCP (planar cell polarity signalling) genes were absent. Thus, multiple voxel models of scanned mouse kidneys were processed by extracting the vascular structure which was then geometrically characterized. This was done using skeletization, distance transformation and other advanced approaches of mathematical morphology. The output was then used for automated reconstruction and level ordering of the vascular tree.



Visualisation of unfiltered (left) and filtered (right) 3D volumetric dataset of a mouse kidney. The latter reveals the vascular network.

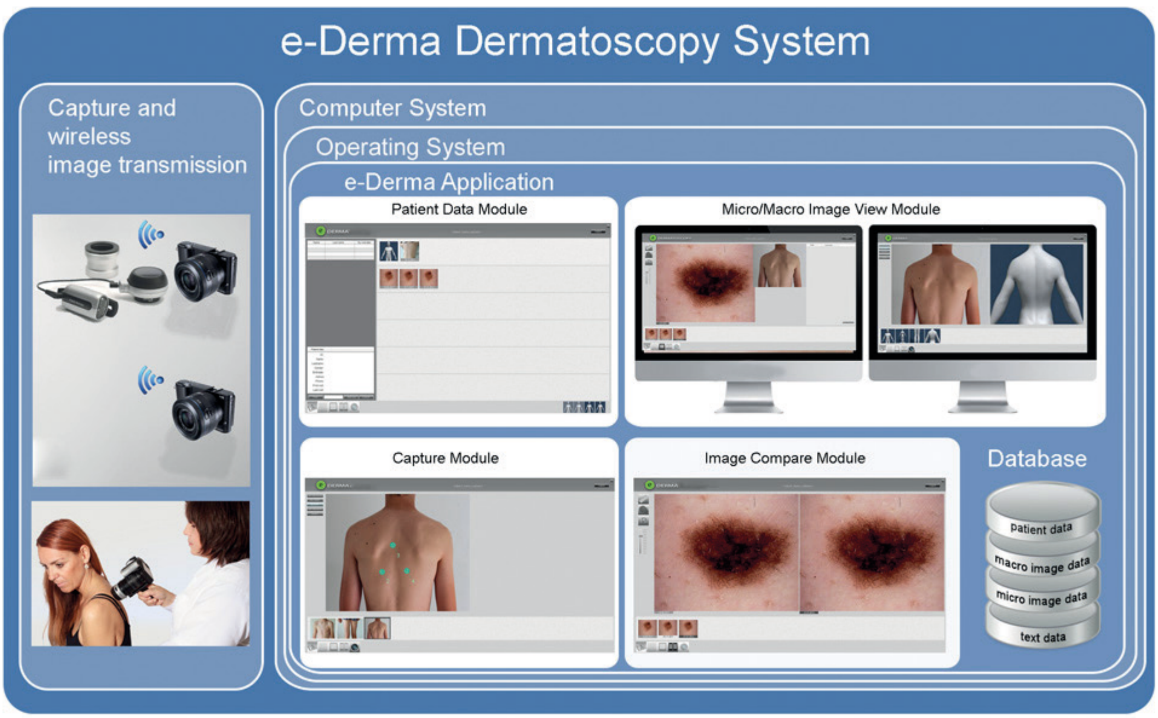
e-Derma – Wireless Dermatoscopy System

Financed by: GeMMA; Laboratory for microcomputer systems (LMS) at UM-FERI

Duration: Since January 2008

Partners: LMS (Bogdan Dugonik), Maribor University Medical Centre (Aleksandra Dugonik)

Cutaneous melanoma (CM) is a malignant tumor, which is one of the most rapidly growing cancers. Discovering a melanoma in the early stages of the disease is extremely difficult and as such only an invasive disease stage is easily identified with the naked eye. Dermatoscopy is a diagnostic method intended to maximize early detection of CM performed by the dermatoscopy system. To address the limitations of existing systems a novel, wireless digital dermatoscopy system is presented for providing the high-resolution images. It integrates a wire-free camera operation and offers a safe transfer of captured images to the computer. We perform the working process of evaluation on available dermatoscopy systems the most commonly used in everyday dermatology practice. Some findings like operability, image quality, scalability, user-friendliness, and safety are used for the development motivation of an e-Derma dermatoscopy system. The integrated wireless image transfer technology eliminates the movement limitations of a therapist working with cables. The image resolution is not limited by the integrated camera; it is easily upgradable with alternative or improved camera models.



The e-Derma system overview.

Analysis of Cells From Islet of Langerhans

Financed by: ARRS (P2-0041 research programme); Centre for Open Innovations and Research (CORE@UM)

Duration: Since 2012

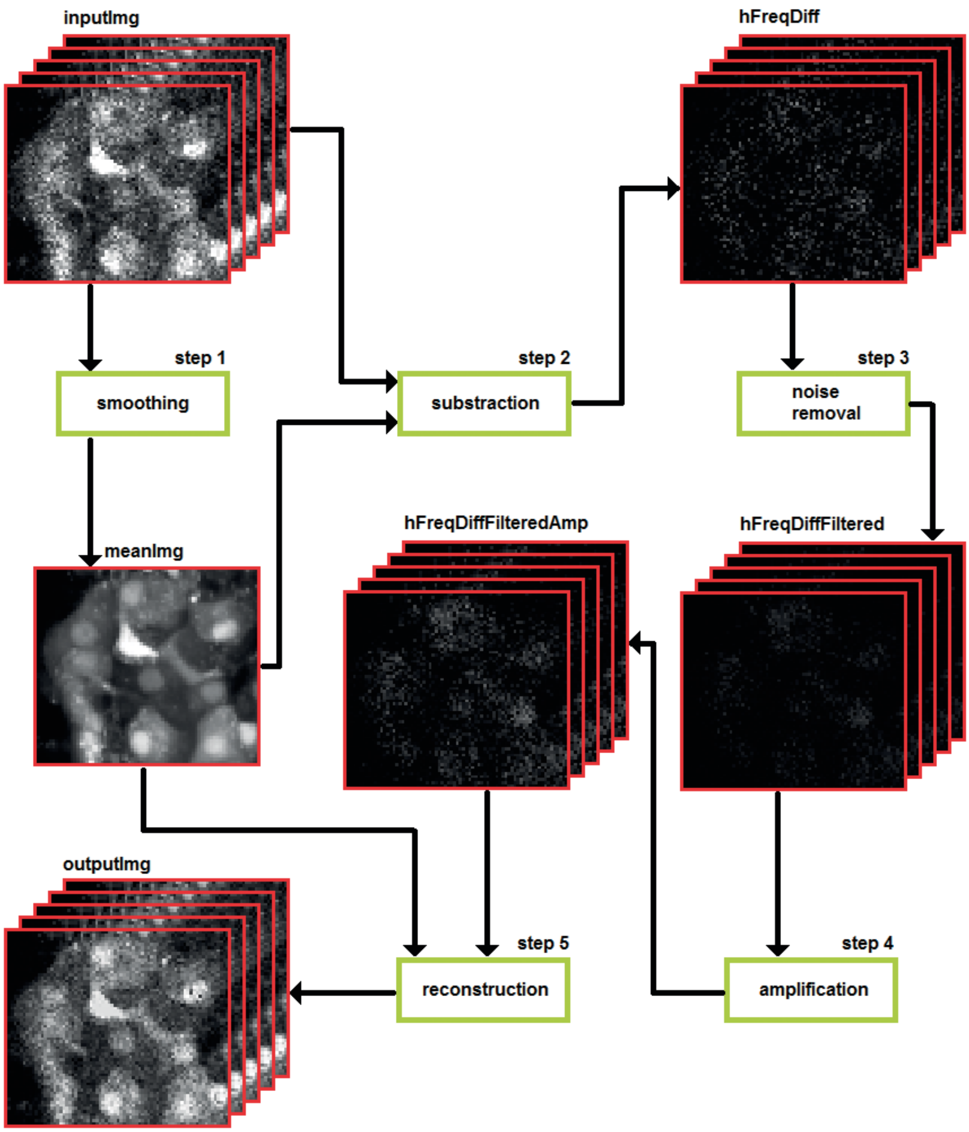
Partner: Institute of Physiology, Faculty of Medicine, University of Maribor

Pancreatic islets of Langerhans include beta cells, which are precise biological sensors for glucose and play a central role in balancing the organism between catabolic and anabolic needs. The main challenge related to the beta cells analysis is how to effectively measure cell membrane's potential and calcium changes simultaneously in as many cells as possible and with high spatial and temporal resolution. Highly sensitive membrane potential reporter dyes in combination with high temporal and spatial confocal calcium imaging can be used for this purpose, but the signals are noisy.

We have developed a complex algorithm for data denoising, consisting of three main steps. Firstly, the detection of changes in the fluorescence signal is achieved by decomposing individual images of the time-series into a series of high-frequency differences HFD and a low-frequency mean LFM image. Secondly, a noise removal filter is applied on each HFD image, such that the meaningful signal containing information about oscillations is preserved. Finally, output images are constructed by summing the denoised HFD and LFM images. This produces a reconstructed image stemming from LFM and the overlaid filtered signal from denoised HFD. The signal can be additionally amplified to make the visualization of the spatio-temporal dynamics of beta cells clearer.

Our and several other image denoising algorithms are integrated into ImageFiltering, a software tool for preprocessing and analysis of time-series images in order to examine beta cells' physiology. The integrated video player can play loaded files with adjustable frame rate since the images can be captured in different time intervals. We can also set the predefined colour look-up tables for the visualization of desired rectangular, elliptic or polygonal regions of interest (ROI) and/or selected value intervals.

We have also proposed a software tool BenchGen for generation of benchmark data for evaluation of denoising algorithms. Such computer generated datasets (CGDs) have an advantage that they may provide the absolute ground truth, free of noise and other distractions. Namely, if a CGD together with systematically designed noise closely mimic real-world data behavior and if this CGD can be satisfactorily denoised afterwards, then it is quite likely that the same denoising algorithm could be successfully utilized in the real-world scenario as well. In our case, a CGD time series simulates a fluorescence microscopy imaging data of $Ca2+$ events in pancreatic beta cells. BenchGen enables a user to precisely tune a range of parameters like cell shapes, noise and signal definition. The latter comprises the number of oscillations, their direction and speed. For each oscillation, a user sets the beginning and duration of up-stroke event, the peak value and duration of peak value event, and finally the duration of release event. The shape of each event can be modelled with a predefined math function.



Flowchart of algorithm used to denoise data obtained from confocal imaging.

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[2] Špelič, D., N. Lukač, B. Žalik. GPU-based method for denoising time series of fluorescent imaging data. In: 2nd International Symposium on Computing and networking, 10-12 December 2014, Shizuoka, Japan. CANDAR 2014, pp. 360-366.

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Miscellaneous

Reconstruction of Controlled Distorted Image Using a Working Circle

Internal project

Duration: 2011 to 2012

The process of deliberate image corruption and reconstruction.

The method reconstructs deliberately corrupted pixels in raster images. Firstly, a faster approach for reconstructing corrupted pixels is proposed by applying a processing-circle instead of a processing-square. It is shown that the obtained quality of the reconstructed image is no worse because of this. The quality of the reconstruction is further improved by controlling the pixel corrupting process within the input image. It is shown that a combination of the processing-circle approach and data-dependent corruption reduces the reconstruction time and the mistakes of the reconstructed pixels.

Additional reading and resources:

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Digital Library for Blind and Visually Impaired Persons

Financed by: Union of Associations of Blind and Visually Impaired of Slovenia

Duration: 2013 to 2014

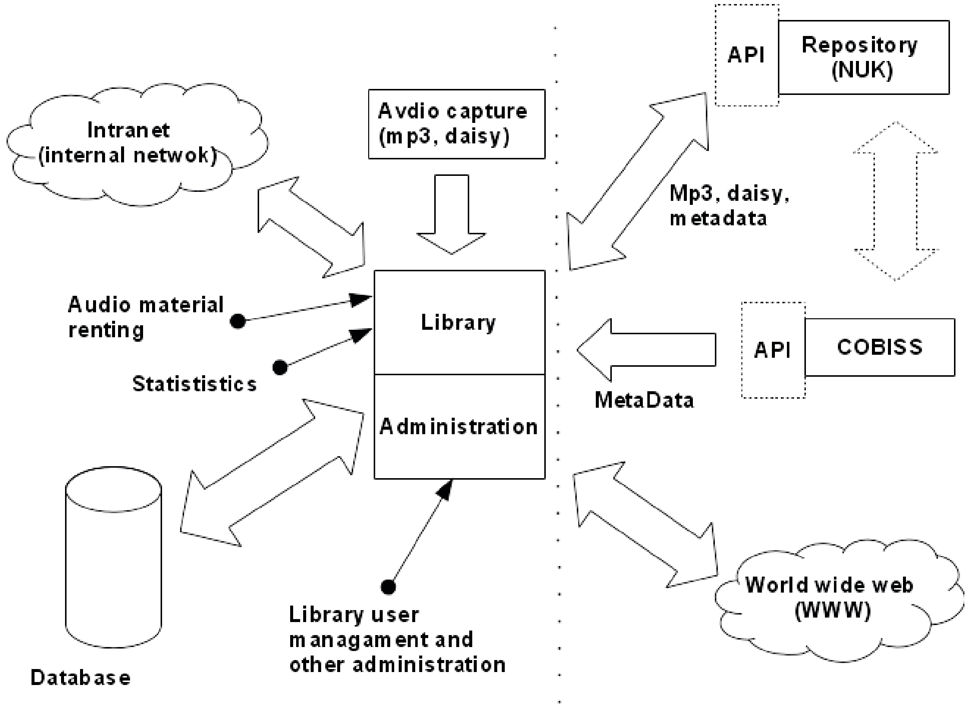
Partners: Geodetic Institute of Slovenia; National and University Library of Slovenia; Faculty of Social Work, University of Ljubljana; KORSO, Robert Paić s.p.

The main project goal was to implement a digital library for blind and visually impaired persons and persons with reading disabilities. The platform consists of several modules with numerous functionalities accessible through a web user interface. Some parts of this interface are specially developed for blind and visually disabled persons. The system provides services needed for the production environment (audio capturing) and the distribution environment (accessing the digital audio material from the digital material repository). The library users can search, select, download and listen the selected digital audio materials. The two acoustic format "mp3" and "daisy" are supported. The latter is specially designed for blind and visually impaired persons and those with reading disabilities, and enables them more flexible and pleasant reading experience. The Administration module provides numerous functionalities for management of users and digital materials and collecting numerous statistics.

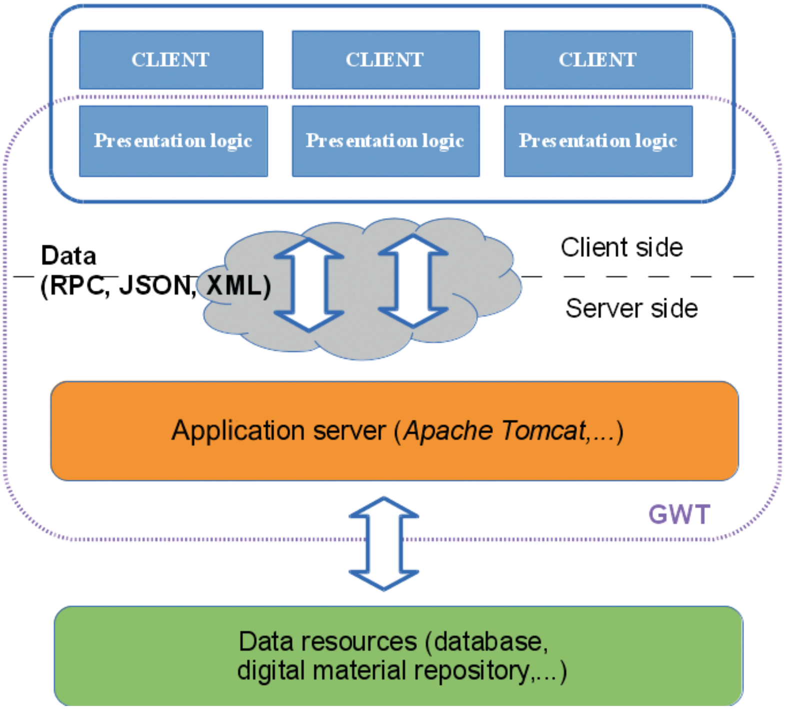
The platform is based on the open source developer tool GWT (Google Widget Toolkit) which is specially designed for running web

Digital library for blind and visually impaired.

applications on different web browsers, including those on mobile devices and smartphones. The web application runs on the Apache Tomcat application server.



The system design.



Basic system architecture.

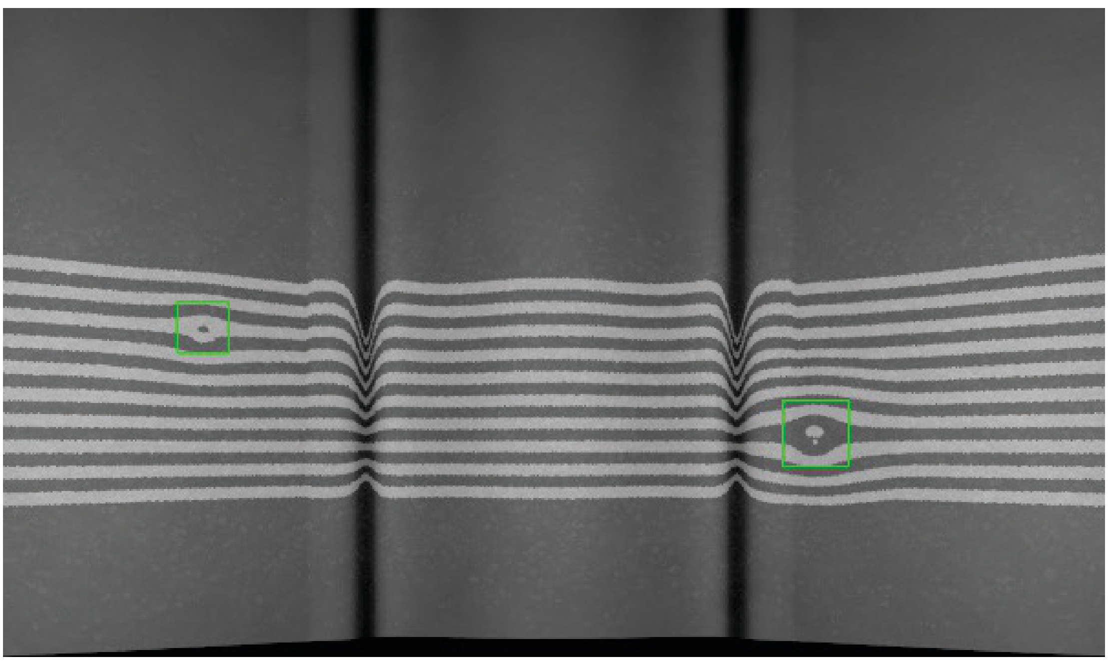
Device for Damage Detection – D^3

Financed by: Nano Solver GmbH, Germany

Duration: March 2015 to May 2015

This project represented the development of a device for damage detection of a vehicle. Such solutions already exist but are expensive, scanning takes long and can take up much space for their construction and are also complicated to use. The main focus of this project was to make an easy to use, price efficient device, yet fully functional to detect damage on the car. An important characteristic of the device was also, that it should enable quick scanning of the vehicle, without any preparations of the car. As the device should take as little space as possible, it was based on a gate-like construction type. The main target groups of damage for detection were dents, scratches and glass damage. At the time, the main focus was exploiting and acquiring data of surfaces containing dents and also scratches on painted surfaces.

The result of the project was a prototype gate-type device that exposed car damage using deflectometry. A series of price efficient cameras were positioned around the gate in such a way, that they could capture the shape of most car models. To expose dents on the surface, illuminated stripped patterns were positioned all around the gate, with the mentioned cameras recording their reflection. The pattern deformed upon crossing a dent and therefore indicating possible damage.



Example of two detected dents on a bent surface.

The device's operation is based on specular reflection from the surface of a vehicle.

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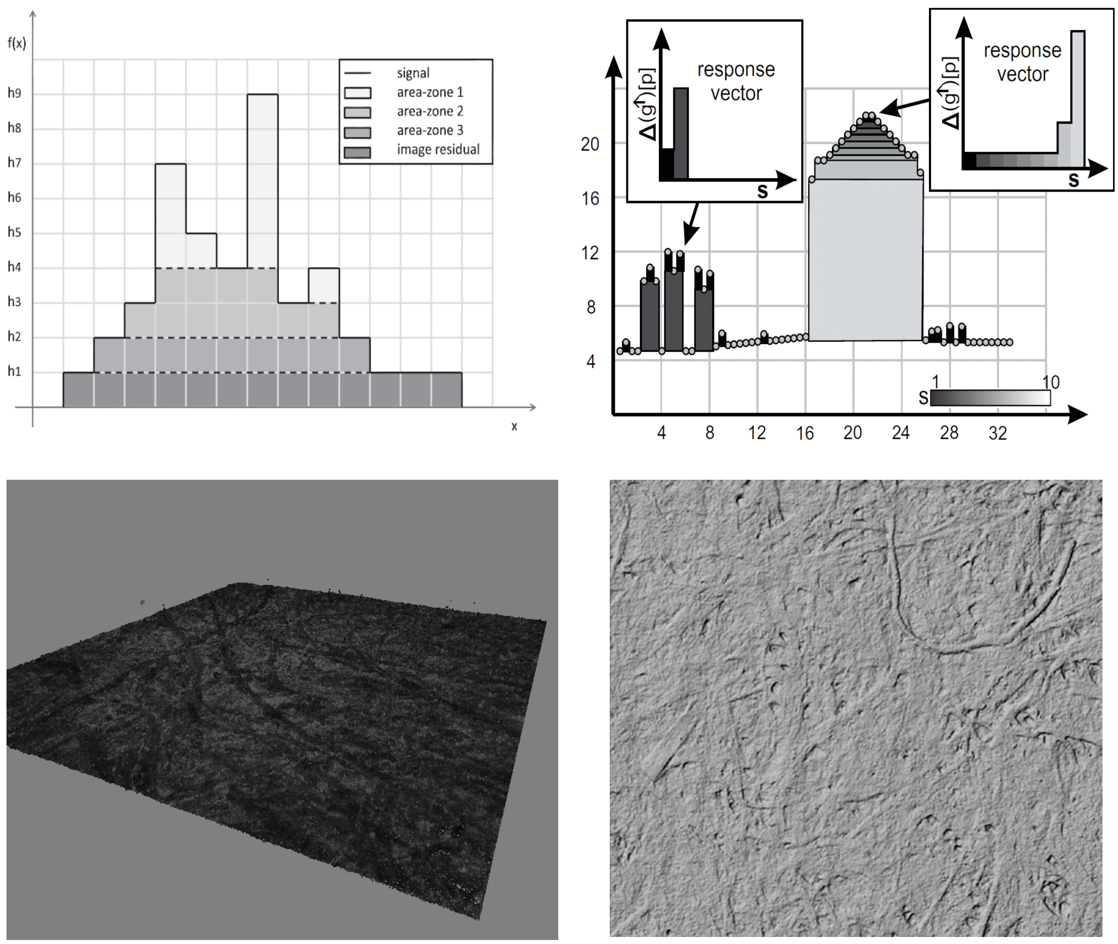
A Method for Estimating Paper Roughness

Internal project

Duration: 2015

Partner: Institute of engineering materials and design at the faculty of mechanical engineering, University of Maribor.

The surface topography and morphology of high grade office and print papers is of immense importance for high printing performance and a constant product quality. As a result, reliable analytical methods are necessary to assess the influence of production parameters. In addition, it is of high interest to analyze the influence of paper morphology on the printability of the products. Several surface sensitive methods have been used in the past to investigate and illustrate high-resolution topography of paper. One of these methods is confocal laser scanning microscopy (CLSM), which provides nanometre depth precision. Even though CLSM is a very powerful technique that is frequently used in life sciences, sample preparation and data analysis



Paper roughness estimation procedure and results [1].

are far from being trivial. In order to define the surface, images are stacked one over the other. At each XY position, the column of intensity values is inspected and the Z coordinate of the surface is defined by the voxel with the highest intensity. Although this surface definition gives relatively good surfaces, it still contains noise. Additional filtering is therefore required in order to remove small undesirable peeks and holes, which appear as a consequence of thresholding error. However, when smoothing the data, we need to be careful and remove only the noise without damaging the actual surface. We achieve this by estimating heights and widths of peeks and removing only those peaks, which are too small to represent the fibres. For this purpose, we filter the surface with a series of different filters, ranging from the smallest one to the largest one. The filter that removes the highest peek at a particular pixel is obviously the most important one and it defines the height and the width of the peak. Since fibres are of round shape, they should produce lower peaks at highest scales, while noise is characterized by sharp high peaks. Based on this, we can efficiently delete these values and replace them with interpolated values. For interpolation, we use an inverse distance weighting method, as it does not introduce any additional variations. Denoised surface is then ready for evaluation of roughness. However, the paper is not completely flat when it is being scanned and thus, the output surface is concave. In order to minimize this effect, the average height within the neighbourhood of each pixel is estimated and subtracted from the height of the pixel. The obtained difference is then used to calculate the root mean square value that is essentially the estimation of paper roughness.

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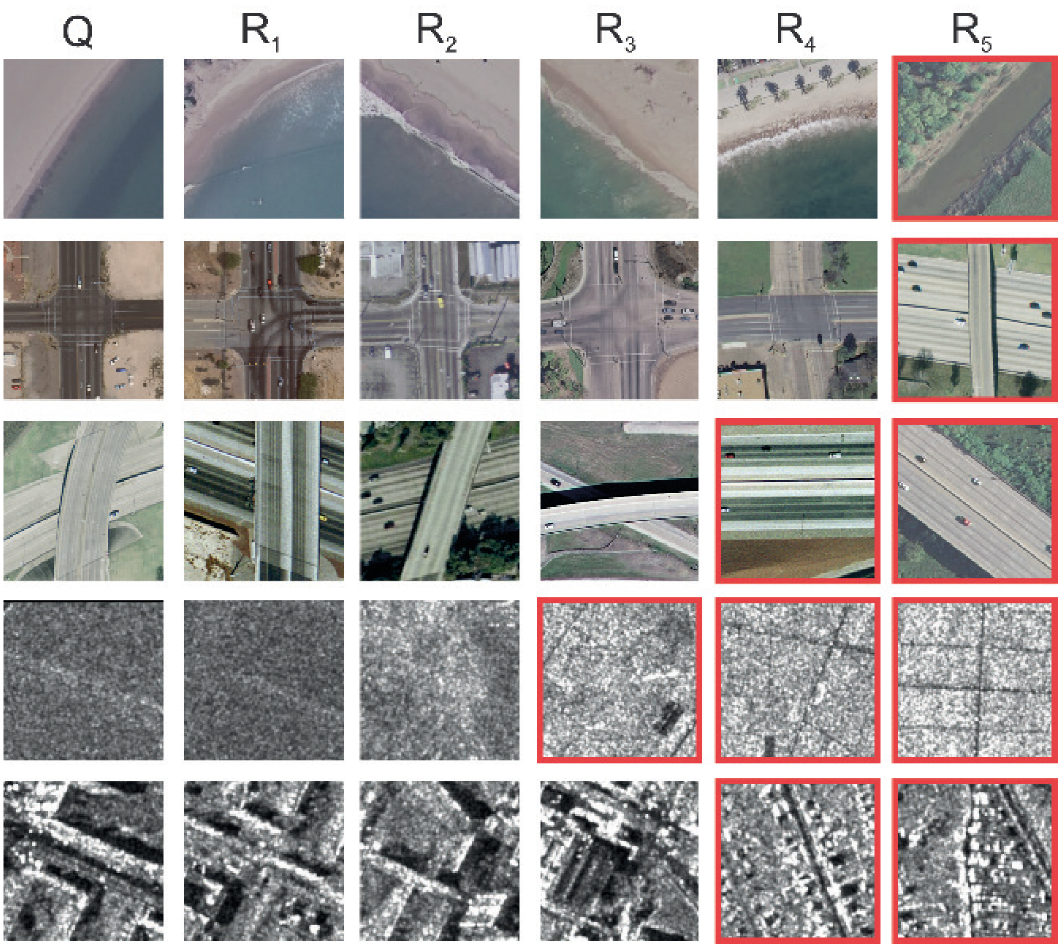
GPU-Based Locality Sensitive Hashing for Approximate k-Nearest Neighbour Search

Financed by: ARRS (grants 1000-13-0552, P2-0041, J2-5479)

Duration: 2014 to 2015

Partner: DLR (German Aerospace Center)

Over recent years, the amount of structured data has increased immensely, where new approaches are required for fast retrieval of similar data samples. Locality sensitive hashing (LSH) is a new method for finding approximate neighbours within high-dimensional data space. LSH works by projecting high-dimensional data into random low-dimensional planes, which are then also bucketed. Two high-dimensional data samples should be with high probability in the same or neighbouring buckets. Therefore, the accuracy-speed trade-off can be tuned for specific datasets,



Content based image retrieval using parallel implementation of LSH on GPU for finding 5 most similar images to the query image [2].

as the accuracy depends on the number of planes considered. LSH is generally used for finding approximate k-nearest neighbours (k-nn).

Although LSH itself has sublinear time for the retrieval of k-nn of a given data sample, it still takes considerable amount of time for processing of large data, especially when creating a k-nn graph. We have introduced a parallelization of the LSH method using general purpose computing on graphical processing unit (GPGPU), based on NVIDIA CUDA technology. The method was applied for the content-based image retrieval over large dataset of optical and SAR (synthetic aperture radar) satellite imagery, as shown in the above figure.

Additional reading and resources:

[1] Lukač, N., B. Žalik. Fast Approximate k-Nearest Neighbours Search Using GPGPU. GPU Computing and Applications (2014), pp. 221-234.

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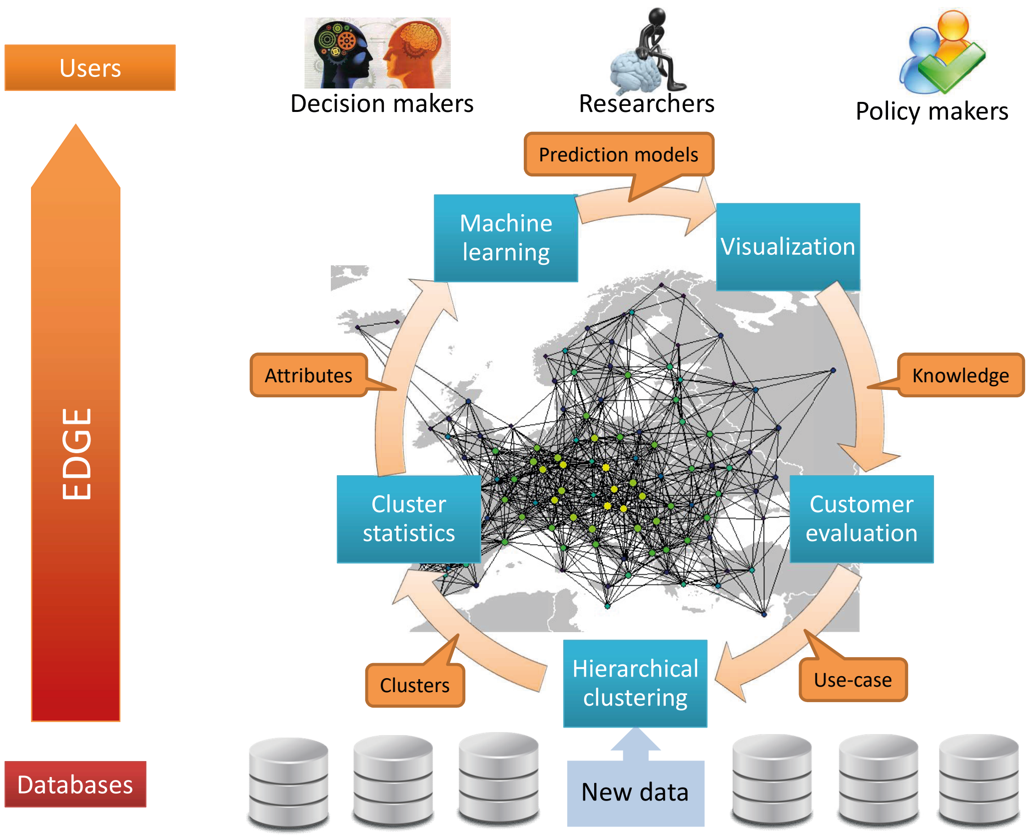
EDGE – Data Mining Analytical Engine

Financed by: Solverminds Solutions & Technologies, India

Duration: 2014 to 2015

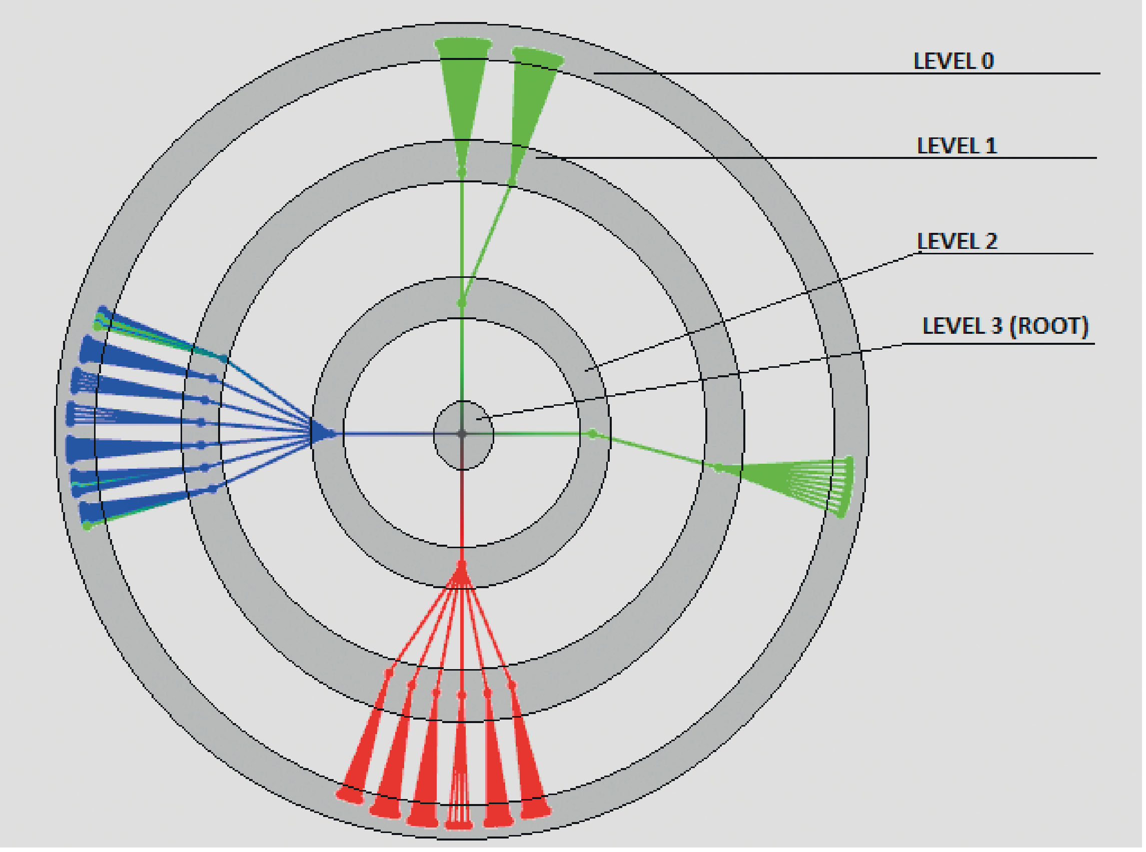
EDGE is a data mining application programming interface (API) developed and implemented by GeMMA for the customer Solverminds Solutions & Technologies (shortly SVM), a software and analytics solution company from India specialized in providing enterprise application and analytical solutions for maritime transport. Although the SVM's primary focus is developing and delivering software and analytical systems and tools that empower liner container shipping companies & agencies, EDGE represents a general data mining engine that can be used in many domains, from shipping and other business transactions to health care, etc.

EDGE consists of three components: pre-processing, visualization and machine learning (prediction). It provides multidimensional data representation, displays correlations among them and supports different methods of machine learning (principal component analysis, clustering, support vector machines, neural networks, decision tree, linear regression,…). The detailed flow process, actually a single iteration

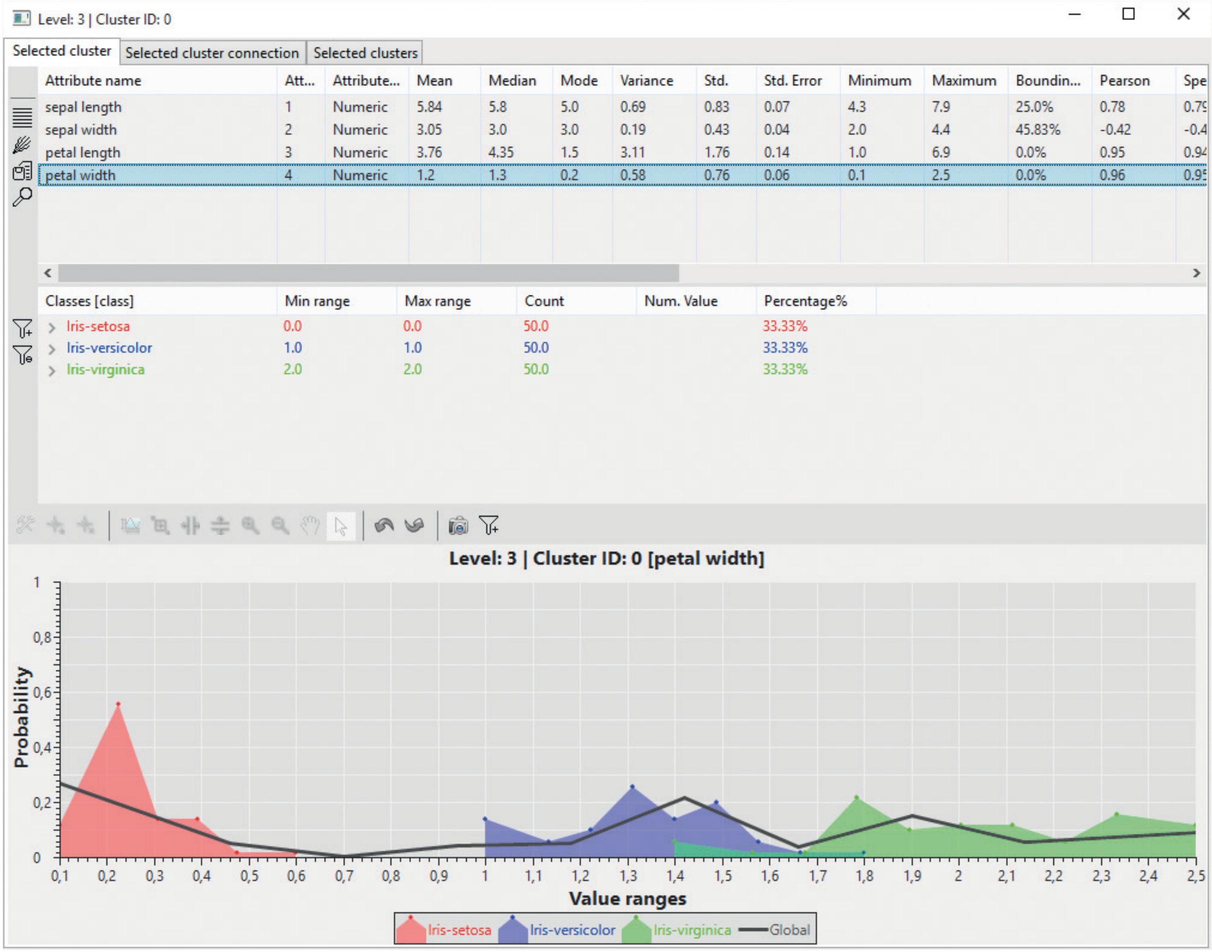


EDGE flow process.

of a continuous process with many loops and feedbacks, is shown in the above figure. Data cleaning (removing noise and inconsistent data) and data integration (where multiple data sources are combined) must be realized by SVM in order to meet the requirements of a concrete end-user. The EDGE API accepts a correct 2D table in TXT or CSF format where each line represents an entity, and each column is an attribute. A user selects one of the columns as a target attribute and interactively observes how other attributes affect the target one. The data selection step retrieves the data relevant to the analysis task from the dataset, while the data transformation transforms or consolidates the selected data into forms appropriate for mining by performing summary or aggregation operations, for instance. The data mining is an essential process where intelligent methods are applied in order to extract data patterns. Patterns are then evaluated to identify those representing knowledge. Finally, knowledge presentation uses visualization and knowledge representation techniques to present the mined knowledge to the user.



Cluster radial tree. The root cluster is in the centre (level 3), level 2 contains sub-clusters of the root, clusters on level 1 are sub-clusters of those from level 2, and original data is on level 0.



Window of the selected cluster with the detailed information.

ACHIEVEMENTS

- Publications
- Prizes, Awards, Honours, Medals
- Young Researchers, Ph.D. and M.Sc. Graduates Supervised in GeMMA
- Functions and Honours in National and International Associations

Publications

Original Scientific Articles

1. Žalik, B., D. Mongus, K. Rizman Žalik, N. Lukač. Chain code compression using string transformation techniques. Digital signal processing 53 (2016) 1-10.
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Prizes, Awards, Honours and Medals

UM awards and honours for employees

2006: Borut Žalik, Gold Sign of University of Maribor for the research achievements

UM-FERI awards and honours for employees

2012: Domen Mongus, Award for research achievements.
2013: Domen Mongus, Award for pedagogical achievements.
2015: Niko Lukač, Award for research achievements.

Other awards and honours for employees

2013: Domen Mongus, Niko Lukač, Borut Žalik, Exellence in Science, ARRS.
2014: Sašo Pečnik, 1st place in the RO3D SMART project team at Cita Smart Collaboration Challenge Symposium, Dublin, Ireland.
2015: Domen Mongus, Danubius Young Scientist Award.
2015: Domen Mongus, Information Society Award.

UM award for research work of students (Andrej Perlach's award)

2002: Gregor Klajnšek.
2015: Marko Bizjak.

UM-FERI awards for students

2010: Niko Lukač, Award for student research achievements.
2011: Niko Lukač, Award for student research achievements.
2015: Marko Bizjak, Award for student research achievements.
2015: David Jesenko, Award for above-average student engagement (as a member of the UM-FERI football team).
2015: Žiga Leber, Award for the best undergraduate student.

Imagine Cup student technology competition

2006: Denis Špelič as a member of sparcoNET team (with Sergej Jurečko, Denis Justinek, Igor Tasič, mentor Tomaž Kosar), 1st place on national competition in Ljubljana, Slovenia, 1st place in Central and Eastern Europe, Maribor, Slovenia, 7th place in World Finals, New Delhi, India.
2012: Denis Špelič as the mentor of IntelliDerm team (Dušan Škerget, Matej Kotnik, Nenad Čikić): 2nd place on national competition, Ljubljana, Slovenia.
2013: Denis Špelič as the mentor of Beezinga team (Nenad Čikić, Jernej Škrabec, Jernej Gračner): 1st place on national competition, Maribor, Slovenija, attending the World Finals, Sankt Petersburg, Russia.

Other student awards

2013: Danijel Žlaus, 2nd place at Central European Seminar on Computer Graphics for students (CESCG), Slovakia.
2015: Marko Bizjak, 1st place on student papers competition of IEEE region 8, ERK 2015.

Young Researchers, Ph.D. and M.Sc. Graduates Supervised in GeMMA

Young researchers

All 10 researchers were/are supervised by professor Borut Žalik Ph.D..

- Krivograd, Sebastian, 1 November 2000 – 31 October 2003.
- Klajnšek, Gregor, 1 January 2002 – 31 December 2005.
- Zadravec Mirko, 1 January 2002 – 30 June 2006.
- Domiter, Vid, 1 October 2004 – 31 March 2009.
- Špelič, Denis, 1 November 2006 – 30 April 2011.
- Mongus, Domen, 15 October 2008 -30 September 2012.
- Gangl, Simon, 1 December 2010 – 31 May 2014.
- Lukač, Niko, 1 December 2012 – 31 May 2016.
- Horvat. Denis, 1 October 2013 - 31 March 2017.
- Jesenko, David, 1 November 2014 -30 April 2018.

Doctorands in Computer science

All 19 disertations have been completed through the UM-FERI computer science & informatics study programme, 14 in the old postgraduate Ph.D. programme and the last 5 at the third Bologna level. All the works have been supervised by professor Borut Žalik Ph.D..

- Podgorelec, David. Odprt sistem za načrtovanje z geometrijskimi omejitvami (Open system for constraint-based geometric design), 2002.
- Lamot, Marko. Triangulacija enostavnega mnogokotnika z enakomerno delitvijo ravnine (Simple polygon triangualtion based on uniform plane subdivision), 2003.
- Krivograd, Sebastian. Stiskanje trikotniških mrež s sočasnim procesiranjem parov trikotnikov (Compression of triangular meshes by simultaneously processing pairs of triangles), 2003.
- Kaučič, Branko. Varovanje poliedrskih površij z aproksimativnimi metodami (Guarding polyhedral surfaces with approximative methods), 2004.
- Gomboši, Matej. Algoritmi vsebnosti pri geometrijskih očrtjih (Containment algorithms for geometric buffers), 2005.
- Klajnšek, Gregor. Postopek brezizgubnega stiskanja vokselskih podatkov s štiriškimi drevesi (An algorithm for lossless compression of voxel data using quadtrees), 2005.
- Zadravec, Mirko. Metode Delaunayeve triangulacije, skoraj neodvisne od porazdelitve vhodnih točk (Delaunay triangulation methods almost independent on point distribution), 2006.
- Domiter, Vid. Algoritmi triangulacije s strategijo prebiranja (Triangulation algorithms using a sweeping strategy), 2009.
- Pipan, Gregor. Učinkovita hevristika za gradnjo najmanj utežene triangulacije v prekrivnem omrežju (An efficient heuristic for building minimum weight triangulation in overlay networks), 2010.
- Špelič, Denis. Postopek brezizgubnega stiskanja razčlenjenih vokselskih podatkov (Lossless compression of segmented voxel data), 2011.
- Globačnik, Timotej. Stiskanje in rekonstrukcija rastrskih pisav z verižno kodo (An algorithm for compression and reconstruction of raster fonts using chain codes), 2011.

- Šinjur, Smiljan. Vgnezdene izbočene lupine kot značilnice za zaznavo dvojnikov digitalnih slik in video posnetkov (Convex layers as a feature for near-duplicate detection of digital images and video clips), 2011.
- Mongus, Domen. Brezparametrični algoritem gradnje digitalnega modela reliefa iz podatkov LiDAR (Parameter-free algorithm for digital terrain model generation from LiDAR data), 2012.
- Kovač, Boštjan. Dinamična podatkovna struktura za točkovno upodabljanje točk izven pomnilnika (Dynamic data structure for out-of-core point based rendering), 2012.
- Gangl, Simon. Algoritem stiskanja domenskih zaporedij slik s projekcijo v prostor osnovnih komponent (Domain-bound image sequence compression algorithm based on projection to principal component space), 2014.
- Kuder, Marko. Upodabljanje velikih količin letalskih podatkov LiDAR (Visualizing large amounts of airborne LiDAR data), 2014.
- Smogavec, Gregor. Aproksimacijski algoritem gradnje srednje osi enostavnih mnogokotnikov, temelječ na omejeni Delaunayevi triangulaciji (Approximation algorithm for medial axis computation on simple polygons using constrained Delaunay triangulation), 2014.
- Jurič, Simon. Bližje-infrardeča spektroskopija na standardni računalniški mobilni napravi za zaznavo in vizualizacijo podkožnih ven (Near-infrared spectroscopy using a standard mobile device and its application in visualization of peripheral veins), 2015.
- Lukač, Niko. Algoritem za celostno vrednotenje fotovoltaičnega in vetrnega potenciala večjih geografskih območij (Algorithm for the determination of photovoltaic and wind potential over large geographic areas), 2016.

Masters of Science in Computer science

All 4 works have been completed through the UM-FERI computer science & informatics M.Sc. postgraduate study programme, and supervised by professor Borut Žalik Ph.D..

- Čapelnik, Sergej. Iskanje geometrijskih podatkov z adaptivno uniformno delitvijo prostora (A search of geometric data using an adaptive uniform spatial subdivision), 2000.
- Podgorelec, David. Pristopi k reševanju ciklov pri načrtovanju z geometrijskimi omejitvami (Approaches to cycle solving in geometric constraint based design), 2000.
- Kaučič, Branko. Algoritmi vidnosti nad diskretnim modelom terena (Visibility algorithms on discrete terrain model), 2001.
- Gomboši, Matej. Algoritmi nad množicami mnogokotnikov v E2 (Algorithms on sets of polygons in E2), 2002.

Functions and Honours in National and International Associations

Domen Mongus

EUROGI members (blue)

- Member of the executive committee of the **European umbrella organization for Geographic Information (EUROGI)**. EUROGI was established in 1994 by the European Commission with the mission is to maximise the availability, effective use and exploitation of geographic information throughout Europe in order to ensure good governance, economic and social development, environmental protection and sustainability, and informed public participation. Through national associations, more than 6.000 European organisations from 26 countries are incorporated under the EUROGI umbrella. Within the EUROGI's ExCom, Domen Mongus is serving his second term (from 2016 to 2019) as a project portfolio leader in charge of coordinating project activities of the organisation. He is also coordinator of organisation's policy positions in regards to Big Data and Internet of Things.
- From 2008 to 2012 he was a member of **Executive Committee of ACM Slovenia**

Borut Žalik

- Member of the **European Academy of Science and Arts** since 2014.
- Vice president of **ACM Slovenia**, the main society for computer science in Slovenia, since 2014.
- In the period 2011-2012 he was also a member of the management board of the **Slovenia Research Agency** in 2011 and 2012.

Niko Lukač

- One of the founders of the first **ACM (Association for Computing Machinery) student chapter in Slovenia**, namely ACM Maribor, where he served as vice chair in 2015.

Top results on an international scale have been recently achieved by GeMMA members particularly in developing new methodologies for LiDAR data processing and their practical validation. They include the United States patent for lossless LiDAR data compression and decompression, two Slovene national patents for progressive and lossy LiDAR data compression, a series of top scientific publications in the most prestigious international journals on remote sensing and several awards and honours at the international, national or faculty level. Our current LiDAR-related research activities are being performed through two ongoing national research projects titled Morphological operators for pattern recognition in large point clouds and Algorithms of ecosystems dynamics modelling with methods of mathematical morphology and lattice theory. These activities also represent the core of GeMMA's participation in the ongoing national research programme Computer Systems, Methodologies and Intelligent Services, a strategic research direction of the Institute of Computer Science at UM-FERI. Consequently, this book is primarily aimed to support dissemination and to demonstrate possible practical usages of outcomes of these two projects and the programme. But, moreover, it is also a survey of selected research projects through the past 16 years, demonstrating how the GeMMA research group has gradually gained knowledge and experience necessary to participate in the aforementioned projects and programme, while the summarized applied projects from the past may additionally show some possible directions of the lab's latest research results utilization.

Borut Žalik, Head of GeMMA

University of Maribor

Faculty of Electrical Engineering
and Computer Science

GeMMA