TEN YEARS OF TECHNOLOGY ADVANCEMENT IN REMOTE SENSING AND THE RESEARCH IN THE CRC-AGIP LAB IN GGE

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This paper briefly reviews the development of remote sensing technologies in the last ten years, including the development of optical, radar, and laser sensors and the trend of remote sensing software development. It also introduces some of the research activities and achievements of the Canada Research Chair Laboratory in Advanced Geomatics Image Processing (CRC-AGIP Lab) in the Department of Geodesy and Geomatics Engineering (GGE) at the University of New Brunswick (UNB). According to literature review and our research experience, we have concluded that the "bottle neck" of remote sensing is still the lack of software tools for effective information extraction from remote sensing data, especially after the rapid advancement of remote sensing sensor technologies in the last ten years and the increased demand for quickly updated, accurate geo-spatial information.

Cet article examine brièvement le développement des technologies de télédétection au cours des dix dernières années, y compris le développement des capteurs radars, optiques et lasers et les tendances du développement des logiciels de télédétection. Il présente également certaines activités de recherche et certaines réalisations du Laboratoire des chaires de recherche en traitement de pointe des images de la géomatique (CRC-AGIP Lab) du Département de géodésie et de génie géomatique (GGE) de l'Université du Nouveau-Brunswick (UNB). À la suite d'une analyse documentaire et de notre expérience de recherche, nous avons conclu que le « goulot d'étrangement » de la télédétection demeure toujours le manque d'outils logiciels permettant d'extraire des renseignements utiles des données de télédétection, plus particulièrement après le progrès rapide des technologies de télédétection au cours des dix dernières années et l'augmentation de la demande d'information géospatiale précise et rapidement actualisée.

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1. Introduction

In the last ten years, remote sensing technologies and remote sensing applications have been experiencing a revolutionary advancement in various areas, including sensor development, software development, and applications.

1.1 Remote Sensing Sensor Development

In the area of sensor development, all of the sensor technology domains (optical, radar, and laser) have exhibited evidence of the revolution:

- In optical remote sensing:
  1) The spatial resolution of satellite images dramatically increased from tens of metres to metres and to sub-metre (Table 1). This allows users to see increased detail of the earth's surface, from streets and buildings 10 years ago to cars and even individual people now.
  2) The first digital aerial cameras were presented to the photogrammetric community in 2000 at the ISPRS congress in Amsterdam. Now, digital airborne cameras/sensors with 50-cm to 5-cm resolution are increasingly used by the mapping industry (Table 2). Traditional film-based cameras are being gradually phased out.
- In radar remote sensing:
  1) The spatial resolution of radar images has also increased from tens of metres to metre level (Table 3).
  2) More importantly, the sensor capacity has improved from collecting single-polarization images to capturing multi-polarization images (Table 3). This improvement provides more textural information of land cover types and allows for better land cover classification.
- In laser remote sensing:
  1) Laser was invented in 1960 [*Lidar Remote Sensing Overview* 2007]. The use of LiDAR (Light Detection and Ranging) for producing high-accuracy digital elevation

Table 1: Optical earth observation satellites, sensors, and their spatial and spectral resolutions [*Zhang and Kerle* 2007; *Stoney* 2008].

Optical satellite	Spatial resolution (m) (# of bands)				Swath (km)	Year of launch
	Pan*	MS*				
		VNIR*	SWIR*	TIR*		
Landsat 5		30 (4)	30 (2)	120 (1)	185	1984
SPOT 2	10	20 (3)			60	1990
IRS-P2		36.4 (4)			74	1994
IRS-1C	5.8	23.5 (3)	70.5(1)		70, 142	1995
IRS-1D	5.8	23.5 (3)	70.5(1)		70, 142	1997
SPOT 4	10	20 (3)	20 (1)		60	1998
Landsat 7	15	30 (4)	30 (2)	60 (1)	185	1999
CBERS 1 and 2	20	20 (4)			113	1999, 2003
Ikonos 2	1	4 (4)			11	1999
Terra/ASTER		15 (3)	30 (6)	90 (5)	60	1999
KOMPSAT-1	6.6				17	1999
EROS A1	1.9				14	2000
Quickbird 2	0.61	2.44 (4)			16	2001
SPOT 5	2.5–5	10 (3)	20 (1)		60	2002
IRS-P6 / ResourceSat-1	6	6 (3), 23.5 (3)			24, 70, 140	2003
DMC-AlSat1		32 (3)			600	2002
DMC-BILSAT-1	12	28 (4)			25, 55	2003
DMC-NigeriaSat 1		32 (3)			600	2003
UK-DMC		32 (3)			600	2003
OrbView-3	1	4 (4)			8	2003
DMC-Beijing-1	4	32 (3)			24, 600	2005
TopSat	2.5	5 (3)			25	2005
KOMPSAT-2	1	4 (4)			15	2006
IRS-P5/CartoSat-1	2.5				30	2006
ALOS	2.5	10 (4)			35, 70	2006
Resurs DK-1	1	3 (3)			28.3	2006
WorldView-1	0.5				17.5	2007
RazakSat	2.5	5 (4)			20	2008
RapidEye A–E	6.5	6.5 (5)			78	2008
GeoEye-1	0.41	1.64 (4)			15	2008
EROS B – C	0.7	2.8			16	2009
WorldView-2	0.46	1.84 (8)			16	2009
Plèiades-1 and 2	0.7	2.8 (4)			20	2010, 2011
CBERS 3 and 4	5	20 (4), 40	40 (2)	80	60, 120	2009, 2011

* Pan: panchromatic; MS: multispectral; VNIR: visible and near infrared; SWIR: short wave infrared; TIR: thermal infrared.

Table 2: Airborne digital cameras/sensors, their ground coverage (pixel x pixel), and spectral bands [*GIM International* 2008].

Brand	Name	Date of update	Weight (kg)	# of lenses	# of CCD[a] chips	# of pixels across track	# of pixels along track	Spectral bands[b]
Applanix	DSS 422	2007	7	1	1	5,436	4,092	R,G,B or NIR,R,G
	DSS 439	2007	24	1	1	7,216	5,412	R,G,B or NIR,R,G
DIMAC	DiMAC 2.0	2006	100	2 to 4	2 to 4	10,500	7,200	R,G,B, NIR
IGI	DigiCAM-H/39	2007	1.8	1	1	7,216 or 5,412	5,412 or 7,216	R,G,B, or NIR
	DigiCAM-H/70	2008	3.6	2	2	13,500 or 10,000	10,000 or 13,500	R,G,B, or NIR
Intergraph	DMC	2003	88	8	8	13,824	7,680	Pan, R,G,B, NIR
Jena	JAS 150s	2007	65	1	9	12,000/line	Unlimited	Pan, R,G,B, NIR
Leica	ADS40	2006	61-65	1	8 or 12	12,000/line	Unlimited	Pan, R,G,B, NIR
RolleiMetric	AIC x1	2004	1.4	1	1	5,440 or 4,080	7,228 or 5,428	RGB or IR
	AIC x2	2007	12 no lenses	2	2	10,227 or 4,080	13,588 or 5,428	RGB and IR / RGB or IR
	AIC x4	2008	38	4	4	10,227 or 7,670	13,588 or 10,204	RGB and IR / RGB or IR
Vexcel	UltraCam X	2006	54	8	13	14,430 (pan)	9,420 (pan)	Pan, R, G, B, NIR
Wehrli	3-OC-1	2006	25	3	3	8,002/line	Unlimited	R,G,B

[a] CCD: Charge Coupled Device (each CCD chip forms one digital frame or line sensor)

[b] R,G,B and NIR: red, green, blue, and near infrared

Table 3: Radar earth observation satellites, sensors, spectral bands, and their spatial resolution and polarization [*Zhang and Kerle* 2007; *Düring et al.* 2008].

Satellite	Sensor	Year of launch	Band	Wavelength (cm)	Polarization	Resolution range (m)	Resolution azim. (m)	Scene width (km)
ERS-1	AMI	1991	C	5.7	VV	26	28	100
JERS-1	SAR	1992	L	23.5	HH	18	18	75
ERS-2	AMI	1995	C	5.7	VV	26	28	100
Radarsat-1	SAR	1995	C	5.7	HH	10 – 100	9 – 100	45 – 500
Envisat	ASAR	2002	C	5.7	HH/VV	30 – 150	30 – 150	56 – 400
Alos	PALSAR	2006	L	23.5	All[a]	7 – 100	7 – 100	40 – 350
Radarsat-2	SAR	2007	C	5.7	All	3 – 100	3 – 100	50 – 500
TerraSAR-X	TSX-1	2007	X	3	All	1 – 16	1 – 16	5 – 100
Cosmo/SkyMed 1, 2, 3, 4	SAR-2000	2007, 2007, 2008, 2010	X	3	HH/VV	1 – 100	1 – 100	10 – 200
TerraSAR-L	SAR	2008 (plan)	L	23.5	All	5 – 50	5 – 50	20 – 200
TanDEM-X[b]	TSX-SAR	2010	X	3	HH/VV	1.7 – 3.5	18.5	100

[a] All four polarization combinations HH, HV, VV, and VH (HH: horizontal sending horizontal receiving; HV: horizontal vertical; etc.)

[b] TanDEM-X (**T**erraSAR-X **a**dd-o**n** for **D**igital **E**levation **M**easurement)

models (DEMs) was brought about by the demand for mass DEMs from the telecommunications boom in the 1990s [*LiDAR—Overview* 2006].

2) In the last ten years, airborne LiDAR sensor technology has developed to the stage of maturity, which can capture highly accurate terrain data through the collection of *xyz* point clouds in a highly automated fashion [*LiDAR—Overview* 2006; *GIM International* 2009] (Table 4).

1.2. Remote Sensing Software Development

In the area of software development, several breakthroughs have been achieved to more effectively utilize and extract information from available remote sensing images, despite the reality that its progress is still far behind the advancement of the sensor technology and the demand from end users to solve real-world problems. For example:

- In optical remote sensing:
  1) More than 80% of the modern earth observation satellite sensors and many airborne digital cameras simultaneously collect high-resolution panchromatic (Pan) and low-resolution multispectral (MS) images. The demand for effectively sharpening low-resolution MS images using high-resolution Pan images has been growing rapidly. However, traditional image fusion (also called pan-sharpening) algorithms and software tools could not produce satisfactory pan-sharpening results, even though operators' intervention was required in the fusion process to achieve the best possible results.
     - To solve this problem, the first fully automated pan-sharpening software

Table 4: Airborne LiDAR sensors, vertical and horizontal precisions, and maximum point density [*GIM International* 2009].

Brand	Name	Date of update	Weight (kg)	Wave-length (nm)	Elevation precision at 1km (cm)	Overall planimetric precision (cm)	Max. # / no. of points/m^2
Airborne Hydro-graphy AB	Dragon Eye	2008	25	1,000	GPS/INS Pending	GPS/INS Pending	50 @ 150m, 300kHz, 20m/s
	Hawk Eye II	2006/ 2008	95	532 / 1,064	Bathy<50 Topo<30	Bathy<5m Topo<1m	Bathy 1/m^2, topo 10/m^2
Leica Geo-systems	ALS60	2008	38.5	1,064	14 - 16	20 - 26	91 @ 150km/h, 200m, 15°
Optech	ALTM Gemini	2006	23.4	1,064	< 10	1/11 000	
	ALTM Orion	2008	27	1,064	< 10	1/5 500	
RIEGL	RIEGL VQ-480	2008	11.5	1,550	< 15	< 10	50 @ 50km/h, 150m, 60°
	RIEGL LMS-Q560	2008	16	1,550	< 15	< 10	4 @ 200km/h, 500m, 60° 66 @ 50km/h, 150m, 60°
	RIEGL LMS-Q680	2009	17.5	1,550	< 15	< 10	5 @ 200km/h, 500m, 60°
TopoSys	Harrier 56/G4	2008	42	1,550	< 15	< 10	4 @ 200km/h, 500 m, 60° 66 @ 50km/h, 150m, 60°
	Harrier 68/G1	2009	N/A	1,550	< 15	< 10	5 @ 200km/h, 500m, 60°
	Falcon II	2000/ 2008	41	1,560	< 15	< 10	12 @ 200km/h, 500m, 14.3°

tool (PCI-Pansharp) was released by PCI Geomatics Inc. in early 2003, which can fuse Pan and MS images from all satellites with optimal fusion results in a one-step process. Since then, PCI-Pansharp has been widely used throughout the world.
- DigitalGloble Inc. also installed the same technology into their production line in late 2003. Since then all the pan-sharpened QuickBird images have been produced using the technology and distributed worldwide.

2) With the significantly increased image resolution, human operators can interpret much more information. However, traditional image classification algorithms and software tools failed to effectively extract the information which human eyes can clearly see.
- To overcome this problem, a breakthrough software package—eCognition—involving a new concept for image classification (i.e. object-based classification) was first introduced into the commercial market in 2000. It has now become the most advanced and most popular software for classification of high-resolution satellite images.
- However, the major drawbacks of eCognition are that
  - the software is very complicated to use,
  - it needs a tedious trial-and-error process to achieve reasonable results in an iterative fashion, which is, therefore, very time consuming, and
  - the classification quality depends heavily on the knowledge and experience of the operator.

  These drawbacks have prevented the software from being widely used by remote sensing practitioners.

3) Due to the rapid increase of digital aerial photos and high-resolution satellite images, photogrammetric image processing software has also come into a fully digital processing stage, i.e. digital photogrammetry. The first commercial digital photogrammetric software—SOCET SET—was developed in the 1990s [*Center for Photogrammetric Training* 2008; *Hughes et al.* 2010]. Now, many digital photogrammetric software packages (Digital Photogrammetric Workstations) dealing with geometric aspects of image mapping and measurement have been released into the market.
- Sensor modeling and image matching are two of the most important technical components of the software packages. However,
  - current sensor modeling techniques are still sensor specific and contain certain geometric errors, and
  - existing image matching algorithms cannot find reliable matching points in smooth areas such as forest, grass, and roof areas, so that no software can achieve fully automated, accurate matching of images with a large coverage of smooth land covers.

- In radar remote sensing:
  1) Because of the newly emerging multi-polarization radar images and the increase of the spatial resolution, software packages dealing with image polarization are being quickly developed, and research in utilizing polarization information for improved land cover classification is also growing rapidly.

- In LiDAR remote sensing:
  1) LiDAR software development, compared to sensor development, is surprisingly immature. Major commercial hardware vendors just provide software for essential processing of their data. Very few companies produce commercial LiDAR editing packages. And, the LiDAR editing process is still very labour intensive [*LiDAR—Overview* 2006].
  2) The potential application opportunity of LiDAR data, except for DEM generation, will be the utilization of the "noise" in the data, i.e. the laser points that are not reflected from the bare earth but from anything standing above the ground, such as building roofs, trees, and electric power lines [*LiDAR—Overview* 2006]. For this new opportunity, new software tools need to be developed.

1.3. Remote Sensing Applications

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fields where location information is needed. Natural resourse management, environment monitoring, urban planning, disaster relief, and law enforcement are just a few examples where remote sensing information has played an important role. Thanks to the significant increase of image resolution and image diversity, remote sensing has increasingly influenced our daily life. One of the most influential remote sensing applications that has emerged in the last ten years is:

- The launch of Google Maps in 2004 and Google Earth in 2005 [*Google Milestones* 2010], which initiated the revolution of bringing remote sensing application from government, research, and industry uses into people's everyday lives.

2. Technology Development in the CRC-AGIP Lab of GGE

UNB-Pansharp can produce optimal pan-sharpening results of available Pan and MS images from all remote sensing satellites.

Joining UNB (the University of New Brunswick) in 2000, Dr. Zhang and his research group, named CRC-AGIP Lab (Canada Research Chair Laboratory in Advanced Geomatics Image Processing) since 2008, have done remote sensing research in all of the three remote sensing areas—optical, radar, and LiDAR. The goal of the research is to develop new algorithms and software tools for improved remote sensing applications. The main emphasise of the research has been high-resolution optical remote sensing.

In the areas of radar and LiDAR remote sensing, research conducted by the research lab includes, for example, algorithm and software development to utilize radar polarization information for improved land cover classification and to extract above-ground LiDAR points for GPS (Global Position System) applications. In the optical remote sensing field, some research results of the research lab are introduced below.

2.1. Pan-Sharpening of MS Images

Since the launch of Landsat 7 and Ikonos in 1999, traditional image fusion techniques can no longer produce satisfactory fusion results of the Pan and MS images of the new satellites launched thereafter. Because the spectral band width of the Pan images of most new satellites is extended from traditional visible wavelength range into near infrared range, traditional image fusion (pan-sharpening) techniques failed to consider this additional information in the image fusion, causing significant colour distortion (Figure 1). In addition, operator dependency was also a main problem of traditional fusion techniques, i.e. different operators with different knowledge and experience usually produced different fusion results.

To overcome these problems, Dr. Zhang started a research program in 2000. Based on his image fusion research experience gained in his Ph.D. studies, he quickly achieved a breakthrough in 2001, resulting in the new fusion technique—*UNB-Pansharp*. It solved the image fusion problems and produced optimal fusion results of the then-available Pan and MS images of Ikonos and Landsat 7, achieving minimum colour distortion, maximum spatial detail, and optimal integration of colour and spatial detail (Figure 2). The results were presented at IEEE IGARSS 2002 [*Zhang* 2002a] in Toronto and at the 2002 ISPRS, CIG and SDH Joint Symposium in Ottawa [*Zhang* 2002b]. The UNB-Pansharp technique was then licensed to PCI Geomatics Inc. and DigitalGlobe Inc. in 2002 and 2003, respectively, resulting in PCI-Pansharp being widely used throughout the world and DG-Pansharp producing significantly improved QuickBird pan-sharpened MS images for global distribution.

Around 80% of earth observation satellites collect low-resolution MS and high-resolution Pan images simultaneously (see Table 1). UNB-Pansharp can produce optimal pan-sharpening results of available Pan and MS images from all remote sensing satellites [*Zhang* 2004]. Figure 3 shows one example of GeoEye-1 pan-sharpening using UNB-Pansharp.

Due to the superior fusion quality and fully automated one-step process, UNB-Pansharp is now being used by industrial, governmental, academic, and military organizations worldwide at all levels, from globally leading organizations such as NASA to local organizations such as a marine conservation organization in Mauritius. It was selected by the Association of University Technology Managers (an international organization) as one of nine Canadian research achievements for "The Better World Project 2006" and reported in *Technology Transfer Works: 100 Cases from Research to Realization* [*AUTM* 2006]. Other universities being reported include MIT, Stanford and Yale.

2.2. Control Network-Based Image Matching

Image interest point (also called feature point) matching is a key technique for image registration. It is widely used for 3D reconstruction, change detection, medical image processing, computer vision, and pattern recognition. It is also an essential

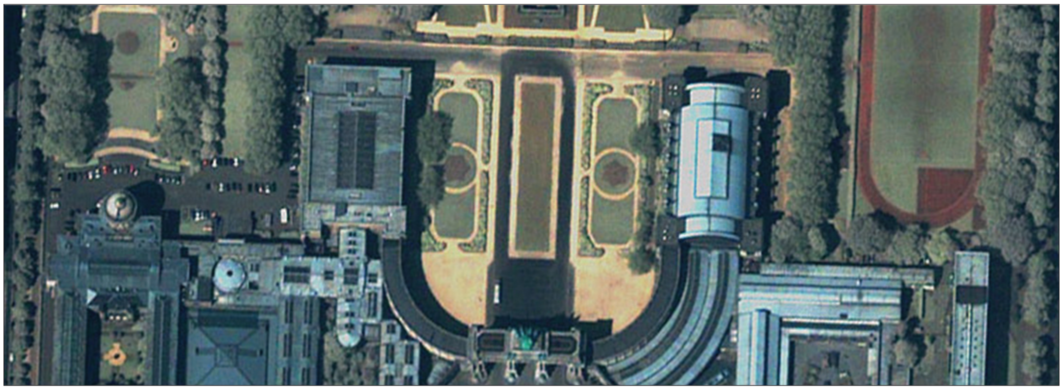

Figure 1: Colour distortion of pan-sharpened QuickBird natural colour image, downloaded from *www.DigitalGlobe.com* in 2003. (The image was taken on June 2, 2002 covering Brussels, Belgium.)

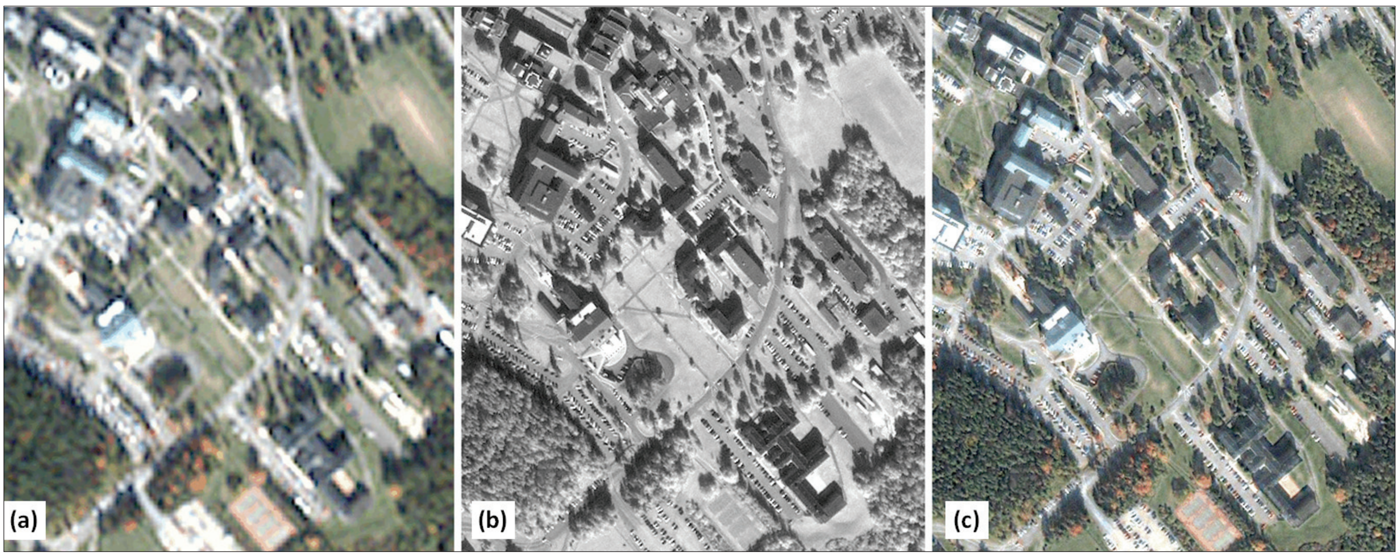

Figure 2: Image fusion quality of UNB-Pansparp. (a) Original Ikonos MS image, 4m resolution; (b) Original Ikonos Pan image, 1m; (c) Pan-sharpened Ikonos MS image, 1m, using UNB-Pansharp. (The image shows a portion of UNB campus in Fredericton. The image was taken in October 2001.)

Figure 3: Fusion quality of UNB-Pansharp for GeoEye-1 images (launched in 2008). (a) Original GeoEye-1 MS image, 2m resolution; (b) Original GeoEye-1 Pan image, 0.5m; (c) Pan-sharpened GeoEye-1 MS image, 0.5m, using UNB-Pansharp.

technique in digital photogrammetry. Although numerous algorithms have been developed, matching images with local distortions caused by viewing angle differences and relief variations remains problematic. In earth-oriented remote sensing, however, local distortions are unavoidable in high-resolution satellite images and aerial photos, because the images are normally acquired at widely-spaced intervals and from different viewpoints.

Currently, there are two main types of interest point matching algorithms: area-based and feature based. Although each type has its own particular advantages in specific applications, they all face the common problem of dealing with ambiguity in smooth (low-texture) areas, such as forest, grass, highway surfaces, building roofs, etc. However, low texture areas appear everywhere in real-life remote sensing images. This limitation has significantly lowered the accuracy and the degree of automation of image matching in many aspects.

The new algorithm and software developed in CRC-AGIP…can find matching points at a much higher speed and with a much better accuracy than any existing feature point matching methods.

To deal with the image matching problems caused by local distortions and low-texture areas, a new algorithm—*Control Network Based Matching*—was developed in the CRC-AGIP Lab in 2008. The algorithm consists of (1) the detection of "super points" (i.e. those points which have the greatest interest strength and represent the most prominent features) and (2) the subsequent construction of a control network. Sufficient spatial information can then be extracted to reduce the ambiguity in low-texture areas and avoid false matches in areas with local distortions [*Xiong and Zhang* 2009a].

The experiment with a variety of remote sensing images, including Ikonos, QuickBird, and ordinary digital photos, have shown that the new algorithm and software developed by CRC-AGIP can successfully process local distortion and avoid ambiguity in matching smooth areas (Figure 4, 5, and 6).

The new algorithm and software developed in CRC-AGIP, because of the construction of a control network, can find matching points at a much higher speed and with a much better accuracy than any existing feature point matching methods. It exhibits a tremendous potential in improving the current image matching process, accuracy, and automation.

2.3. Generic Method for RPC Sensor Model Refinement

In remote sensing image processing, geometric sensor models are used to represent the geometric relationship between object space and image space, and transform (or rectify) image data to conform to a map projection. An RPC (Rational Polynomial Coefficient) is a commonly used sensor model that has been used to transform/rectify images of a variety of high-resolution satellite sensors. It can also be used to transform images from airborne digital sensors. But, certain geometric errors exist, so that the RPCs provided by image vendors usually need to be refined.

To date, numerous research papers have been published on RPC refinement, aimed at improving the accuracy of the transformation. The Bias Compensation method is, so far, the most accepted one and has been widely used in the remote sensing community. But, this method can only be used to improve the RPCs of the images obtained by sensors with a narrow field of view, such as those sensors on board of Ikonos or QuickBird satellites, and under the condition that the sensor's position and attitude errors are sufficiently small. In many cases, however, images may be collected by sensors with a wide field of view and/or with large sensor position and attitude errors, such as airborne digital sensors, which usually have a very large field of view, and some satellite sensors, which may have large position and attitude errors. Therefore, it is desirable to have a more robust method that can be used to refine the RPCs of images collected by a wider range of sensors and containing larger sensor position and attitude errors.

The CRC-AGIP Lab developed a generic method for RPC sensor model refinement (named *Generic RPC Refinement Method*) in 2008, which can refine the RPCs of a much wider range of sensors, has a much larger tolerance for sensor position and attitude errors, and still reaches sub-pixel to 1-pixel accuracy. The method first restores the sensor's pseudo position and attitude, then adjusts these parameters using ground control points. Finally, a new RPC is generated based on the sensor's adjusted position and attitude [*Xiong and Zhang* 2009b].

Experiments with Ikonos and SPOT-5 images confirmed that the Bias Compensation method (the current industry standard method) worked well only under the condition when the sensor's field of view is narrow and the sensor position and attitude errors are small. Under this condition, the Generic RPC Refinement Method developed by the CRC-AGIP Lab also reached the same accuracy (Figure 7). However, the accuracy of the Bias Compensation method decreased rapidly when the sensor's position error and attitude error increased (Figure 8 and 9, case 3 and 9). In contrary, the Generic RPC Refinement Method was found to yield highly accurate results under a variety of sensor conditions with different position and attitude errors (Figure 8 and 9).

Because of the superior advantages of the Generic RPC Refinement Method—(1) reaching sub-pixel to 1-pixel accuracy for a wide range of optical sensors, including satellite and airborne sensors, under a large range of sensor errors, (2)

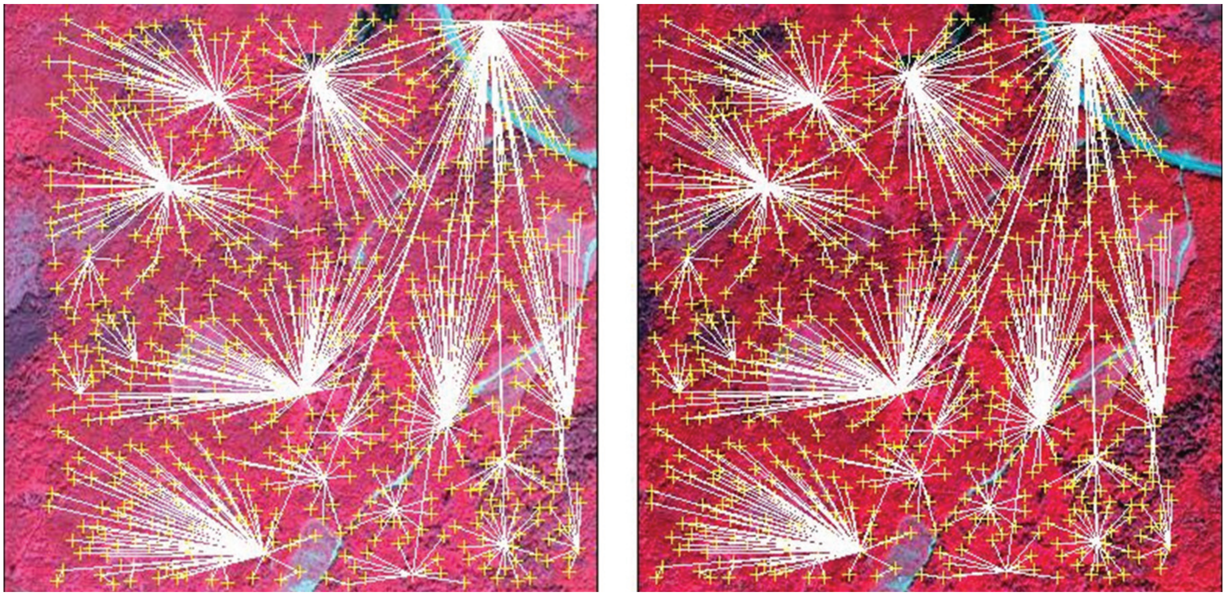

Figure 4: Feature points in forest area of a QuickBird MS image pair (2.8m) extracted and matched by the control network-based matching technique developed in the CRC-AGIP Lab.

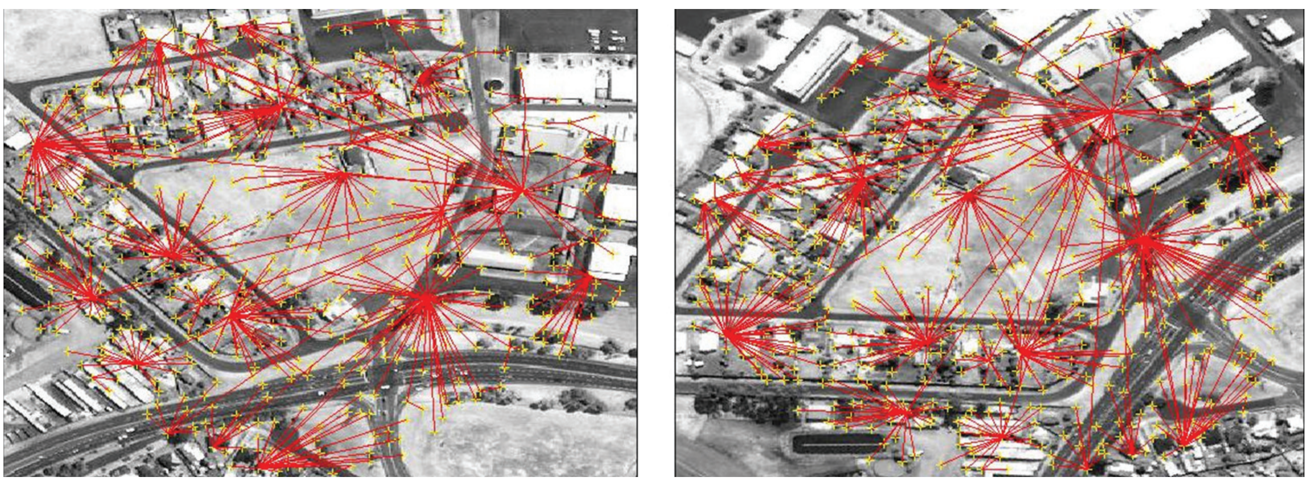

Figure 5: Feature points in built-up and grass areas of a 315-degree rotated Ikonos Pan image pair (1m) extracted and matched by the control network-based matching technique.

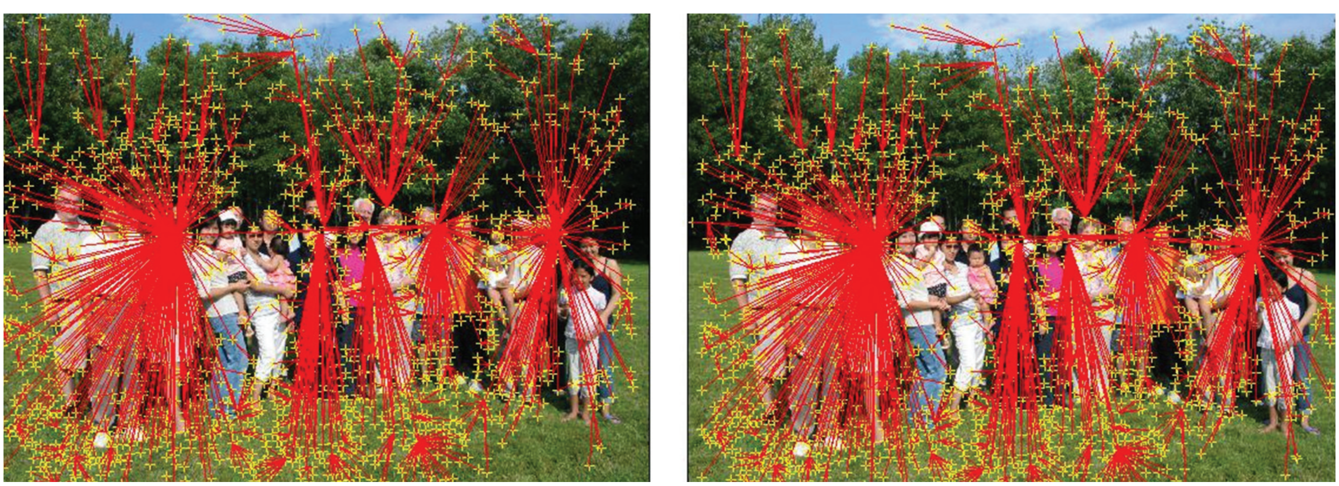

Figure 6: Feature points in tree and grass areas of a pair of ordinary photographs extracted and matched by the control network-based matching technique.

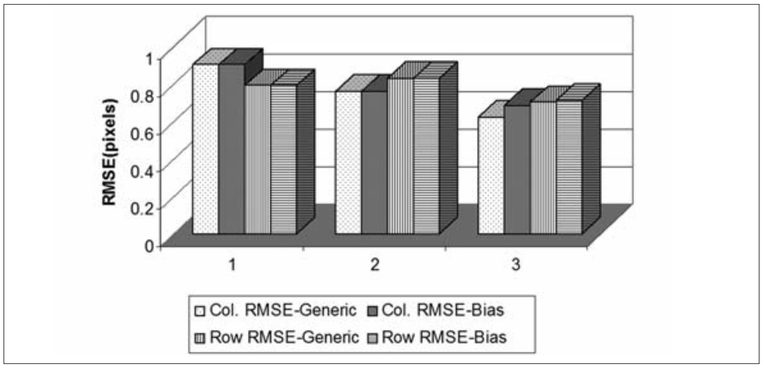

Figure 7: Accuracy comparison between the Bias Compensation method and the Generic RPC Refinement Method developed in CRC-AGIP using Ikonos images (narrow field of view) in three cases (all with small sensor position and attitude errors). (Note: RMSE = Root Mean Square Error; Row = Row direction of image; Col. = Column direction of image; Generic = Generic RPC Refinement Method; Bias = Bias Compensation method.)

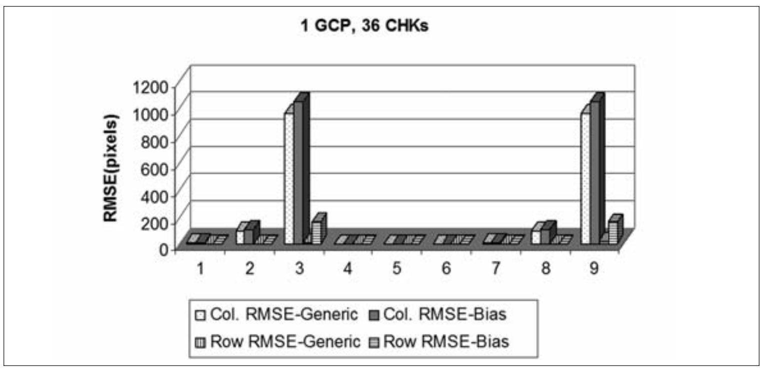

Figure 8: Accuracy comparison between the Bias Compensation method and Generic RPC Refinement Method using simulated SPOT-5 data with nine different magnitudes of errors and using one GCP as ground control and 36 check points for accuracy assessment. (Case 2: The sensor position error is 100m in x, y, and z directions, and the sensor attitude error is 0.01 radian about the three axes; Case 3: Position error is 1000m in x, y, z, and attitude error is 0.1 radian about the three axes; Case 8: Position error is 0, and attitude error is 0.01 radian; Case 9: Position error is 0, and attitude error is 0.1 radian; and Cases 1, 4, 5, 6, and 7: The sensor position error varies from 10m to 1000m in x, y, z, and attitude error varies from 0.0 to 0.001 radian.)

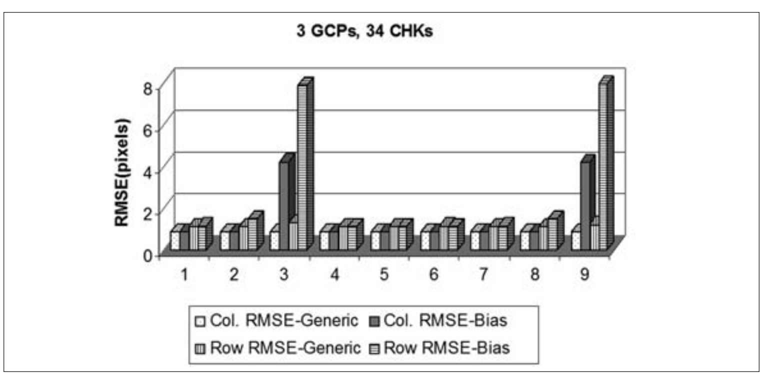

Figure 9: Accuracy comparison between the Bias Compensation method and Generic RPC Refinement Method using simulated SPOT-5 data with nine different magnitudes of errors and using three GCP as ground control and 34 check points for accuracy assessment. (The magnitudes of errors of the nine cases are the same as in Figure 8.)

working well with any number of GCPs, (3) not requiring any other auxiliary data (except for one or a few GCPs), and (4) simple in calculation and stable with the results—the method exhibits a great potential for upgrading the current industry standard solutions in sensor modeling and RPC sensor model refinement.

2.4. Supervised Image Segmentation

Along with the significant improvement of spatial resolution of remote sensing imagery since 1999, traditional per-pixel based classification techniques have been facing increased problems in achieving acceptable classification results. Object-based classification has proven to be a promising direction for classifying high-resolution remote sensing imagery, such as Ikonos, QuickBird, GeoEye-1, and airborne digital multispectral images.

In object-based classification, the image needs to be segmented into individual object segments first. The segments will then be classified into different classes. The object segmentation is a crucial process. It significantly influences the classification efficiency and accuracy. However, current state-of-the-art techniques, such as eCognition, rely heavily on the operator's experience to achieve a proper segmentation through a labour-intensive and time-consuming trial-and-error process, in which a set of proper segmentation parameters are repeatedly selected, tested, and compared with the previous one until the operator cannot find any better set or does not want to continue the comparison anymore. Therefore, the experience of the operator heavily influences the accuracy of the classification.

In the CRC-AGIP Lab, a breakthrough algorithm for supervised image segmentation was developed in 2005, a Fuzzy-Based Supervised Segmentation algorithm [*Maxwell and Zhang* 2005]. The algorithm can find/calculate a set of optimal segmentation parameters for segmenting objects of interest for the state-of-the-art commercial software eCognition (now renamed Definiens), through an algorithm training and fuzzy logical analysis process, instead of through operator's trial-and-error process.

In 2009, a software tool for supervised segmentation was developed by CRC-AGIP Lab based on the concept of the Fuzzy-Based Supervised Segmentation algorithm (Figure 10). To find the optimal segmentation parameters, the operator just needs to use eCognition for an initial segmentation (Figure 11.a), and then use the initially segmented sub-segments of an object of interest (also called target object) (e.g. building in Figure 11.b) to train the algorithm. After the training, the algorithm can then identify a set of most suitable segmentation parameters for the object of interest through a fuzzy logic analysis. Finally, this set of parameters is inputted into eCognition to segment the entire image, achieving an optimal segmentation of all objects of interest (e.g. buildings in Figure 11.c).

The supervised segmentation software tool can be integrated into eCognition. It can identify the optimal segmentation parameters through a semi-automatic process and achieve much better segmentation results than a trial-and-error process within a few minutes. Using the software tool, the segmentation of other objects of interest can also be achieved within a few minutes, producing significantly improved segmentation results (Figure 12).

The Fuzzy-Based Supervised Segmentation software tool developed by CRC-AGIP is (1) independent of operator's experience, (2) fast and accurate, and (3) easy to use. It demonstrates the ability to produce convincing segmentation results across the entire image through a simple training process. Therefore, this software tool has exhibited the potential to significantly improve the current industry standard in image segmentation and reduce the labour-intensive trial-and-error process.

2.5. Satellite Imagery for 2D and 3D Online Mapping

Along with the rapid development of Internet technologies, online mapping presents tremendous potential for timely delivery and visualization of useful map information. Since the availability of high-resolution satellite imagery in 1999, the integration of remote sensing imagery into online mapping has made it possible to dramatically improve the timeliness, vitality, and interpretability of geo-spatial information through the colour and detail of the imagery. This has been demonstrated by the success of Google Maps (launched in 2004) and Goolge Earth (launched in 2005) in integrating 2D satellite imagery into online mapping. Because of its tremendous influence on people's daily lives, Microsoft launched Virtual Earth in 2005 [*Virtual Earth News* 2009], integrating more diverse remote sensing images to attract users. Online 3D mapping was then promoted through Virtual Earth's initiative.

Research in this area has been conducted by Dr. Zhang's research group since early 2001. An online satellite image mapping system was developed for the local community and schools of Fredericton, NB, Canada, in 2002 (Figure 13). In this system, pan-sharpened Ikonos 1m colour image (produced by UNB-Pansharp) was used for the online mapping.

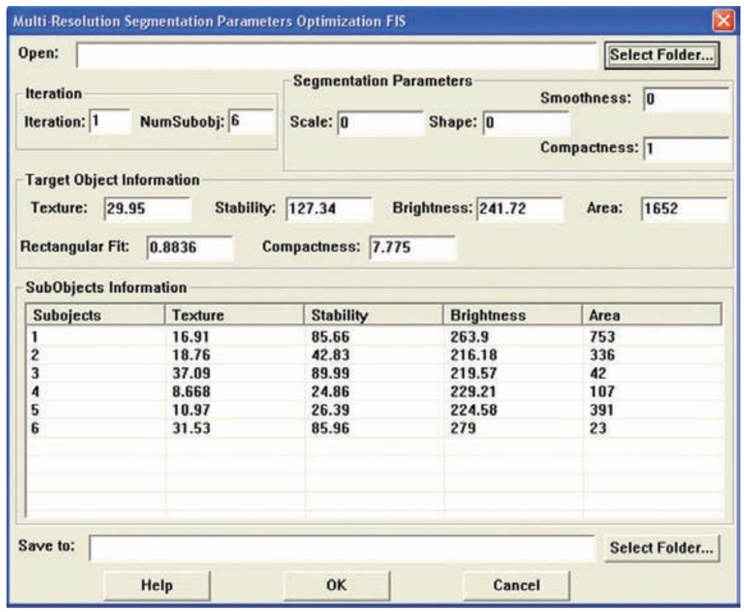

Figure 10: Interface of the Fuzzy-Based Supervised Segmentation software tool developed in CRC-AGIP, through which information of target object and sub-objects (segments) can be inputted and optimal segmentation parameters for the target object can be calculated.

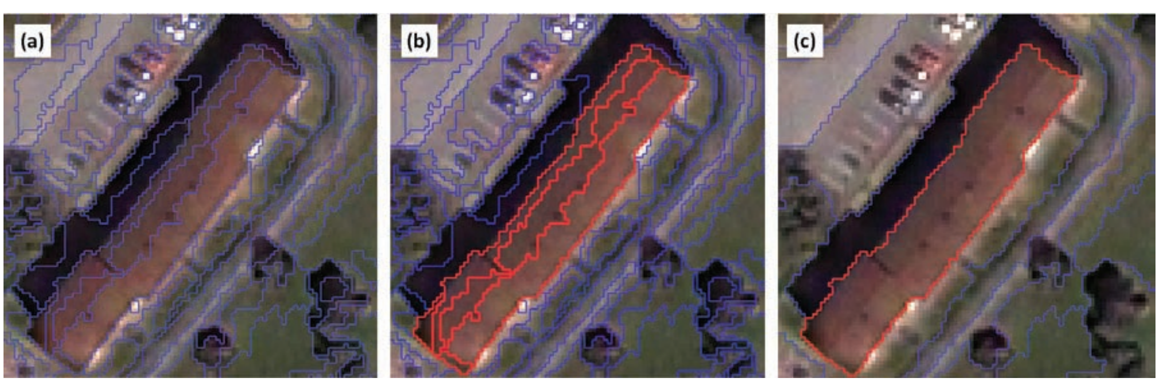

Figure 11: Process of the fuzzy logic-based, supervised segmentation, developed in CRC-AGIP at UNB. (a) Initial segmentation obtaining sub-segments of an object; (b) Selection of sub-segments of a building (red) for training to obtain optimal building segmentation parameters; (c) Final building segmentation using the optimal segmentation parameters obtained from (b).

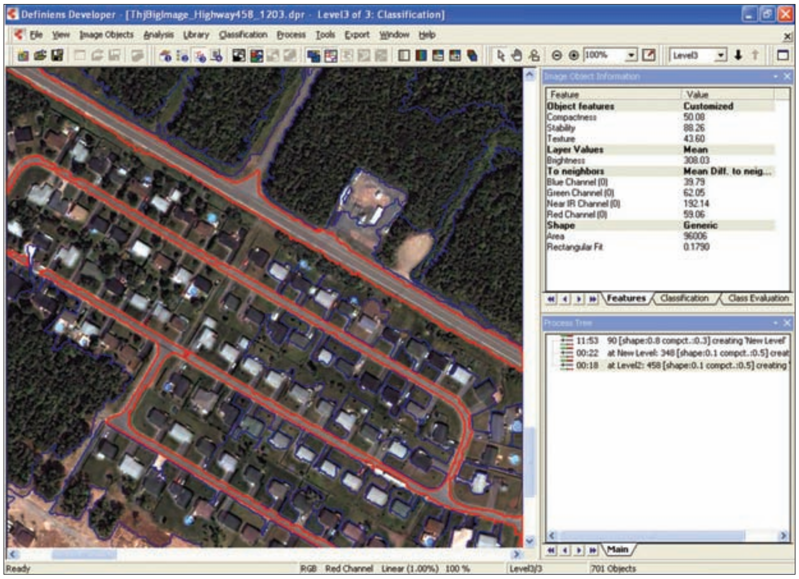

Figure 12: Example of street segmentation obtained using the parameters identified by the Fuzzy-Based Supervised Segmentation software tool in the eCognition environment.

Users can select a destination (such as a school), and then the system can "fly" from the current location to the destination (e.g. Leo Hayes High School in the example in Figure 13). A full screen view can also be displayed to allow viewers to zoom in, zoom out, and move the image. This system had been widely used by the local community until 2006 when a high-resolution satellite image of the Fredericton area was made available on Google Maps.

In 2003, an initial research result of generating colour 3D satellite images for online mapping was achieved in GGE [*Zhang and Xie* 2003]. After further development, an automated software system for 3D satellite image generation and online visualization was developed in 2005. Now, the system has been improved with more functions (Figure 14 and 15). The system can produce, distribute, and visualize 2D and 3D satellite images at different scales. Satellite images from a variety of satellites, from Landsat (15m Pan, 30m MS) to GeoEye-1 (0.5m Pan, 2m MS), can be used for the 2D and 3D image generation.

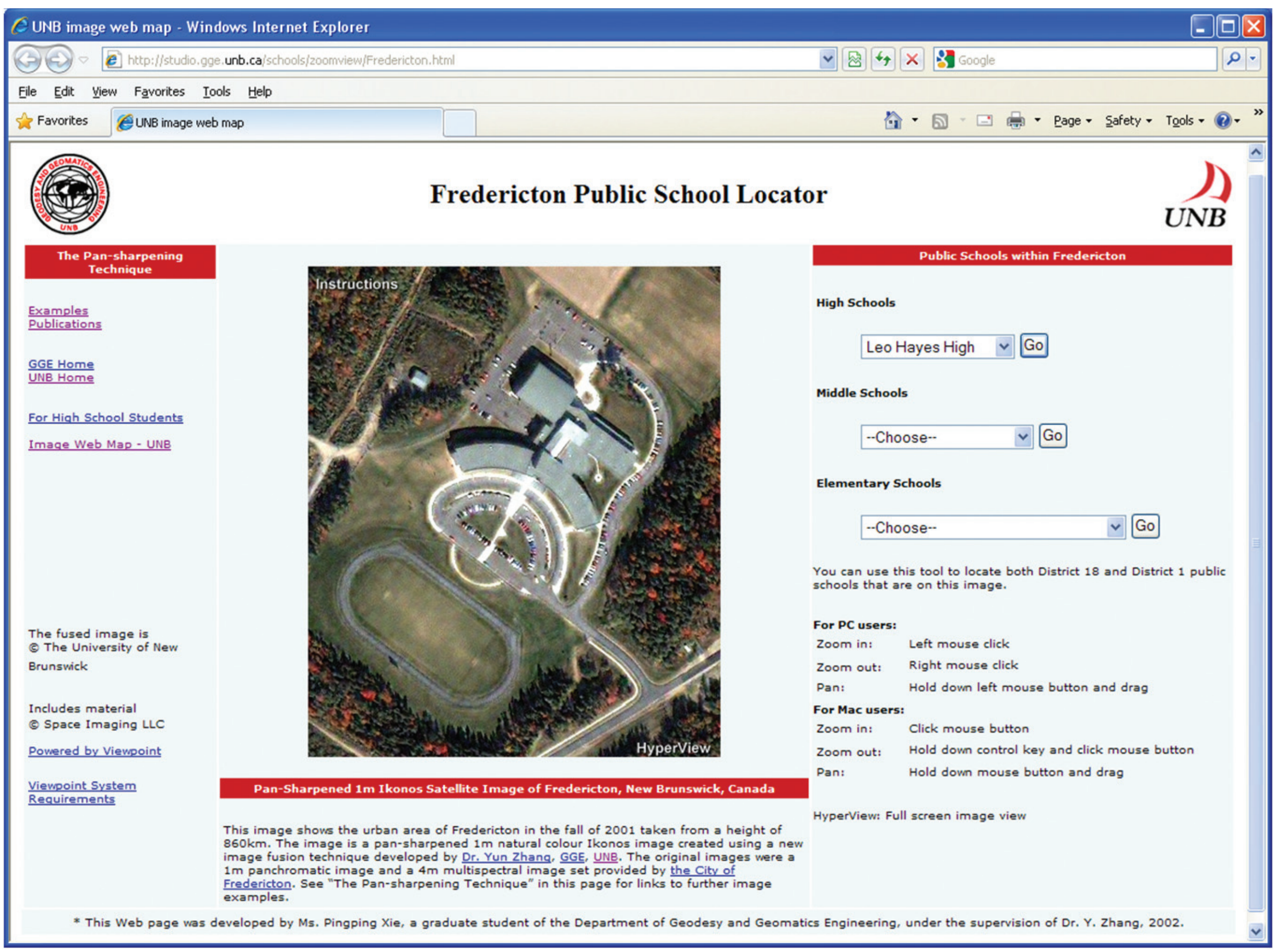

Figure 13: Online 2D satellite image mapping system developed in GGE in 2002 with pan-sharpened Ikonos image of Fredericton.

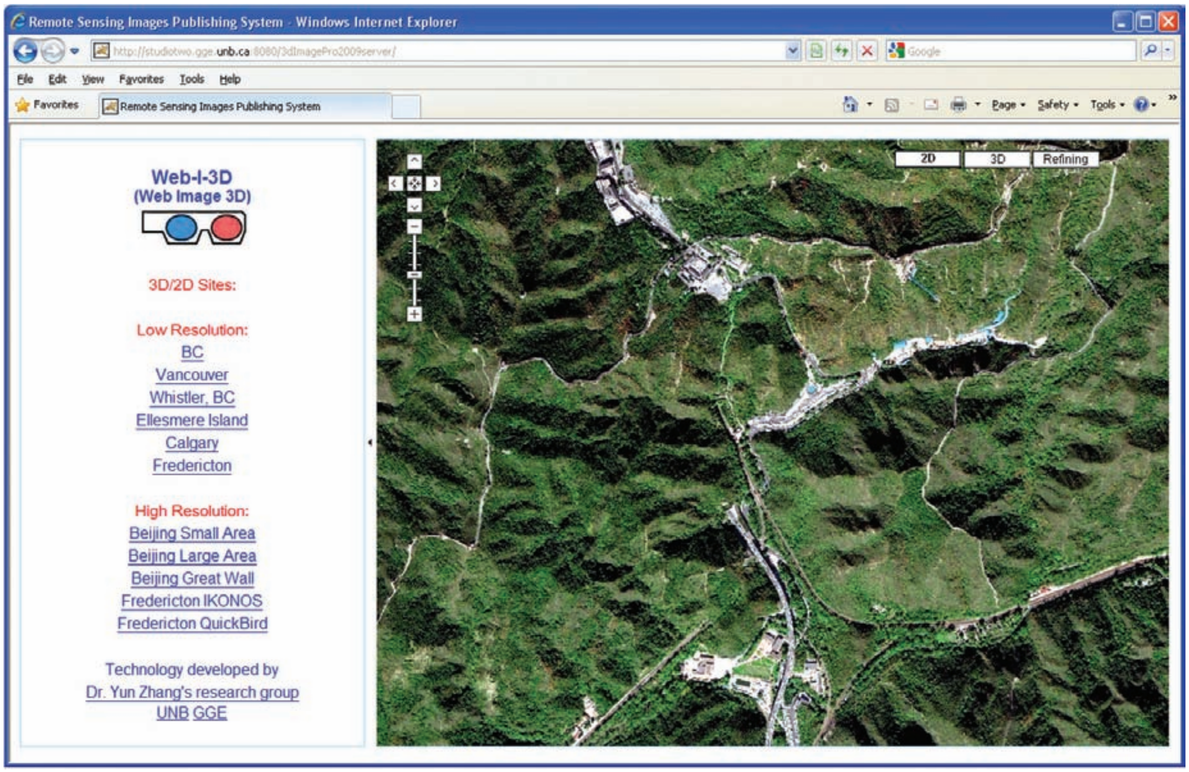

Figure 14: 2D view of the online 2D and 3D satellite image mapping system developed in CRC-AGIP of GGE (pan-sharpened QuickBird image of a part of the Great Wall near Beijing).

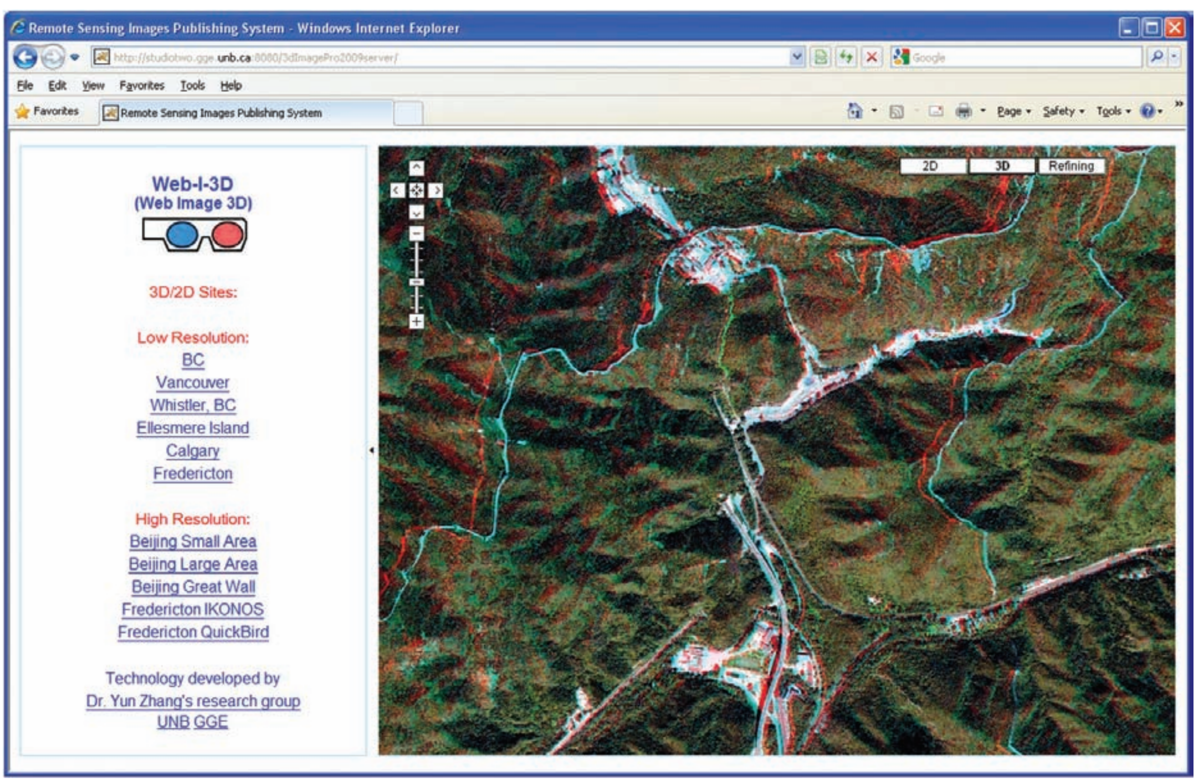

Figure 15: 3D view of the online 2D and 3D satellite image mapping system developed in CRC-AGIP of GGE (produced using pan-sharpened QuickBird image, the Great Wall near Beijing).

Using current 2D displays, such as computer screens and digital televisions, viewers can see the same colour 2D satellite images as on Google Maps. However, with a pair of inexpensive colour stereo glasses, viewers will see colour 3D images of the earth's surface, adding the third dimension into the online satellite image mapping. Along with the emergence of modern glasses-free 3D displays and televisions, the online 3D image mapping technology developed in the CRC-AGIP Lab will have a much higher application potential, because no 3D glasses are needed and a better 3D effect is achieved.

2.6. Moving Information Extraction from Single-Set Satellite Imagery

To collect high-resolution colour/multispectral images at a very high speed from space, an effective solution is to simultaneously record a low-resolution multispectral (MS) image (Figure 16.a) and a high-resolution panchromatic (Pan) image (Figure 16.b) from the same satellite, and then fuse the Pan and MS images (also called pan-sharpen) to reconstruct a high-resolution MS image (Figure 16.c).

However, to reduce the satellite payload, the linear CCD (Charge Coupled Device) array of the Pan sensor and those for the MS sensor are built into the same sensor system to share the same optical lens. Consequently, the optical axes of the Pan and MS sensors cannot be exactly parallel to each other, causing a very small viewing angle difference. This angle difference leads to a slight time delay and relief distortion (geometric distortion caused by height variation of ground objects) between the Pan and MS images. Due to the time delay, any moving objects are recorded at two slightly different locations (see Figure 16.d), resulting in annoying "tails" for all moving objects when the Pan and MS images are fused to reconstruct a high-resolution MS image (Figure 16.c). Objects with different heights are also displaced to different extents between Pan and MS, causing strange artefacts along building edges and edges of other objects in pan-sharpened MS images. These are unwanted problems in remote sensing and need to be removed through image processing.

These problems were identified by Dr. Zhang in his image fusion research in 2001 using Ikonos Pan and MS images. While exploring solutions for solving or mitigating these problems for image fusion, the idea of utilizing these unwanted problems for useful information emerged. However, the research challenge for moving information extraction from a single set Pan and MS imagery is very high, because:

- The time delay is too small to detect moving information using any existing state-of-the-art solutions,
- The double positions of any moving object is not only caused by movement of the object but also the elevation where the object is located,
- No available sensor model is precise enough to achieve acceptable position accuracy for moving speed and direction calculation, and
- No proper methods or algorithms have been found which are capable of extracting cars and their exact centres from available satellite images.

With funding support from NSERC, successful algorithms and computer software for moving information extraction from a single set of high-resolution satellite imagery were developed in 2006. The algorithms consist of a refined new sensor model, new solutions for detecting cars, and a new algorithm for speed calculation [*Xiong and Zhang* 2008]. The initial experiment with QuickBird Pan (0.7m) and MS (2.8m) images resulted in an accuracy of speed information extraction at ± 20 km/h, despite limited image resolutions and other technical challenges (Figure 17).

The initial research result was published in *Photogrammetric Engineering and Remote Sensing* in 2008 [*Xiong and Zhang* 2008]. It was then quickly recognized by the remote sensing community and was selected by ASPRS (American Society for Photogrammetry and Remote Sensing) in 2009 for the *First Place Recipient* of the prestigious *John I. Davidson President's Award for Practical Papers*. Former recipients of the award include NASA scientists at the Goddard Space Flight Center.

After the publication of CRC-AGIP's research papers, researchers in other countries also started similar research. Papers on this topic can now be increasingly seen in conference proceedings and scholarly journals.

3. Discussion and Conclusion

Driven by the increasing demand from industry, government, academia, and military for updated, more detailed, more diversified, and more reliable geo-spatial information, many earth observation optical and radar satellites have been developed, launched, or planned to launch in the last ten years, in order to collect data with a large coverage of the

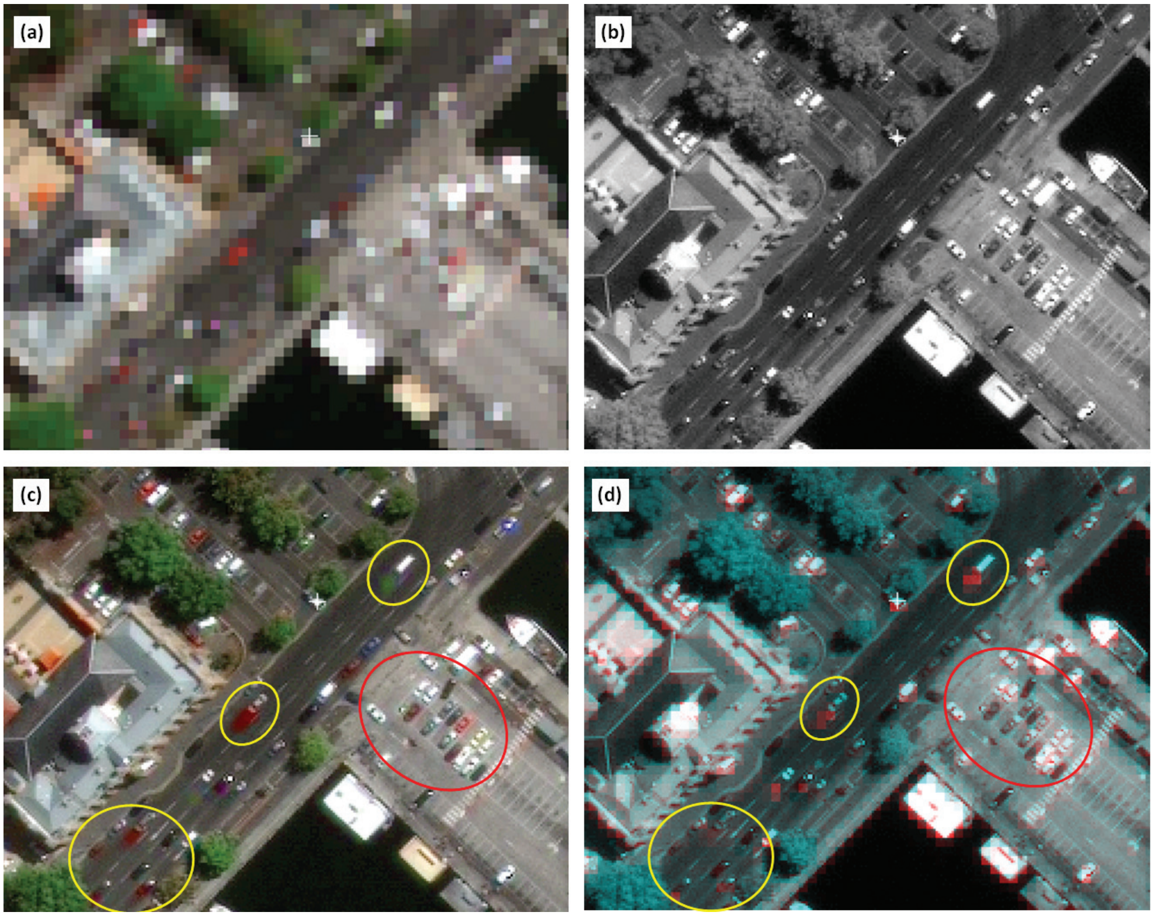

Figure 16: State-of-the-art solution to collect high-resolution colour satellite images and the problems of the modern high-resolution remote sensing sensors, such as Ikonos (launched in 1999, Pan 0.82m, MS 3.28m), QuickBird (launched in 2001, Pan 0.61m, MS 2.44m), GeoEye-1 (2008, Pan 0.41m, MS 1.64m), and WorldView-2 (2009, Pan 0.46m, MS 1.84m). (a) Original GeoEye-1 MS image (2m); (b) Original GeoEye-1 Pan image (5.0m); (c) Pan-sharpened GeoEye-1 MS image (0.5m) (using UNB-PanSharp) (yellow circle: moving objects with "tails"; red circle: static objects without "tails"); (d) Overlay of original GeoEye-1 MS (red) and Pan (cyan) images (yellow circle: moving objects with double images; red circle: static objects without double images).

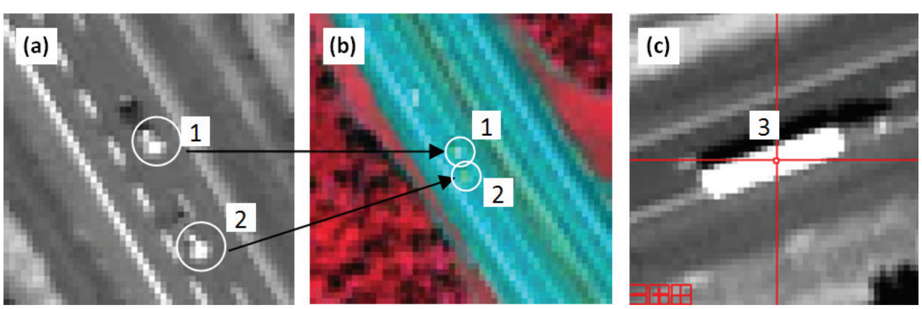

Figure 17: Challenge in determining vehicle's size and centre position in QuickBird Pan and MS images. (a) and (b) The distance between vehicle 1 and 2 is just several pixels on the Pan image and only 1 pixel on the MS image. (c) Vehicle 3 is very long, with a length of about 20 pixels on the Pan image.

earth's surface with increased detail and increased revisit rates (some aiming at daily update). Airborne digital cameras and LiDAR scanners have also been quickly developed and have become mainstream technologies in the last ten years in the mapping industry and many other areas, to collect highly accurate 2D and 3D data of the earth's surface. The data made available by these modern sensors have been overwhelming.

However, technologies for effective use of the data and for extracting useful information from the data are still very limited. In practical applications, the use of remote sensing data still stays mostly at the level of visualizing the data as background images, or producing digital or hardcopy image maps. To extract useful information from the image data, manual interpretation and editing are still the major methods in practical operations. These limitations have significantly limited the effectiveness of geo-spatial information updating, leading to the reality that numerous remote sensing data have been collected for information updating, but many have become outdated before being effectively used or ever being used.

The research activities in the CRC-AGIP Lab at UNB have mainly focused on algorithm and software development for improved utilization of remote sensing data and improved information extraction from the data. To date, the research lab has achieved several breakthroughs in this area, leading to advanced technologies for improved remote sensing applications globally. However, numerous technical problems and challenges still exist. The research lab is continuing its effort in solving or mitigating some the problems and challenges.

Along with the fast development of modern sensor technologies, new technical problems and challenges are continually emerging. The fast development of sensor technologies has brought tremendous challenges to the technology development of information extraction, but it has also brought tremendous opportunities in the extraction of more accurate and reliable geo-spatial information. Therefore, research on technology development for improved information extraction has now become more important than ever before. In order to meet the demand for updated, more detailed, more diversified, and more reliable geo-spatial information, an increased research effort on technology development for automated information extraction is required nationally and internationally.

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