Applications of projective transformation for stereo photogrammetry

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- Tutkijaohjaus
  - Ilkka Niini, DI, TkL, TkT
  - Petteri Pöntinen, DI, TkL
  - Milka Nuikka, DI
  - Petri Rönnholm, DI
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    - Projective Geometry, Multiview Geometry and Uncertainty (Full day tutorial, March 2003)
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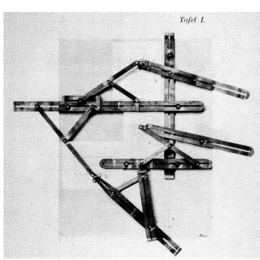
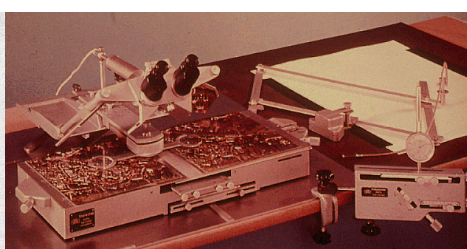
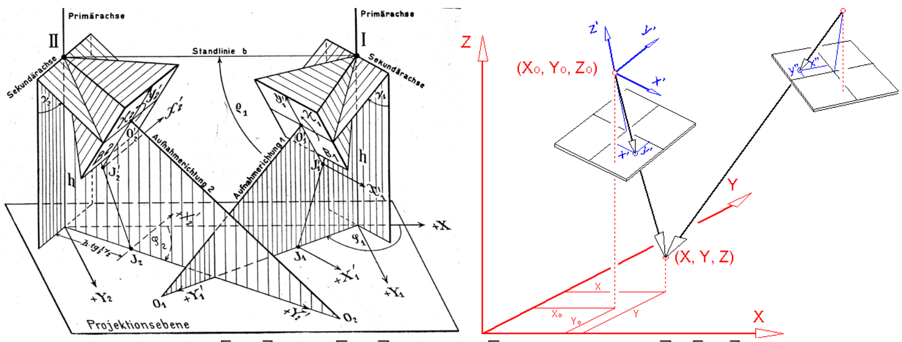
Background

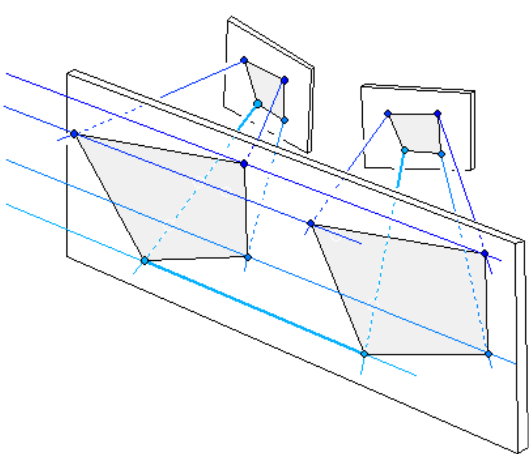
The early photogrammetry was applying convergent photography only as this was analog to theodolite based surveying technology (Meydenbauer, 1891). The images simply replaced the manual field readings and were processed afterwards in office. Photogrammetric instrumentation for processing of convergent image pairs were developed according to the theory of projective transformation (Haug, 1884). However, the optical-mechanical realisation of such a system never became practical. In 1901 stereoscopic comparators were invented where the image interpretation was based on stereo viewing (Pulfrich, 1901). This led to the development of photogrammetric instrumentation where primarily only stereo photography could be processed (von Orel, Scheimpflug, Hugershoff and many others). After the World War I the aerial photography became practical and the main application of photogrammetry has since then been producing topographic maps from vertical photographys. Within the instrumentation the the stereo images have replaces the use of convergent images, the analog mechanics has been replaced by digital processing, as well as the analog images by digital ones. This evolution chain is here exemplified by a Stereotop analog stereo plotter from Zeiss (1950's), Aviolyt analytical stereo plotter from Wild (1980's) and DSW digital stereo work station from Leica (1994).



$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{Pi} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{0} + \lambda_{pi} \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}_{i} \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix}_{pi}$$

The mathematics of photogrammetry has developed parallel to the instrumental development. In 1800's the primary approach for convergent imagery was to apply the same formulae for photogrammetric calculations as was already developed for processing of geodetic mesurements. However, in case of vertical aerial photography this was not practical and this led to the invention of collinear formulae. The collinearity equations form the perspective transformations for each image and the image-to-object-point relationship is described as bundle of collinear rays through the projection centre of the image. The transformation includes the 3-D rotation matrix between coordinate systems of each image and the object space. These perspective equations were especially developed for simultaneous processing of large blocks of aerial images for triangulation purposes in 1960's (e.g. Schmid and Brown) and have then applied to analytical and digital stereo plotters (e.g. Helava).

Projective transformation and normal case of stereo



$$X = \frac{a\,x + b\,y + c}{g\,x + h\,y + 1}$$

$$Y = \frac{d\,x + e\,y + f}{g\,x + h\,y + 1}$$

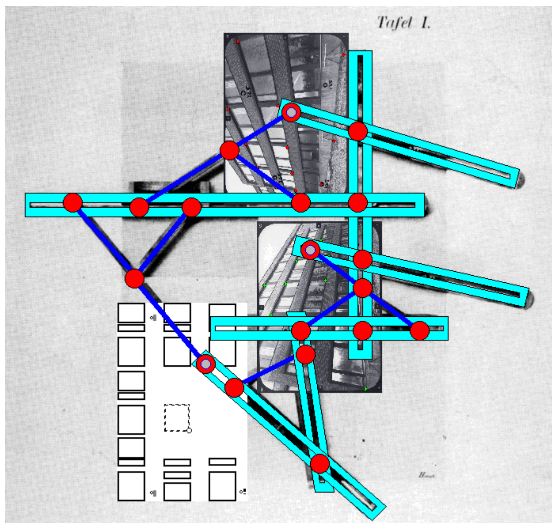
$$X' + px = X''$$

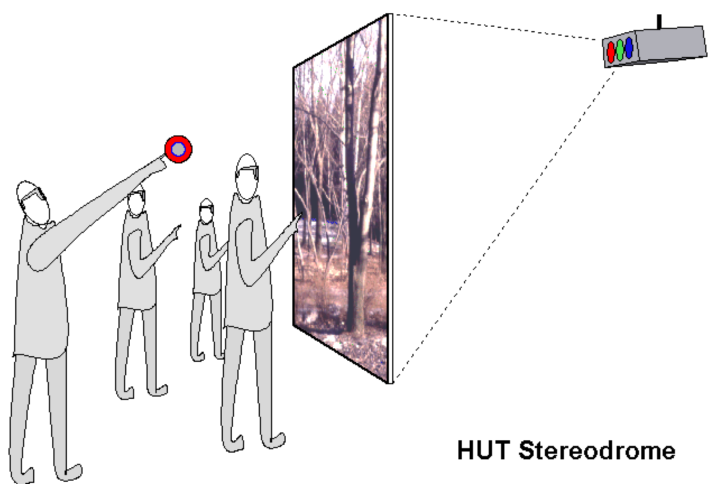
$$Y' = Y''$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{Pi} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{0} + \lambda_{pi} \begin{bmatrix} x' \\ y' \\ -C \end{bmatrix}_{pi}$$

In projective transformation the collinear perspectives in 3-D spave are replaced by coplanar transsections in planes. By reprojecting two images of different perspectives to a common plane the new image-to-image-point correspondence on that plane is collinear and will produce collinear pencils of epipolar rays in that plane. If we simultaneously require that the epipolar rays become parallel to each other (Y' = Y''), the images will produce a stereoscopic pair according to the normal case of stereo. The rotation matrice inside the stereo model becomes then a unity matrix, which makes the transformation of the image-to-object-point simple, i.e. the rotations are compensated by projective rectification.

Motivation of the Research

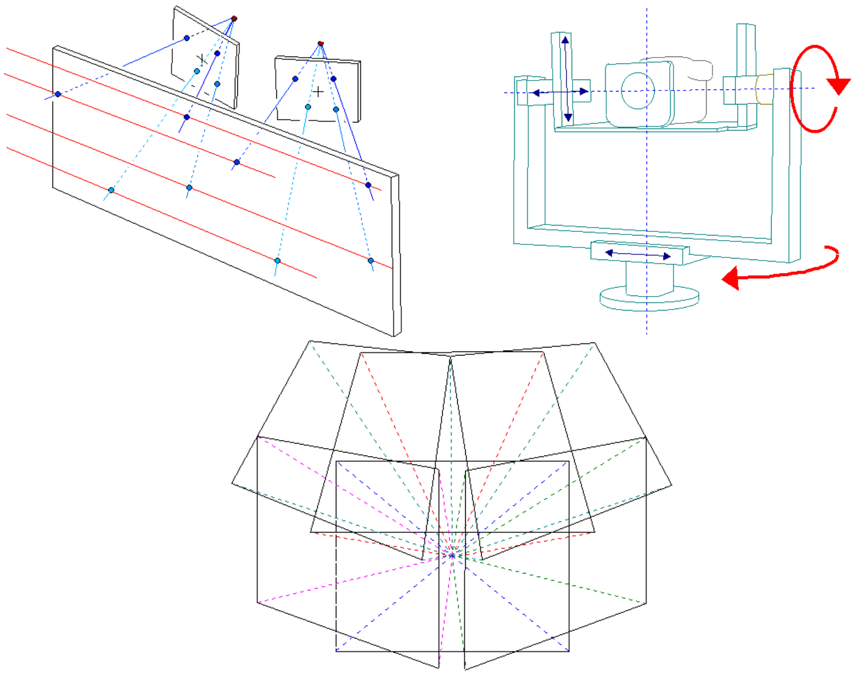




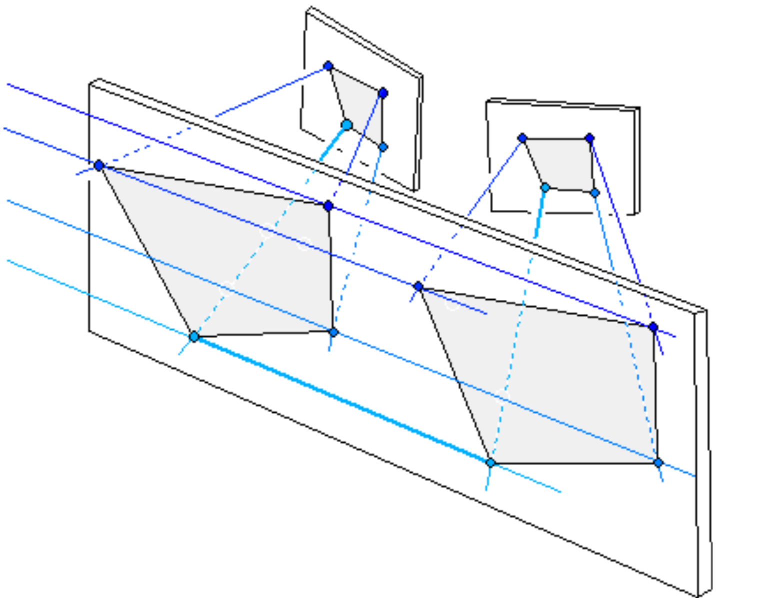
HUT Stereodrome

The motivation of this research is based on the hypothetical assumtion, that instead of perspective transformations, the projective transformations would be applied for photogrammetric "instrumentation", like it was proposed by Hauck in 1884? Meanwhile, the instrumentation has become consisting of formulae and digital images only, without any limitations caused by analog mechanisms. Thus it is supposed that the research of projective application by Hauck would reveal new understanding of photogrammetric processing theory. A consequent assumption would be whether the same approach would be practically applicable for stereoscopic visualization environments, like for "drawing" in virtual stereo views?

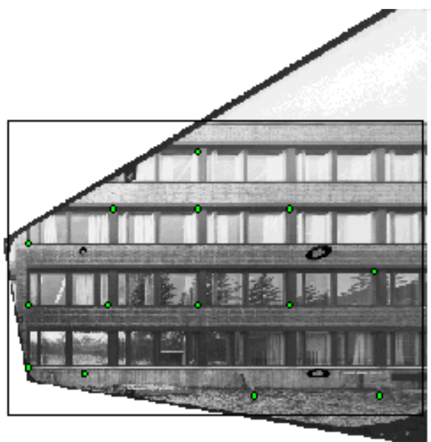
Expertise and Previous Work on the Subject

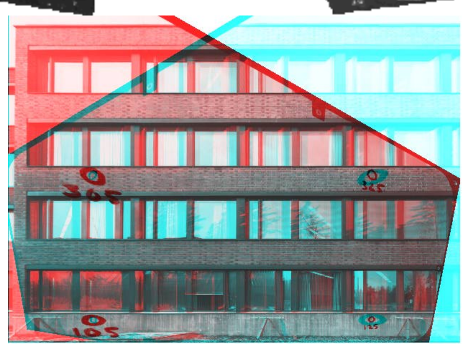


The use of projective transformations in analytical photogrammetry have been applied rarely. However, Stefanovic and Thompson developed theory based on projective transformation in 1960's. Later it has been used within coputer vision for solving the correspondence problem within image sequences (Haralick, Mohr, Förstner, Wrobel, Brandstätter, etc.) At HUT Institute of Photogrammetry and Remote Sensing Haggrén and Niini applied projective equations for relative orientation of stereo pair based on projective transformations with singular correlation (Haggrén et al., 1990). Niini further developed calibration methods of triangulation blocks by adding parameters of non-linear image deformations to the transformation (Niini 2000). The application of projective transformations for panoramic images have been studied at HUT since 1997 (Haggren 1999). Petteri Pöntinen (2000, 2001) has developed algorithms for creating and combining both planar and sperical panoramic images from cocentric image sequences and also the rotation platforms needed for panoramic images (Kukko 2001). Pöntinen together with Jyrki Mononen (1999) developed an algorithm for relative orientation of cocentric image sequences. Milka Nuikka (2002) has oriented and measured panoramic image pairs in a digital stereo workstation. Petri Rönnholm and Olli Jokinen (2001) have developed methods to combine laser scanner data and digital images.

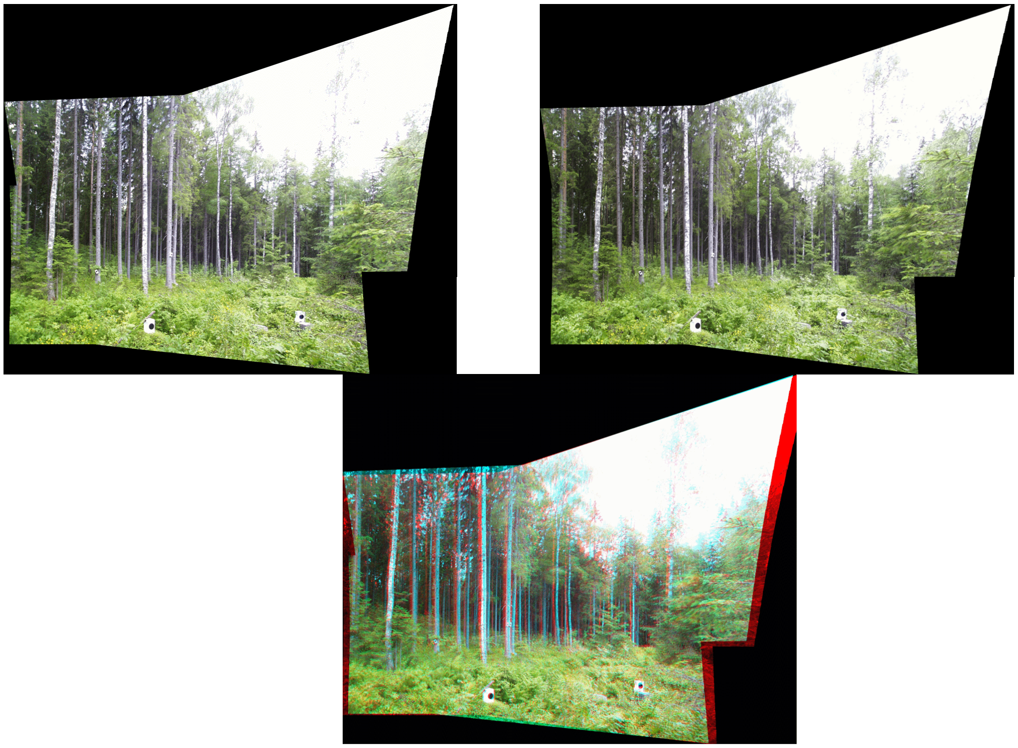


$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{Pi} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{0} + \lambda_{pi} \begin{bmatrix} x' \\ y' \\ -C \end{bmatrix}_{pi}$$

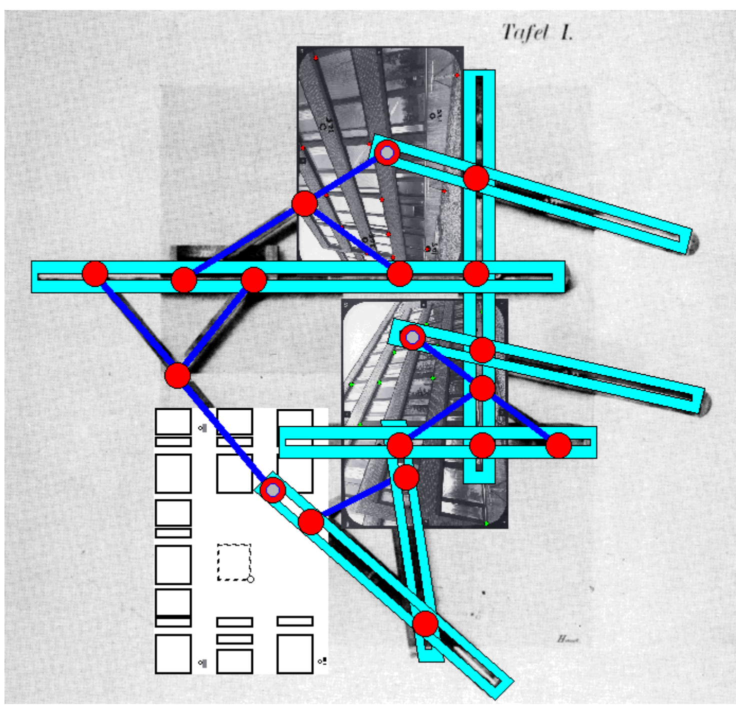


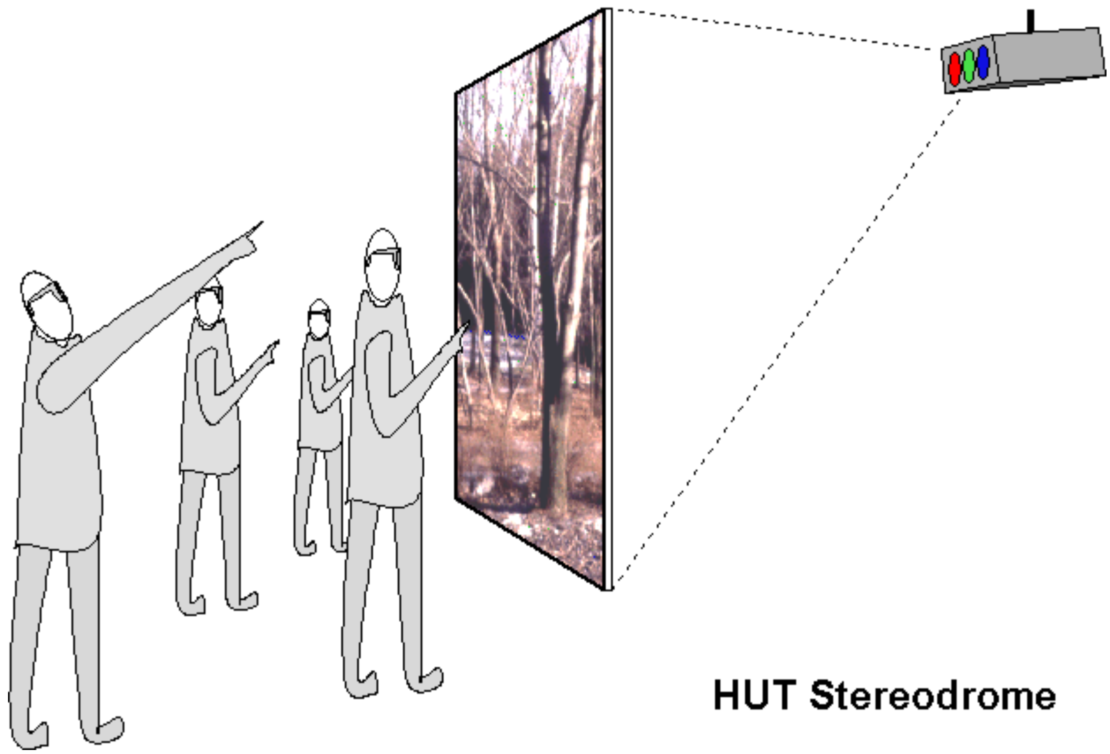


Normaalitapauksen mukaisessa stereokuvauksessa kuvien oikaisutarve on vähäinen. Näissä konvergenttikuvissa tilanne on päinvastoin. Kuvia ei voi edes tarkastella stereoskooppisesti ilman oikaisua.



Kukko, 2001.





Stereodrome is a recent installation at HUT and is specifically aimed for natural display of full scale 3-D sceneries. It consists of a photogrammetric workstation, a high resolution graphics stereo projector, necessary stereo eye ware, and a back projection screen. The size of the screen is 2,7 m high and 3,6 m wide and allows full scale display of spherical images. With full-scale we understand image scale 1 : 1 and viewing distances as close as 25 cm. This corresponds to a natural stereoscopic plasticity. The use of a stereodrome type of installation for 3-D visualization of geoinformation has shown to be an innovative approach and has already raised up new research issues. How will the natural stereoscopic plasticity preserve in full scale displaying? In which way the laser scanner data should be fused in order to facilitate the change of the original perspective of spherical image while viewing? In which way the full-scale stereo display can be used for validating the quality of existing 3-D geoinformation, like laser scanner data or geographical features.

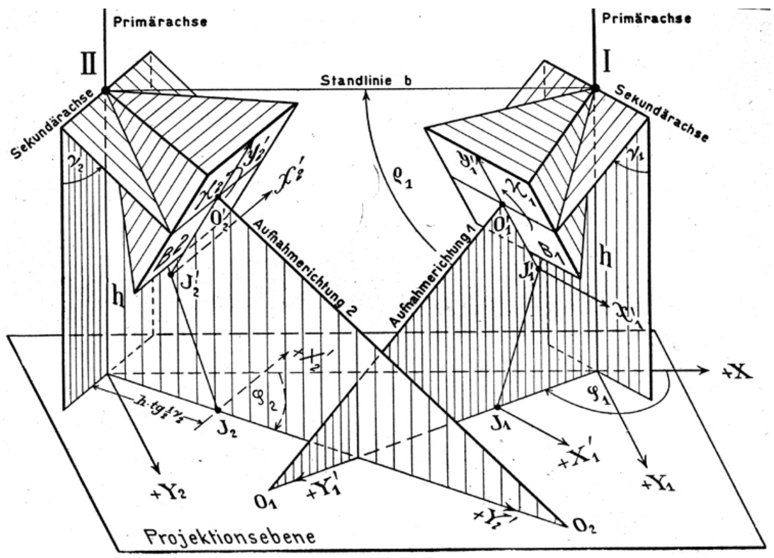
- 1 Background
    - 1.1 Background and Motivation of the Research
        - Photogrammetry is a technology of measurement, observation and control in 3-D within the science of surveying and mapping. The principal media are images of varying imaging geometries, either physical or mathematical. By application we refer here to recording and presenting the scenery. Finally, all activity aims for both acquiring and managing geoinformation.
        - Spherical imaging is a technical approach of collecting scenery like viewing it through a single perspective. A typical realization of spherical imaging is a panoramic mosaic covering a part of the hemisphere. We introduce here a photogrammetric definition, according to which spherical imaging is an exact central projection explicitly determined by its projection center. They are linear images without any geometric distortions within their spherical coverage. We have already applied spherical imaging for recording of both interior and exterior surroundings.
    - 1.2. Back to basics: Panoramic imaging
        - Basic solutions of panoramic imaging are the use of super wide-angle optics, or a fish-eye lens, a swinging lens or a rotating camera. These old and well functioning panoramic techniques are still in use but the modern technology presents also other possibilities. Panoramic images can be created also by combining a sequence of digital images. Panoramic imaging has originally been

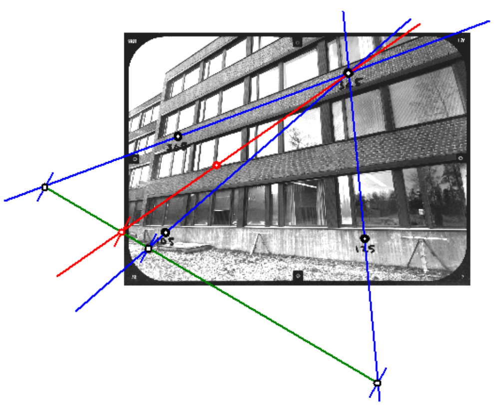
developed to imitate the seeing of human being. Full spherical coverage is difficult to perform, but wide-angle or half-hemispheric images are applied in theatres, like in IMAX® theatres, or in Verne theatre of Tiedekeskus Heureka. (Haggrén, 1999, 2001).

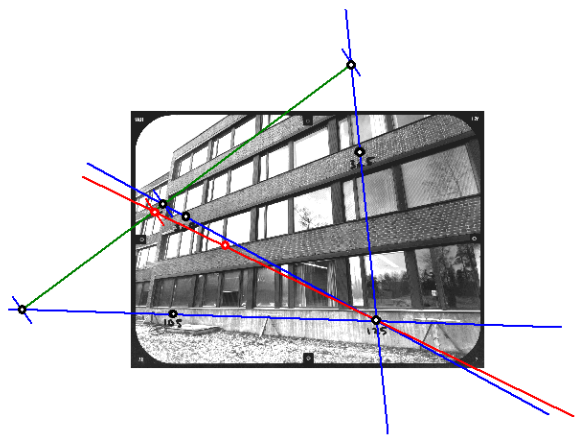
- Panoramic mosaics visualize three-dimensional space. When virtual models can provide the observer the possibility to move from one place to another, the power of panoramic imaging is in its localness. The observer can stop and look at the details by zooming. Also, one can look at the surroundings by turning the image on the screen. A practical web-based application of displaying panoramic images is the QuicktimeVR. In order to facilitate producing of panoramic image sequences for virtual models, several camera systems are commercially available, e.g. by Panoptic Vision, Inc., to name one only.
- Panoramic mosaics are images, which at best cover the whole vision. The production of panoramic mosaics deals with combining two or more images taken from same place into one wide-angle image. The adjacent images should have an overlap of 20-30 %. The projection center should not move during photo acquisition. The quality of the final images is related to the stability of the projection center from image to image (Haggrén, 1999). Chapman (2000) uses a camera attached to a motorized theodolite for collecting exactly co-centric image sequences. The mosaic is produced based on the direction recorded by the instrument.

- 1.3 Expertise and Previous Work on the Subject
  - The applications include environmental monitoring with satellite imagery, large-scale urban mapping with aerial imagery, 3D virtual modeling of buildings, industrial plants, and natural environment. The number of researchers on a pay-roll is about 20 persons, half of us being active postgraduates as well.
  - The most important publications of the subject are
- Research in spherical images
  - Panoramic images have been studied in the Institute of Photogrammetry and Remote Sensing since 1997 (Haggren 1999). The novel method - circular image block method - for automated 3D model measurements is being developed (Heikkinen 2001). Petteri Pöntinen (2000, 2001) has developed algorithms for creating and combining both planar and sperical panoramic images from cocentric image sequences and also the rotation platforms needed for panoramic images (Kukko 2001). Pöntinen together with Jyrki Mononen (1999) developed an algorithm for relative orientation of cocentric image sequences. Milka Nuikka (2002) has oriented and measured panoramic image pairs in a digital stereo workstation. Petri Rönnholm and Olli Jokinen (2001) have developed methods to combine laser scanner data and digital images. Ilkka Niini (2000) has depeloped orientation and calibration methods based on projective transformations with singular correlation in his dissertation thesis. Arzu Cöltekin (2002) has connected VRML and photogrammetric image databases and also used ortho-textures from panoramic images.
  - Whenever applied for surveying and mapping processes, the exact georeference of an image becomes crucial. The modeling and solving of georeference, called image orientation, is one of the primary tasks of photogrammetry. In case of spherical imaging the number of parameters in the physical model becomes minimal. It consists of three coordinates of the projection center and two directions of the attitude, namely the horizon and the azimuth, or, the Zenith and North. After the georeference is solved, the images can be used for updating of geoinformation. As the obvious ease of orientation is a major advantage of using spherical imaging, a complete procedure of utilizing them for surveying and mapping processes will be introduced in the project. The presenting of spherical image mosaics may follow any mathematically defined map projection, like plane, cylindrical, conical, or spherical projection, to name only few. As far as it regards the photogrammetric application of spherical imaging, we emphasize full-scale perspective projections, the specifications of which are investigated in this project. The technical realization will be the stereodrome, which is a recent innovation of ours and is specifically aimed for display of natural 3-D sceneries. The approach of using stereodrome for full-scale display of spherical images is introduced in the project for the first time.

- 2 Objectives and Research methods







Academic Revival of Terrestrial Photogrammetry

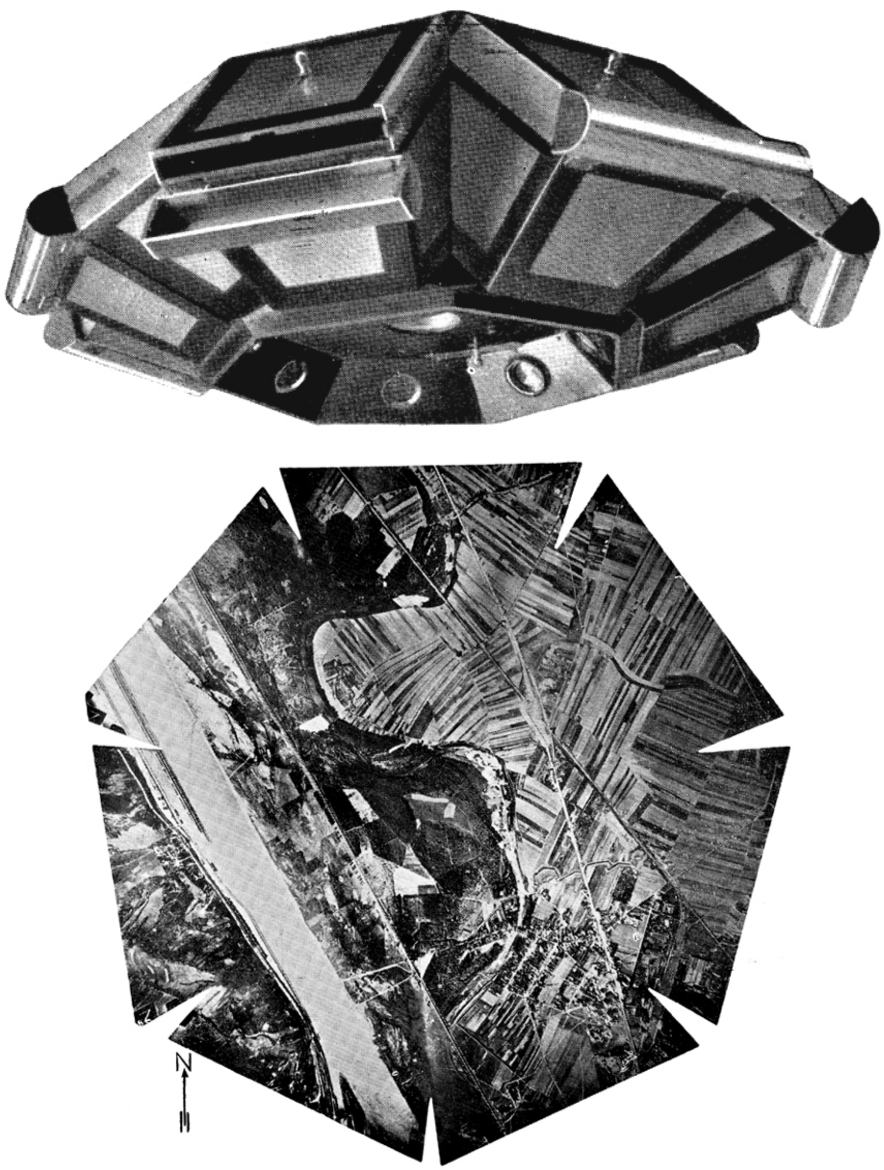
Henrik Haggrén

Academic motivation

- The basic tasks of any academic institution is to conduct scientific research, to provide teaching at highest level, united with research, and to promote science and arts. The same tasks can be described and projected along three dimensions as function of information transformation. The dimensions cover, first, transformation from theory to technology, second, progress in professional education and academic competence, and third, social impact of scientific knowledge.
- The potential between theory and technology is considered to be the prerequisite for any academic life, whereas education and socialization are considered more as its consecutives. In case of photogrammetric research it is evident that this prerequisite still exists. New sensor technology, like used e.g. for navigation, laser scanning and imaging, is providing us ever new research needs.
- Modern photogrammetric research begun upon the invention of photography. The early practical applications were terrestrial, but since the first use of airplanes, aerial photogrammetry has played a dominant role in research. Development of aerial application is clearly technology driven, whereas research on terrestrial photogrammetry reveals its main academic potential from theory side.
- My intuition is, that there still exists wide range of theory e.g. within projective geometry, which may

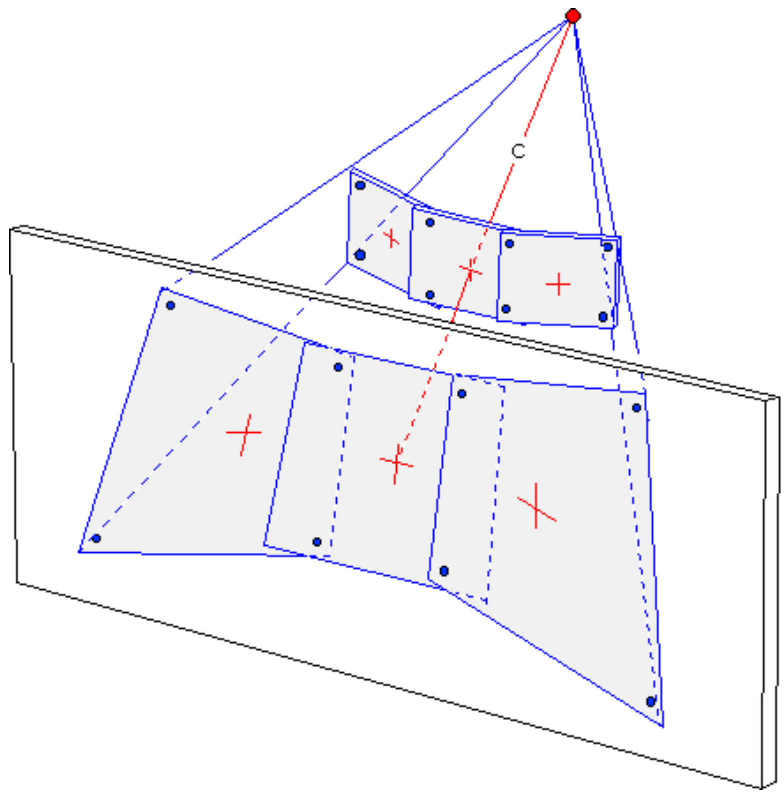
especially promote application of terrestrial photogrammetry. I will present this by four examples which are all based on panoramic imagery. The first one dates back to 1907 and an deals with an early aerial application. It is from Theodor Scheimpflug, a pioneer in photogrammetry, who developed photographic technology based on projective geometry. The next two are examples of our current research, and present applications of today's panoramic imaging. The fourth prospects future use of panoramic images for stereoscopic visualization.

Vogelperspektiv-Panorama

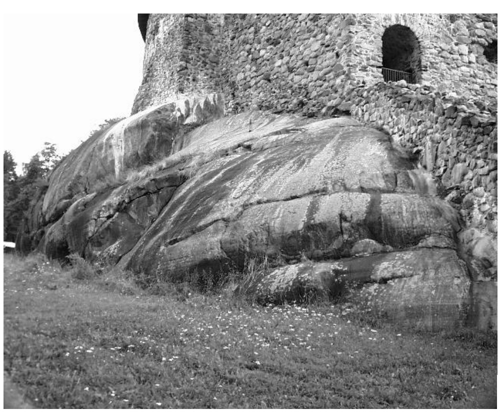


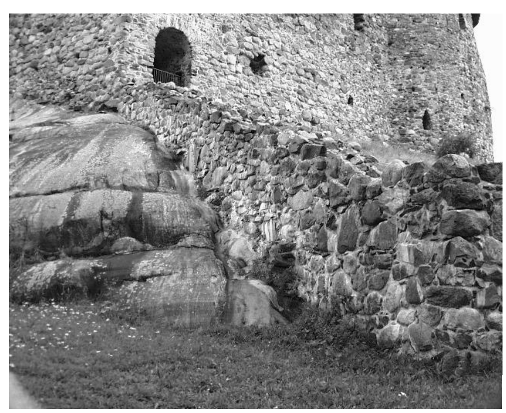
In 1907 Theodor Scheimpflug used his panoramic camera for aerial photography from balloons. The motivation of developing a panoramic imaging was to develop practical application of aerial photogrammetry. By composing panoramic wide-angle images Scheimpflug supposed to facilitate orientation of images using existing maps. He also proposed to rectify the images to their nadir projection in order to observe nadir angles for triangulation of new control points. These control points would then have been used for orientation of more detailed photography. Both wide-angle photography and aerial triangulation were principal research issues within aerial photogrammetry and its procedural development during the following 50 - 60 years. This "birds eye perspective panorama" presents Danube area North of Vienna and corresponds to an angle of view of 140°. *(Krames, 1956)*

Panoramic imaging

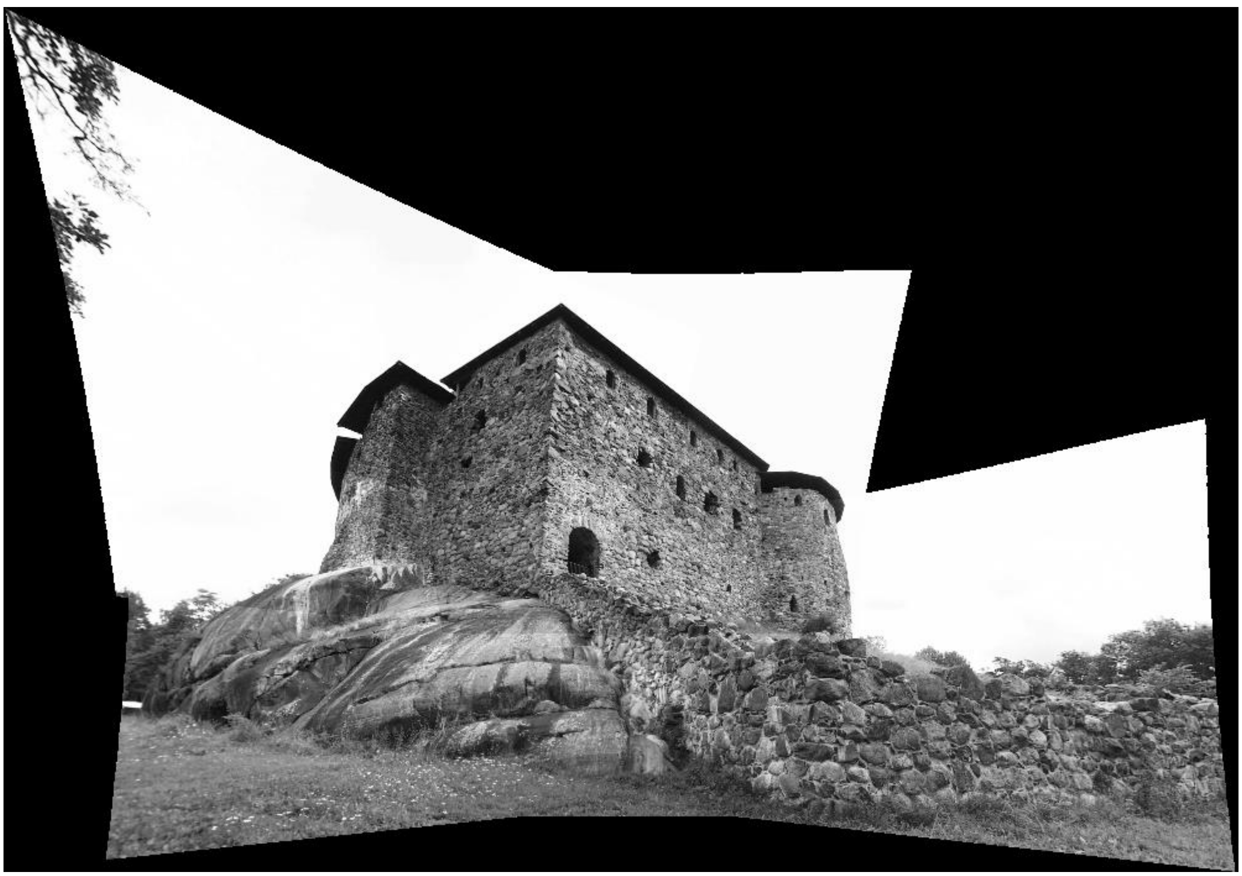


We have applied projective rectification of concentric image sequences for composing wide angle images. The images of a sequence are reprojected to a new plane by projective transformations. All transformations are solved by geometric registration of mutually overlapping parts of images. Expecting that the images are exactly concentric, they will coincide geometrically on the new plane. The registration is controlled image wise for every pixel and adjusted by principle of least squares image matching. For the purpose of image acquisition of panoramic images we have equipped a camera head with either a cross slide or a tilting and turning device. The co-centricity of the camera mount is calibrated based on collinearity, i.e. by checking that the perspective will not change while the camera is turned or tilted.



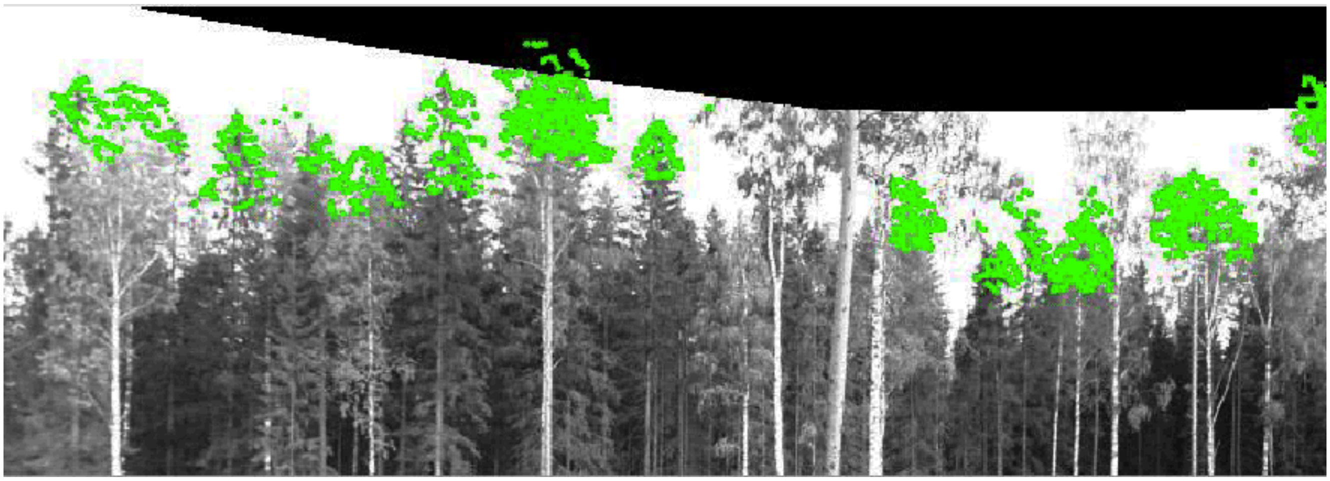


Concentric images of the south-west corner of the Raasepori castle. The image size is 1280 x 1024 and the camera constant 1400 pixels, and the scene of an image corresponds approximately to an angle of view of 50° x 40°. *(Pöntinen, 2001)*



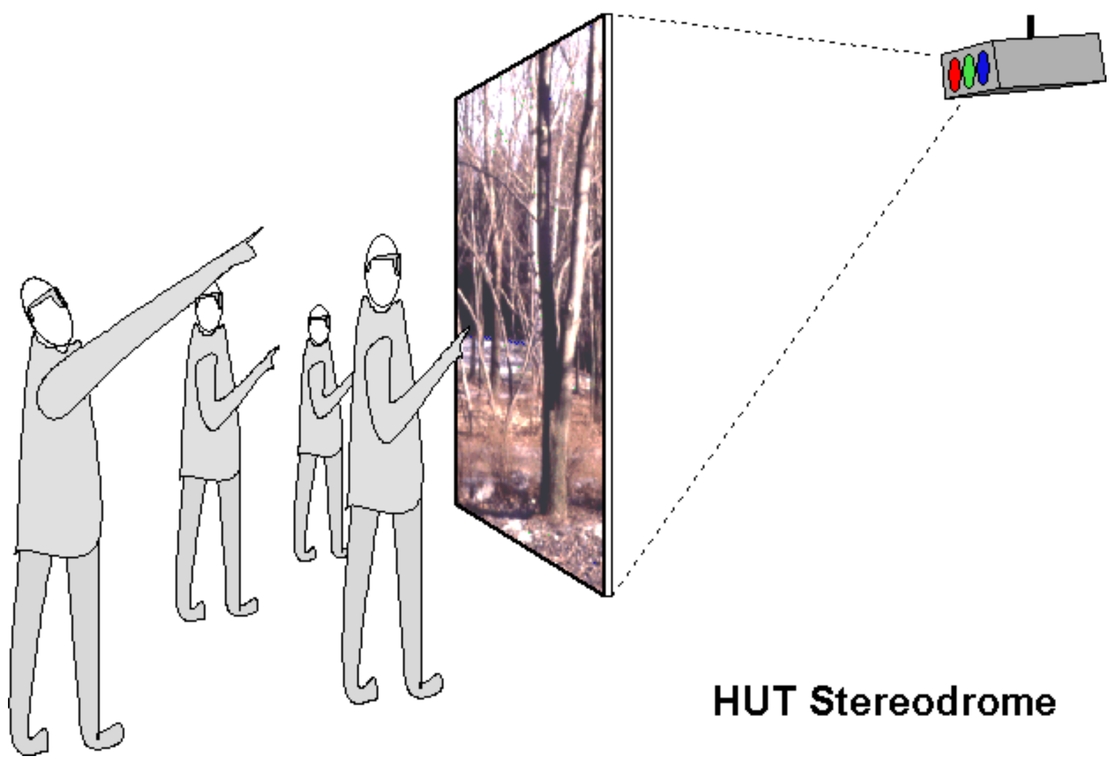
The panoramic image mosaic composed of seven concentric images and projected to plane. This view is projected on plane, image size being 3998 x 2802 pixels and the camera constant 1400 pixels. The collective scene corresponds to an angle of view of 110° x 90°. In case of full panoramic views, the composites have to be projected on a sphere. *(Pöntinen, 2001)*

Fusion of laser scanner data and panoramic images



The advantages of panoramic image mosaics are wide angle of view, high resolution, and collinearity. Wide angle of view facilitates the exterior orientation of the image with minimal control information. The resolution of the composite image corresponds to the resolution of the original images in the sequence. The collinearity is useful for photogrammetric applications of panoramic images. Here it is used for validation of airborne laser scanner data collected from the tree canopies. The laser data and the panoramic images will be either both georeferenced or directly registered to each other. The overlaid point clouds can be then visually checked. The registration becomes robust in 3-D if the point cloud and the image are both spatially wide. However, the exact 3-D validation would need both stereoscopic registration and stereoscopic viewing facility. (Image processing by Petri Rönnholm, 2001)

Stereodrome



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Conclusion

- I described my presentation with the title "Academic Revival of Terrestrial Photogrammetry". I tried to address the necessity of photogrammetric research in spite of all technological evolution. The basic theory is still widely not researched nor applied. It only changes its appearance according to ever available technical resources. I have always been convinced that the primary potential of photogrammetry lies on general perspective imaging, without no regard on whether it is applied for airborne or terrestrial applications. However, this address was provoked for the revival of terrestrial application. This was argued by the fact that the terrestrial applications are less technology dependent than the aerial ones and thus just suitable for academic research.

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[1] coming back into knowledge