UNDERSTANDING RADARSAT DATA IN STEREO[1]

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ABSTRACT

Depth perception is a sophisticated process which actively combines physiological and psychological cues with a mental model. Little is known of how this cues are combined in our brain. Viewing radar data in stereo is then sometimes more difficult than optical data. This paper presents the basic aspects of visual mechanisms to better understand depth perception from radar data, and how to use at its best RADARSAT in stereo.

1 INTRODUCTION

Not so long ago, a hill top view was the largest vista from which to observe nature's workings. Discoveries in optics, photography and flight have allowed us to see the Earth as never before. Advanced methods in computing and signal processing technologies et cetera have enabled us to increase our ability to visualize and perceive the Earth's surface. Today, Earth observation satellites orbit our planet collecting data needed to produce images which allow us to monitor, understand and plan the use of our world's resources.

Mapmakers and other illustrators have traditionally used rendering techniques such as shading, overlapping and perspective views to give an impression of three dimensionality. In the last 200 years, many advances in representing three dimensions have been made. Stereomodels, anaglyphs, chromo-stereoscopic images and holograms can provide three-dimensional (3D) information about our planet that flat, two-dimensional (2D) images can not.

Why is it important that the third dimension be conveyed? Humans are naturally able to see in three dimensions. The 'naturalness' of a 3D representation of reality enhances our ability to interpret 2D imagery. Cartographers, engineers, geologists, hydrologists, and other scientists use 3D viewing methods, such as stereo viewing of aerial photos and satellite images, in order to better understand the Earth's surface. Representation of the third

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dimension supplies important information about relationships between land shape and structure, slopes, water ways, surface material and vegetative growth.

RADARSAT, Canada's first Earth observation satellite, was launched in November 1995. It is a C-band SAR satellite with the ability to provide imagery of any part of the Earth's surface, in any climatic conditions, and by day or night. RADARSAT imagery is well suited to be used in stereo because it can be collected from different look directions, beam modes, beam positions, and at resolutions fine enough to provide a good level of detail of the Earth's surface. To demonstrate the feasibility and potential of stereoscopy with RADARSAT data, the understanding of some basic aspects are first mandatory. This paper will then address the major elements related to visual mechanisms (colour vision and depth perception), present the most common 3D viewing methods and discuss the applicability to radar data in general and RADARSAT data in particular.

2 VISUAL MECHANISMS

Vision is not a passive 'photographic' recording of surrounding objects. Instead, it is the active process of perceiving those objects. We attach meaning to objects by recognizing their colour, contours and relationships with each other. This is perception, the process whereby stimulation is actively translated into organized experience. The brain integrates the electrical stimulus received from the eyes with other information. The eye, as part of the brain, acts as an organizer, building a meaningful world of objects. At this time we know little about the way in which the brain recognizes objects, therefore a large portion of depth perception is simply not understood.

The theory of perception suggests that experience enhances understanding of our environment. We can better interpret our surroundings if we know what to look for, where to look for it and how to look at it (Hoffman, 1991). Colour and depth perception rely on experience.

2.1 Colour Vision

In every day life, objects are described by particular colours, and often are identified with reference to familiar things. For example, as blue as the sky, as green as grass, as white as snow could be used to describe the colour of an object. More scientifically, theory on the physics of colour began with Isaac Newton early in the 18th century. Using a prism, he separated sunlight into the spectrum of colours. He was able to distinguish seven colours: violet, indigo, blue, green, yellow, orange and red. Newton was able to separate rays of sunshine because light of different wavelengths is refracted by varying degrees when passing from one medium (air) to another (a crystal prism).

Wavelengths within the visual spectrum range from 400 to 760 nanometres. Within this spectrum an infinite number of colours can occur. A colour can vary in hue (chromaticity), intensity (brightness), or saturation (purity), separately, or in combination with the other components. It has been shown that with experience, humans can discriminate 120 or more hues when intensity and saturation are held constant. More if intensity and saturation vary. However, with practical experiments scientists have shown that, most commonly, differentiation begins to break down when more than seven to twelve colours along with black, white and grey tones are used at the same time in a display.

2.2 Depth Perception

Depth perception is based on ten cues. These cues contain information which, when added to the 2D image projected onto the retina, allow us to relate the objects of the image to 3D space. There are four physiological and six psychological cues. The four physiological cues are:

- accommodation, the adjustment of the focal length of the lens;
- convergence, the angle made by the two viewing axes of a pair of eyes;
- binocular disparity, the disparity between images of the same object projected onto the retinas; and
- motion parallax, the result of changing positions of an object in space due to either the motion of the object or of the viewers head.

Accommodation and convergence are associated with the eye muscles and interact with each other in depth perception. Accommodation is considered a monocular depth cue since it is available even when we see with a single eye. This cue is effective only when combined with other binocular cues, and for a viewing distance of less than two metres (Okoshi, 1976). Convergence is the ability to focus the optical axes of the two eyes onto a single object. It becomes ineffective beyond ten metres (Okoshi, 1976). Accommodation and convergence are considered to be minor cues in depth perception.

Binocular disparity is considered the most important depth perception cue over medium viewing distances. Binocular parallax is the difference between the images of an object projected on each retina. The degree of disparity between the two images depends on the parallactic (convergence) angle. This is the angle formed by the optical axes of each eye converging on an object. The parallactic angle is related to the distance of an object from the eyes. At great distances the parallactic angle decreases and depth perception becomes increasingly difficult. The smallest parallactic angle the average person is able to discern, is three arc-seconds.

Visual motion parallax is a function of the rate at which the image of an object moves across the retina. Distant objects will appear slow in comparison with close objects even when the two are moving at the same speed. Motion parallax can also be caused by the movement of the viewers head. Objects closest to the observer will appear to move faster than those further away. This is an important cue to those who only have the use of one eye.

The six psychological cues are:

- retinal image size, the larger an object image the closer it appears;
- linear perspective, the gradual reduction of image size as distance from the object increases;
- areal perspective, the haziness of distant objects;
- overlapping, the effect where continuous outlines appear closer to the observer;
- shade and shadows, the impression of convexity or concavity based on the fact that most illumination is from above; and
- texture gradient, a kind of linear perspective describing levels of roughness of a uniform material as it recedes into the distance.

Psychological cues are learned cues, therefore, they are assisted by experience. When combined, these cues enhance depth perception greatly.

In remote sensing, several cues are used to represent depths of terrain. Perspective views of remotely sensed data, created with digital elevation models and orthorectified images, provide an important source of 3-D visualization. When stereo viewing aerial photographs and other visible light imagery, such as that supplied by the Landsat, SPOT or other satellites, binocular disparity is the most important cue. Stereo viewing of radar imagery combines binocular disparity and shade and shadow cues for effective depth perception.

3 3D VIEWING METHODS

Since prehistoric times people have attempted to reproduce what they see naturally through drawing, painting and sculpture. In order to overcome the limitations of two dimensional surfaces, psychological cues such as perspective, shade and shadows have traditionally been used to create an illusion of three dimensionality. In the last 200 years, mechanical-optical and digital 3D imaging methods capitalizing on the physiological cues of binocular parallax and convergence have been developed. Prior to the invention of holography, three dimensional imaging techniques such as stereoscopy relied on these two cues. The following sections describe some commonly used 3D imaging methods and systems, especially those related to remote sensing.

The invention of photography in 1822 prompted the development of stereoscopes. The first stereoscopic viewer, a simple two mirrored device, was proposed by Sir Charles Wheatstone in 1838. This simple device allowed a viewer to observe stereoscopic pictures larger than the separation of two human eyes which is approximately 5.6 cm.

His idea was improved upon by Sir David Brewster who, in 1849, constructed a practical stereoscope using prisms instead of the mirrored model designed earlier.

Oliver Wendell Holmes improved the stereoscope by adding convex lenses as eyepieces (Okoshi, 1976). Such lenses improve depth perception greatly. When viewing a flat image, it is the accommodation cue which tells the observer that it is a flat picture. Adding a convex lens makes accommodation less significant. This allows depth sensation due to binocular parallax and convergence to be emphasized.

Stereoscopes allow us to see in three dimensions because they reinforce the physiological cues of binocular parallax and convergence. A stereoscopic viewing system forces our eyes to see two images taken from different viewpoints at the same time. Modern stereoscopes range from relatively cheap pocket models which use only convex lenses to more complex models which use mirrors, prisms and convex lenses.

The last 40 years have seen the development of analytical and digital stereoplotting systems. The concept for these systems was developed in 1957 by U.V. Helava when he was employed at the National Research Council of Canada. Photogrammetric principles -colinearity and coplanarity conditions- mathematically solve the relationship between image coordinates in a 2D image reference system and the ground coordinates of objects in the 3D 'real' world mathematically. The application of these mathematical concepts, in tandem with the development of computers, have allowed the generation of analytical and digital stereoplotting systems. The hardware and software used to transform information from 2D digital imagery into 3D data has allowed the mapping process to become more automated (Helava ,1988; Heipke, 1995).

Digital photogrammetric systems enable stereo viewing to be done on a computer screen using a system of optics and digital stereo images. Digital stereo images are separated either spatially, radiometrically or temporally. Spatial separation is achieved by the use of two monitors or a split screen and an optical system using mirrors and/or convex lenses. Radiometric separation can be achieved by anaglyphic or polarization techniques and coloured or polarized lenses. Temporal separation is achieved by an alternate display of the two images.

Chromostereoscopy, or colour stereoscopy, is a 3D viewing system that does not rely entirely on binocular parallax and convergence. This method is based on the visual phenomenon of chromostereopsis. Einthoven (1885) was the first scientist to study the chromostereopic effect. He attributed this effect to transverse chromatic dispersion and the asymetrical relation of the visual and optical axes. The visual and the optical axes of the eyes are not the same. Rays of light imaged on the fovea strike the corneal surface at an angle. As a result, the cornea and the two lens surfaces act as prisms. Shorter wavelengths (blue) are refracted more than longer wavelengths (red). On the retina, blue light is focused towards the nose while red light is focused towards the temples. Therefore, the red object will appear to be closer than the blue object.

Chromostereopsis can be enhanced by using principles of refraction with ChromaDepth™ 3D glasses (Steenblik, 1986). The method by which chromostereopsis can be used to create 3D imagery with remotely sensed data is to encode depth into an image by means of colour and then to decode the colour by means of optics such as the ChromaDepth™ glasses (Toutin, 1997a).

4 RADAR AND RADARSAT IN STEREO

Stereo viewing reproduces the natural process of stereovision. Viewing a stereo pair of aerial photographs, satellite images, stereo paintings or any other kind of imagery is dependent on x parallax and parallactic angles. X-parallax, which is also known as stereoscopic parallax, is caused by a shift in the position of observation Satellite image stereo pairs are generated when a satellite collects data with two different look angles or two different beam positions. The change in observation points causes an apparent shift in the position of an object with respect to the image frame of reference.

Two fundamental aspects of stereoscopic parallax, which allow height measurements to be made from a stereo pair, are: (i) the parallax of any point is directly related to the elevation of that point, and (ii) the parallax is greater for higher than lower elevations provided the viewing angle is constant.

The parallactic angle, also known as the convergence angle, is formed by the intersection of the left eye's line of sight with that of the right eye. The closer this point of intersection is to the eyes, the larger the convergence angle. The brain perceives the height of an object by associating depth at its top and its base with the convergence angles formed by viewing the top and base. The X-parallax and the parallactic angle are related. As X-parallax increases, so too does the parallactic angle.

As the eyes scan overlapping areas between a stereo image pair, the brain receives a continuous 3D impression of the ground. This is caused by the brain constantly perceiving the changing parallactic angles of an infinite number of image points making up the terrain. The perceived 'virtual' 3D model is known as a stereomodel.

A quick glance comparing radar imagery with aerial photography or VIR satellite imagery will reveal obvious differences. Imaging geometry and electromagnetic wave properties together produce the very different appearances of a radar image, an aerial photograph or a VIR satellite image. Vertical structures on radar images, and aerial photographs or VIR satellite images appear to be very different. The most obvious difference is that relief displacement is in opposite directions. On aerial photographs and other optical sensor images, relief displacement falls away from the nadir point because the base is imaged before the top of a structure. In radar images the top of a structure is imaged before the base. Thus, the relief displacement falls towards the nadir. Relief displacement will be greater in slant range than ground range due to the fact that the image is more compressed in a slant range presentation. Relief displacement is also most pronounced at near range.

Range direction distortions on radar images are comparable to those encountered in oblique photographs. But, relief displacements occur in “opposite directions” for optical and SAR sensors. The radar perspective represented on an image is portrayed as being orthogonal to the radar direction. Consequently, a viewing angle, a, less than 90°, usually employed in SAR systems, has approximately the same effect as an equivalent angle of $90°-a$ for the oblique optical viewing. This approximate relationship help in understanding the impact of geometry on SAR imagery. For example, it is important when considering stereo configuration and the positioning of SAR stereo image pairs.

As with aerial photos, RADARSAT and other satellite image pairs are seqenced from left to right depending on the position of the platform at the time the image was taken. The sequence of a RADARSAT image pair depends on two factors: (i) the beam position of the sensor, and (ii) whether the satellite was on an ascending or descending orbital pass.

As noted previously, RADARSAT has the ability to collect data from a range of beam positions. The beam position sets the viewing angles. These are steepest at the first and shallowest at the last position. On an ascending pass the look direction of the sensor is to the east. The beampositions fan out sequentially towards the east. On a descending pass the sensor faces west and the beam positions fan out towards the west.

For example, in order to image the same geographical area with an S1 and S3 beam mode and position, both on a descending pass, the S3 satellite orbit will be east or to the right of the S1 satellite orbit. This is due to the fact that S3 has a shallower viewing angle than S1.

Thus, the S1 image will take the left hand position of an S1/S3 image pair collected on a descending pass. If both images are collected on an ascending pass, the order of the image pair is reversed.

In the case of an opposite-side stereo configuration the descending image is viewed on the left hand side while the ascending image is viewed on the right hand side. To viewers accustomed to optical sensor stereo image pairs this order seems wrongly flipped around. However, if we recall that on SAR images, relief displacement is towards the sensor, while on optical images relief displacement is away from the optical sensor the order makes sense.

Vertical exaggeration is the difference between imaging (air) base-to-height and stereo viewing base-to-height ratios. The larger the base-to-height ratio the greater the vertical exaggeration. RADARSAT stereo pairs display more or less vertical exaggeration depending on the viewing angle or beam position of the satellite when the data was collected. The base-to-height ratio increases as the distance between two satellite imaging positions decreases. When imaging the same geographical area with steep viewing angles the air base-to-height is less than when viewing the same area with shallower viewing angles. This is true for both same-side and opposite-side stereo configurations. Furthermore, an opposite-side stereo configuration will always result in more vertical exaggeration than a same-side stereo configuration (Toutin, 1997b).

5 CONCLUSIONS

Understanding the visual mechanisms which contribute to the perception of depth by the brain is mandatory when using RADARSAT in stereo. Indeed, the naturalness of viewing optical data in stereo does not always apply to radar data. This paper has first presented the two main characteristics (physiological and psychological) of the active eye/brain perception: colour and depth, and their use in different 3D viewing methods and systems. It then addressed the applicability of stereoscopy to RADARSAT and the main characteristics and parameters which play a role in the understanding of stereo RADARSAT data in their generation and use. Practical examples and interpretation are given in Vester and Toutin (1997a, b).

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