GEOS 2008

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Milan Talich (Ed.)
Cadastre of Real Estate / Katastr nemovitostí

Gabriel Bádescu:
RTK (Real-Time Kinematics) – GPS Technology with Data Transmission through UHF Radio Waves, Used in Cadastre

Vít Suchánek:
Katastr nemovitostí ČR
Cadastre of Real Estates of the Czech Republic

Jiří Poláček:
Služby a produkty informačního systému katastru nemovitostí
Services and Products of the Information System of Cadastre of Real Estates

Anna Ilieva, Yordanka MizoVA:
Elaboration of the Cadastral Plan for the Town of Pazardzhik
Vytvoření katastrálního plánu města Pazardžik

Cadastre of Real Estate, Photogrammetry and Remote Sensing / Katastr nemovitostí, Fotogrammetrie a dálkový průzkum

Jana Zorálová:
Zpracování pozemkových úprav v novém výměnném formátu
Land Adaptation Processing in New Exchange Format

Luis Miguel Cotirim Mateus:
Evaluating a Low Cost Photogrammetry Method with 3D Laserscanning
Výhodnocení fotografické metody s nízkými náklady a třívrstvěním laserovým skenováním

Jan Řezniček:
Tvorba sítě z hladiny mračen bodů z dat laserového skenování metodou zobrazení bodů do roviny
Triangulation and Smoothing of Terrestrial Laserscanner Dataset by Using Method of Point Projection from 3D to a 2D (Plane)

Lubomír Soukup:
Vlícování pomocí identických přímeč
Matching by Ground Control Lines

List of Posters / Seznam posterů

Gabriel Bádescu:
Comparative Study Concerning the Transformation of Coordinates Determined Using GNSS Technology, into the STEREO 70 Projection System
Srovnávací studie transformace souřadnic určených technologií GNSS do projekčního systému STEREO 70

Haddad Mahdi, Abdelaaloui Hassen:
 Algerian Permanent GPS Network: Comparison of Results Obtained by the Bernese 5.0 Software in Interactive and Automatic Mode
Alžiřská stálá síť GPS: Srovnání výsledků získaných softwarėm BERNESE 5.0 v interaktivním a automatickém módě.
EVALUATING A LOW COST PHOTOGRAMMETRY METHOD WITH 3D LASERSCANNING

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Abstract

The aim of this paper is to evaluate the results obtained with the application of a low cost photogrammetric method to architectural surveying. The development is part of a PhD research project. The referred method was developed and implemented using Autolisp Language Programming for AutoCAD and was tested on surveying façades and exterior boundaries (plan) of a well geometrically defined building. This building is a Renascentist XVIIth century church. The method will be described and explained and the study case will be presented as well the obtained results.

Then, the results will be compared to a 3D laser scanning surveying of the same building. This surveying was performed with a Leica Scanner. Assuming 3D laser scanning as an accurate surveying method for the global geometry of the building, façade and plan drawings obtained from this data will be the base for comparison. This is a low cost method and is accessible to non experts in surveying as, in general, architects are and can provide reliable data for some architectural applications that do not evolve structural changes in buildings. It can also be used as a complementary method for other surveying methods both in professional or academic context.

VYHODNOCENÍ FOTOGRAFICKÉ METODY S NÍZKÝMI NÁKLADY A TROJOZMĚRNÝM LASEROVÝM SKENOVÁNÍM

Abstrakt

Cílem tohoto článku je vyhodnotit výsledky získané užitím nízkokostných fotogrametrických metod pro zaměřování architektury. Vývoj je součástí projektu pro získání titulu PhD. Předkládaná metoda byla vyvinuta a zavedena při užití programování v jazyce Autolisp pro AutoCAD a ověřena při zaměřování fasád a vnějších hranic (rovín) dobře geometryčky definované stavby. Touto budovou je renesanční kostel z 16. století. Metoda se popisuje a vysvětluje a studijní případ předkládá včetně získaných výsledků.

Potom se výsledky porovnávají s trojrozměrným zaměřením pomocí laserového skenování téže budovy. Toto měření se uskutečnilo pomocí skeneru Leica. Za předpokladu, že trojrozměrné laserové skenování je přesná měřická metoda pro celkovou geometrii budovy, pak fasáda a rovinné kresby získané z těchto údajů budou podkladem pro srovnávání.

Je to nízkokostná metoda a dostupná i neodborníkům v zeměměřictví, jimiž jsou obvykle architekti a může poskytnout spolehlivé údaje pro některé architektonické aplikace nevyžadující strukturální změny budov. Lze ji též užít jako doplňkovou metodu k dalším měřickým postupům v souvislostech profesních a akademických.
A cut from Professor Karel Kořínský's famous altimetric plan of Prague of 1858 was used for the cover of this volume (text omitted).


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Vážení čtenáři,


Konference GEOS 2008 si klade za cíl stejně jako v předchozích letech podchytit novinky a vývojové trendy ve všech specializacích našeho oboru. Vzhledem k většímu rozšíření schengenského prostoru koncem loňského roku, bylo zvoleno právě motto, které více rešpektuje tuto novou situaci v Evropě. Konference se tak věnuje nejen již tradičním tématům, jako jsou geoinformace a GIS, kartografie a mapová tvorba, navigační systémy a služby založené na lokaci, geodetické základy a geodetické práce, katastr nemovitostí, fotogrammetrie a dálkový průzkum. Ale zaměřuje svou pozornost také na oblasti pohybu zeměměřičů v evropském prostoru, uznání kvalifikací pro výkon zeměměřických činností, požadavky na vzdělávání zeměměřičů a zajišťování kvality zeměměřických prací.

V roce 2008 je konference oproti předchozím letům vyjimečná v tom, že bezprostředně předchází zasedání valného shromáždění Rady evropských zeměměřičů (CLGE), které se koná v Praze v následujících dvou dnech. Motto konference je navíc velice blízké i tématům, kterým se CLGE dlouhodobě věnuje.

Kromě zmíněného zasedání valného shromáždění CLGE probíhá ještě souběžně s konferencí v Praze ve dnech 28. 2. až 1. 3. též 3. mezinárodní veletrh geodézie, kartografie, navigace a geoinformatiky GEOS, který také stojí za shlédnutí.

Únor 2008

Milan Talich
odborný garant konference
Dear reader,

this year again you receive in your hands proceedings from the International Conference of Geodesy, Cartography, Navigation and Geoinformatics GEOS 2008 held under the motto "Our profession in Europe without Barriers" and under auspices of the Chief of the Geographic Service of the Army of the Czech Republic colonel Ing. Pavel Skála.

The main task of conference GEOS 2008 is, similarly to the previous years, to follow news and development trends in all specializations of our field. Regarding the enlargement of Schengen territory at the end of 2007, we decided to choose the above mentioned motto as it reflects this new situation in Europe. Therefore the conference focuses not only on traditional subjects, e.g. geoinformatics and GIS, cartography and mapping, navigation systems and services based on location, basic geodetic control and geodetic work, cadastral of real estate, photogrammetry and remote sensing, but also on the scope of surveyors’ movement within the territory of Europe, recognizing qualifications and education requirements for land surveyors and controlling the quality of land surveying.

In comparison with previous years, conference GEOS 2008 is exceptional as it is held immediately before the General Assembly Meeting of the Council of European Geodetic Surveyors (CLGE) that takes place in Prague in the following two days. In addition, the conference motto is very close to the subjects that are of long-term interest of CLGE.

Besides the above mentioned General Assembly Meeting of CLGE, at the same time as the conference, the 3rd International Fair of Geodesy, Cartography, Navigation and Geoinformatics GEOS (that is worth seeing as well) takes place in Prague from 28 February to 1 March 2008.

*February 2008*

*Milan Talich*

*Professional Warranter of the Conference*
Contents / Obsah

Basic Geodetic Control Not Only for Navigation Systems and Services Based on Location / Geodetické základy nejen pro navigační systémy a služby založené na lokaci

Gerd Rosenthal, Anette Blaser, Jaroslav Šimek:
EUPOS – Regionální infrastruktura pro určování polohy pomocí GNSS v zemích střední a východní Evropy – stav na přelomu let 2007/2008 ................................................................. 1

Marcin Ryczewolski, Artur Oruba, Marcin Leorczyk:
The Precise Satellite Positioning System ASG-EUPOS
Přesný družicový polohový systém ASG-EUPOS .................................................................................. 18

G.Silabriedis, S.Plotnikov, J.Balodis:
The EUPOS-RIGA Application for Mapping Control
Užití EUPOS – RIGA pro mapovací kontroly .................................................................................... 24

M.Premežič, M. Kekić, M. Marjanović, M. Bosiljevac, B. Slevek:
CROPOS (Croatian Positioning System)
CROPOS (Chorvatská polohová soustava) .......................................................................................... 33

Basic Geodetic Control and Geodetic Work CZEPOS / Geodetické základy a geodetické práce CZEPOS

Jan Řezníček:
CZEPOS – Současný stav
CZEPOS – Present State ......................................................................................................................... 40

Vratislav Filler:
Testování stability stanic GNSS na území ČR v místním analytickém centru GO Pecný
Test of Stability GNSS Sites on Czech Republic Area by Local Analysis Centre GO Pecný ......... 44

Miluše Vílímková:
Analýza časových řad souřadnicových změn v CZEPOS
Analysis of the Time Series of Coordinates of theCZEPOS ................................................................ 51

Jaroslav Nágl:
Zkušenosti s modelováním troposféry v sítích APOS a CZEPOS
Experience with Troposphere Modelling by APOS and CZEPOS Networks ........................................ 56

Basic Geodetic Control and Geodetic Work / Geodetické základy a geodetické práce

Dušan Ferianc, Elena Šalátová:
Geodetické základy Slovenska v roku 2008
Geodetic Control of Slovakia in Year 2008 ............................................................................................ 61

Gerd Boedecker:
On Gravity Standardisation and the Unified European Gravity Reference Network UEGN02
O normalizaci tíže a jednotné evropské referenční tříhové sítě UEGN02 ............................................. 68

Martin Kadlec, Pavel Novák:
Porovnání metod pro výpočet terénních korekcí pro území střední Evropy
Comparison of Different Methods for Evaluation of Terrain Corrections for the Area of Central Europe 75

Valerio Baiocchi, Paola Capaldo, Mattia Crespi, Marco Mezzapesa, Grazia Pietrantonio:
Calibration of Geoid Models in Colli Albani Area (Rome, Italy)
Kalibrace modelů geoidu v oblasti Colli Albani (Řím, Itálie) .................................................................. 87

Navigation Systems and Services Based on Location / Navigační systémy a služby založené na lokaci

Miloslav Cimbálník:
Souřadnicové systémy na území České republiky
Co-ordinate Systems On the Czech Republic Territory ........................................................................ 92

Pavel Vaniš, Pavel Tesař:
Webová služba VÚGTK pro transformaci mezi WGS-84 a S-JTSK
Web Service of VÚGTK for Transformation between WGS-84 and S-JTSK ........................................... 124
Pavel Taraba:  
Současné možnosti geodetických měření v sítích permanentních stanic GNSS v ČR  
Current Possibilities of Land Survey in Networks of GNSS Permanent Stations in the Czech Republic  ................................................................. 131

Reiner Jäger, Simone Kälber:  
The New RTCM 3.1 Transformation Messages – Declaration, Generation from Reference Transformations and Implementation as a Server-Client-Concept for GNSS Services  
Nové transformační zprávy RTCM 3.1 - prohlášení, vytváření z referenčních transformací a zavádění jako pojetí server-client-koncept pro služby GNSS  .................................................................................................................. 138

Geoinformation and GIS, Cartography and Map Creation / Geoinformace a GIS, kartografie a mapová tvorba  

Milan Kocáb, Milan Talich:  
Web applications pro zeměměřiče  
Web applications for Surveyors ........................................................................................................................................................................... 159

Hui Lin, Jun Zhu, Bingli Xu:  
A Study on the Particle System Method for Dynamic Modelling in Virtual Geographic Environments (VGE)  
Studie o metodě částic pro dynamické modelování ve virtuálním geografickém prostředí (VGE) .......................................................................................... 174

Ljerka Rašić, Siniša Hofer, Ivana Šimat:  
Reflection of new geodetic datum and map projection introduction on orthophoto production process  
Dopad nového geodetického počátku a mapového zobrazení na ortofotografický výrobní postup .................................................................................................................. 179

Lucie Stavafová:  
Vytvoření interaktivní 3d vizualizace vybraného území  
The Creation of the Interactive 3d Visualization of the Elected Area .......................................................................................................................... 188

V. Gershzenzon, E. Ash:  
ScanEx R&D Center Projects  
Projekty centra ScanEx R&D .............................................................................................................................................................................. 194

Our Profession in Europe without Barriers / Naše profese v Evropě bez hranic  

Jiří Šima:  
Zeměměřictví a katastr nemovitostí v České republice na prahu 21. století  
Surveying, Mapping and Cadastre in the Czech Republic at the Beginning of 21st Century .................................................................................. 197

Alain Gaudet, Michel Patrick Lagoutte, Rafic Khouri:  
The Latest Developments in Educational Standards in France  
Nejnovější vývoj požadavků na vzdělávání ve Francii ......................................................................................................................................................... 205

Václav Slaboch:  
Vyhovuje kvalifikace úředníků ČR v zeměměřických službách a mapování v Evropě?  
Does the Professional Qualification of the Public Appointed Surveyors in Czechia Satisfies the Requirements of the European Professional Organisations? ............................................................................................................. 213

Vladimír Stromček:  
Kontakty slovenských geodetů s Evropou  
Slovak Surveyors Contacts with Europe ............................................................................................................................................................... 227

Zdeněk Fišer, Miloslav Švec, Petr Kalvoda, Jiří Vondrák:  
Výuka Katastru nemovitostí a Mapování v Brně  
Education of Real Estate Cadastre and Mapping in Brno ........................................................................................................................................ 228

Tomáš Caijtham:  
Platforma pro zajištění kvality v národních mapovacích a katastrálních službách  
Quality Assurance Platform in National Mapping and Cadastral Agencies .............................................................................................................. 233

Emmanuel Ouranos:  
Prevention and Management of Physical Disasters and the Surveyor ‘s Involvement  
Prevence a zvládání fyzikálních katastrof a zeměměřičského zapojení .................................................................................................................. 243

Pavla Tryhubová:  
Analýza dopadů směrnice inspíruje na informační obsah ZABAGED  
Analysis of Inspire Directive Impacts on Information Contents Of ZABAGED ........................................................................................................... 246
Eva Mičietová, Juraj Vališ:  
Distribution of Geographic Information in Relation to INSPIRE – Current Condition in SR

Adrian Traian Radulescu, Gheorghe M.T. Radulescu:  
Upon a National Concept of GIS as Basis of the Strategy for Integration in the Euro-Atlantic Structures, the Case Study of the Baia Mare Municipality

Cadastre of Real Estate / Katastr nemovitosti

Gabriel Bădescu:  
RTK (Real-Time Kinematics) – GPS Technology with Data Transmission through UHF Radio Waves, Used in Cadastre

Vít Suchánek:  
Katastr nemovitostí ČR

Jiří Poláček:  
Services and Products of the Information System of Cadastre of Real Estates

Anna Ilieva, Yordanka Mizova:  
Elaboration of the Cadastral Plan for the Town of Pazardzhik

Cadastre of Real Estate, Photogrammetry and Remote Sensing / Katastr nemovitostí, Fotogrammetrie a dálkový průzkum

Jana Zaoralová:  
Land Adaptation Processing in New Exchange Format

Luis Miguel Cotrim Mateus:  
Evaluating a Low Cost Photogrammetry Method with 3D Laserscanning

Jan Řezníček:  
Triangulation and Smoothing of Terrestrial Laserscanner Dataset by Using Method of Point Projection from 3D to a 2D Plane

Lubomír Soukup:  
Matching by Ground Control Lines

List of Posters / Seznam posterů

Gabriel Bădescu:  
Comparative Study Concerning the Transformation of Coordinates Determined Using GNSS Technology, into the STEREO 70 Projection System

Haddad Mahdi, Abdellaoui Hassen:  
Algerian Permanent GPS Network: Comparison of Results Obtained by the Bernese 5.0 Software in Interactive and Automatic Mode

Jindřich Hodač:  
Photogrammetric documentation of historical objects – simple methods

Adrian Traian Radulescu, Gheorghe M.T. Radulescu, Ovidiu Stefan:  
As Means to Assure Structure Safety - Dynamic Surveying
Petr Skála:
Jak poznat dobrou zeměměřickou kancelář?
How Recognise a Good Geodetic Office? .................................................................................................................. 363

Pavel Tesař:
NTRIP – využití IP multicastingu
NTRIP – Using IP Multicasting ................................................................................................................................. 371

Lenka Vlčková:
Optimalizace horizontu v lokalitě hvězdárny a planetária Johanna Palisy v Ostravě
Optimalization of Horizont in Observatory and Planetarium of Johann Palisa in Ostrava ........................................ 372

Jaroslava Kraftová:
Vývoj, význam a rozvoj inženýrské geodézie
Trend, value and development of engineering geodesy .................................................................................................. 378
EVALUATING A LOW COST PHOTOGRAMMETRY METHOD WITH 3D LASER SCANNING

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Abstract

The aim of this paper is to evaluate the results obtained with the application of a low cost photogrammetric method to architectural surveying. The development is part of a PhD research project. The referred method was developed and implemented using Autolisp Language Programming for AutoCAD and was tested on surveying façades and exterior boundaries (plan) of a well geometrically defined building. This building is a Renaissance XVIth century church. The method will be described and explained and the study case will be presented as well as the obtained results.

Then, the results will be compared to a 3D laser scanning surveying of the same building. This surveying was performed with a Z+F Scanner Imager 5006. Assuming 3D laser scanning as an accurate surveying method for the global geometry of the building, façade and plan drawings obtained from this data will be the base for comparison.

This is a low cost method and is accessible to non experts in surveying as in general architects are and can provide reliable data for some architectural applications that do not evolve structural changes in buildings. It can also be used as a complementary method for other surveying methods both in professional or academic context.

1 Introduction

To building surveying, for architectural purposes, many strategies may be adopted. Some are more practical and rapid and others are slower. Some may require experts and other don’t. We must always consider de adequacy of the chosen strategy with surveying purpose.

The method here presented that can be define d as an elementary photogrammetric method can be applied to the survey of buildings with approximately contiguous plane façades. Its operative base consists on three steps: a) drawing rectification, b) angle determination between façades, and c) angle registration. All these steps take place within AutoCAD working environment on drawings produced over inserted images. It is required that one vertical and one horizontal measurement be taken from each façade. In practice only one vertical measurement is needed over the entire exterior of the building.

First step consists on the rectification of vectorial drawing, rather than image, produced over one or more inserted pictures of the façade.

Second and third steps consist on producing, with a minimum effort in field work, the plan of the exterior boundary of the building. This is applicable when the building presents multiple contiguous façades. This may me of interest if we don’t have access to the interior of the building and its boundary presents convex angles. Third step is done manually.

It is not intended to defend the efficiency of this method with respect to others, but to point out that it can be used as a complement of other surveying methods.

To make this set of procedures operative it was programmed two routines in AutoLisp.
2 Drawing rectification

As it was referred, first step of the method consists on drawing rectification. This corresponds to a projective transformation that can be defined as follows:

\[
\begin{align*}
X_u &= e_1 x_n + f_1 y_n + g_1 \\
Y_u &= e_0 x_n + f_0 y_n + 1
\end{align*}
\]

Where:

\[
\begin{align*}
X_u \text{ and } Y_u & \text{ are the coordinates of the unknown point } P_u, \\
x_n \text{ and } y_n & \text{ are the coordinates of the known point } P_n \text{ corresponding to the unknown point } P_u, \\
e_0, e_1, e_2, f_0, f_1, f_2, g_1, g_2 & \text{ are the eight parameters of the projective transformation.}
\end{align*}
\]

It is known that four \(P_n\) points and the corresponding four \(P_u\) points are required to determine the eight parameters of the projective transformation. In practice this means that a minimum of to measurements must be done: height and width.

Let \(P_i (i = \{1,2,3,4\})\) of coordinates \(X_i\) and \(Y_i\), and \(P'_i (i = \{1,2,3,4\})\), of coordinates \(x_i\) and \(y_i\), be corresponding points under the projective transformation. The points \(P'_i\) are associated with the points \(P_n\), of coordinates \(x_n\) and \(y_n\), of the figure \(FF\) that are to be transformed into the points \(P_u\), of coordinates \(X_u\) and \(Y_u\), of the figure \(FF\).

If three of the eight coordinates of the points \(P_i\) are equal to 0, and three of the eight coordinates of the points \(P'_i\) are equal to 0, then the eight projective parameters are easy to calculate.

In general this condition is not in principle fulfilled.

In order to perform the projective transformation fulfilling this condition a set of other transformations must be carried out:

a) A translation according to the vector \(\overrightarrow{P_4O}\) is applied to the points \(P_i (i = \{1,2,3,4\})\), of coordinates \(X_i\) and \(Y_i\), in order to get the points \(P'_i\), of coordinates \(X'_i\) and \(Y'_i\), according to the following expressions:

\[
\begin{align*}
X'_i &= X_i - X_4 \\
Y'_i &= Y_i - Y_4
\end{align*}
\]

b) A translation according to the vector \(\overrightarrow{P'_4O}\) is applied to the points \(P'_i (i = \{1,2,3,4\})\), of coordinates \(x_i\) and \(y_i\), and to the points \(P_n\), of coordinates \(x_n\) and \(y_n\), of the figure \(FF\), in order to get the points \(P'_n\), of coordinates \(x'_n\) and \(y'_n\), and the points \(P'_m\), of coordinates \(x'_m\) and \(y'_m\), of the figure \(FF\), according to the following expressions:

\[
\begin{align*}
x'_n &= x_n - x_i \\
y'_n &= y_n - y_i
\end{align*}
\]
\[x_{nt} = x_n - x_1\]
\[y_{nt} = y_n - y_1\]

e) A rotation is applied to the points \(P_1\) centred in the origin in order to align the vector \(\overrightarrow{P_4P_2}\) with \(xx\) axis, getting the points \(P_{iir}\) of coordinates \(X_{iir}\) and \(Y_{iir}\), according to the following expressions:
\[X_{iir} = X_{iir} \cos \alpha + Y_{iir} \sin \alpha\]
\[Y_{iir} = -X_{iir} \sin \alpha + Y_{iir} \cos \alpha\]

Where:
\[\cos \alpha = \frac{X_{3r}}{\sqrt{X_{3r}^2 + Y_{3r}^2}}\]
\[\sin \alpha = -\frac{Y_{3r}}{\sqrt{X_{3r}^2 + Y_{3r}^2}}\]

d) A rotation is applied to the points \(P_{iir}'\) and to the points \(P_{nir}\) of the figure \(ff',\) centred in the origin in order to align the vector \(\overrightarrow{P_{iir}'P_{2ir}}\) with the axis \(xx\), getting the points \(P_{iir}'\) of coordinates \(x_{iir}\) and \(y_{iir}\) and the points \(P_{nir}',\) of coordinates \(x_{nir}\) and \(y_{nir}\), according to the following expressions:
\[x_{iir} = x_{iir} \cos \beta + y_{iir} \sin \beta\]
\[y_{iir} = -x_{iir} \sin \beta + y_{iir} \cos \beta\]
\[x_{nir} = x_{nir} \cos \alpha + y_{nir} \sin \beta\]
\[y_{nir} = -x_{nir} \sin \beta + y_{nir} \cos \beta\]

Where:
\[\cos \beta = \frac{x_{2r}}{\sqrt{x_{2r}^2 + y_{2r}^2}}\]
\[\sin \beta = -\frac{y_{2r}}{\sqrt{x_{2r}^2 + y_{2r}^2}}\]

e) After these transformations we have four points \(P_{iir}\) and four corresponding points \(P_{iir}'\) under an auxiliary projective transformation. The eight parameters of this projective transformation, \(e_0', e_1', e_2', f_0', f_1', f_2', g_1', g_2'\) can be easily calculated:
\[g_1' = X_{iir}\]
\[g_2' = Y_{iir}\]
\[f_2' = \frac{Y_{iir}x_{4ir} - Y_{iir}x_{3ir}}{x_{3ir}y_{4ir} - y_{3ir}x_{4ir}}\]
f) Now a projective transformation can be applied to the points \( P_{ntr} \), of coordinates \( x_{ntr} \) and \( y_{ntr} \), of the figure \( f'/r \), in order to get the corresponding points points \( P_{utr} \), of coordinates \( X_{utr} \) and \( Y_{utr} \), of the figure \( FF'_{r} \), according to the following expressions:

\[
X_{utr} = \frac{e'_{1} x_{utr} + f'_{1} y_{utr} + g'_{1}}{e'_{0} x_{utr} + f'_{0} y_{utr} + 1}
\]

\[
Y_{utr} = \frac{e'_{2} x_{utr} + f'_{2} y_{utr} + g'_{2}}{e'_{0} x_{utr} + f'_{0} y_{utr} + 1}
\]

\( g \) A rotation is applied to the points \( P_{utr} \), of coordinates \( X_{utr} \) and \( Y_{utr} \), of the figure \( FF'_{r} \), centred in the origin and symmetric to the one applied in \( c \), getting the points \( P_{ut} \), of coordinates \( X_{ut} \) and \( Y_{ut} \), of the figure \( FF \), according to the following expressions:

\[
X_{ut} = X_{utr} \cos(-\alpha) + Y_{utr} \sin(-\alpha)
\]

\[
Y_{ut} = -X_{utr} \sin(-\alpha) + Y_{utr} \cos(-\alpha)
\]

Where:

\[
\cos(-\alpha) = \cos \alpha = \frac{X_{3t}}{\sqrt{X_{3t}^{2} + Y_{3t}^{2}}}
\]

\[
\sin(-\alpha) = -\sin \alpha = \frac{Y_{3t}}{\sqrt{X_{3t}^{2} + Y_{3t}^{2}}}
\]

\( h \) Finally, a translation is applied to the points \( P_{ut} \), of coordinates \( X_{ut} \) and \( Y_{ut} \), of the figure \( FF \), according to the vector \( \overrightarrow{OP}_{4} \), getting the points \( P_{u} \), of coordinates \( X_{u} \) and \( Y_{u} \), of the figure \( FF' \), corresponding to the points of the initial figure \( f' \), according to the following expressions:

\[
X_{u} = X_{ut} + X_{4}
\]

\[
Y_{u} = Y_{ut} + Y_{4}
\]
3 Angle determination between façades

In order to perform this operation, photographs must be taken horizontally and a minimum of three measurements must be carried out in-situ, $V_C$, $D_e$ and $D_d$. To simplify the process it is supposed that a rectangle corresponding to the measurements taken can be drawn over the image in each façade as shown in fig. 1. Then, by selecting the segments $V_C$, $V_e$ and $V_d$ in the picture and the segments $V_C$, $D_e$ and $D_d$ drawn apart, angle between both façades can be calculated.

![Fig. 1](image)

This determination relies on the following.

Let us consider the right façade in fig. 1.

Let $D_dK = [OB] = R$, where $K$ is a scale factor determined by:

$$K = \frac{V_C}{V_C}$$

Let $[ON]$ be the distance, taken over the photo, between verticals $V_C$ and $V_d$.

Let $A$ be any point in the right façade (in practice this point doesn’t have to be identified by the operator; it can be assumed as the crossing point between rectangle diagonals).

Let $M$ be, in the image, the corresponding point to the point $A$ (in practice this point doesn’t has to be identified by the operator; logically it has to be the crossing point of the trapezium diagonals).

On fig. 2 $xx$ axis corresponds to the image plan.

The angle $\alpha$ that right façade does with picture plan is undetermined. However it is known that the projecting rays $A.M$ and $B.N$ cross at the projection centre $P$ as shown in fig. 2.

Let the coordinates of the points $A$, $B$, $M$, $N$ and $P$ be as follows:

$$A = (r \cos \alpha; r \sin \alpha)$$
$$B = (R \cos \alpha; R \sin \alpha)$$
$$M = (d;0)$$
$$N = (D;0)$$
$$P = (X_p;Y_p)$$
The alignments $A.M.P$ e $B.N.P$ can be expressed by:

\[
\begin{vmatrix}
    r \cos \alpha & d & X_p \\
    r \sin \alpha & 0 & Y_p \\
    1 & 1 & 1
\end{vmatrix} = 0
\]

\[
\begin{vmatrix}
    R \cos \alpha & D & X_p \\
    R \sin \alpha & 0 & Y_p \\
    1 & 1 & 1
\end{vmatrix} = 0
\]

From this one can determine $X_p$ e $Y_p$, as follows:

\[
Y_p = \frac{Rr(d - D)}{Rd - rD} \sin \alpha
\]

\[
X_p = \frac{Rr(d - D)}{Rd - rD} \cos \alpha + \frac{Dd(R - r)}{Rd - rD}
\]

These express the parametric equations of a circle $[c]$ with centre $C = \left( \frac{Dd(R - r)}{Rd - rD}, 0 \right)$ and radius $R_{[c]} = \left| \frac{Rr(d - D)}{Rd - rD} \right|$. Proceeding in an analogous way to the left façade one can determine a circle $[e]$ with centre $E$ and radius $R_{[e]}$ as show in fig. 3.

The centre of projection $P$ that allows to reconstruct simultaneously the geometry derived from the projection of both façade planes is one of the intersection points of the two circles $[c]$ and $[e]$. 
Like this one can determine the angle $\pi$ between both façades referred to the dimensions $D_{x}K$ and $D_{y}K$. Scale factor can then be eliminated dividing both values with $K$.

![Diagram](image)

**Fig. 3**

### 4 The case study

As referred, the surveying method described was implemented with AutoLisp Programming Language for AutoCad. Then the principal façade and exterior boundary of a Renaissance XVIth century church were surveyed to test the application.

![Facade and boundary surveying](image)

**Fig. 4**

To façade drawing some assumptions were made that may not be correct. It was assumed that left and right limits of the façade are vertical, and that the upper limit is horizontal. Control measures were taken with metric tape.

Fig. 4 represents façade surveying and fig. 5 represents boundary surveying.
5 Evaluation with 3D laser scanning and conclusions

After the previous step was completed, a 3D laser scanning survey of the church was carried out with a Z+F scanner Imager 5006, by the company 3D Total. From the 3d model obtained it was produced a horizontal section and a façade ortho-image with RGB values assigned.

These two elements served as basis for accuracy verification, by comparison, of the proposed photogrammetric surveying method. It was assumed that laser scanning provides reliable results.

Two evaluations were done.

First, façade survey was overlapped to the ortho-image both being in the same scale. This procedure was accomplished identifying two corresponding horizontal lines. In the overlapped drawing and image this line is identified as $L_1$ and its extremities are identified as $P_1$ and $P_2$ as shown in fig. 6.
Then distances between corresponding points were taken. It was observed that in the lower part of the façade, distances vary within a range of 4cm and that in the upper part of the upper part of the façade distances vary within a range of 8cm.

These differences can be explained with the assumptions that were made when surveying, with the control measurements and with the fact that camera distortions were not taken into account.

In an analogous way, the plan survey was overlapped with the section obtained from the 3d model and discrepancies were measured, as shown in fig. 7.

In red we have the 3d model section and in black we have the survey carried out with the present method. The alignment between both surveys was accomplished identifying both lines corresponding to the principal façade.

Here two verifications were made.

On one hand, it were measured distances between corresponding points. In this case, and for the selected area, distances vary from 0 to 25cm.

On the other hand, corresponding angles were compared. In this, case and for the selected area, angles vary from 0 to 2.5°.

These differences can be explained with the assumptions that were made when surveying (façades being plan), with the control measurements, with the fact that camera distortions were not taken into account, with the fact that camera axis is not exactly horizontal, and with the fact that the registration between angles is manual and errors are summed.

With respect to façade surveying, this evaluation shows that the results can be found reliable for some architectural applications that don’t involve structural changes such as area calculation, pathology mapping, and stylistic analysis, among others.

With respect to plan surveying the results are more difficult to accept. It is required that further work is done in order to minimize discrepancies verified. This can consist on the consideration of camera distortion parameters, a better control while taking the pictures, and a more accurate mean of to proceed to angle registration.

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