# Fukui City - 3D-Cadastral Map and Kyoto University - 3D-Forest Map based on 4D-Image Map Archive Designed Aerial Survey

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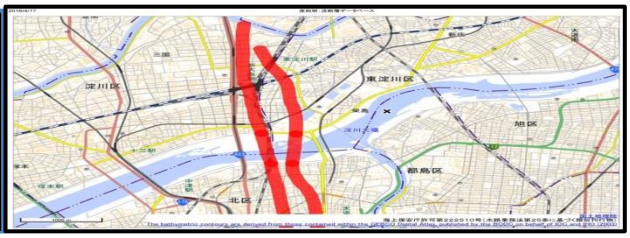
**Key words:** 3D- DX(digital transformation initiative) mapping, 3D-Cadastral Map , 3D-Forest Map, 4D-Image Map Archive Designed Aerial Survey (IMADAS)

**SUMMARY**

3D cadastral map for Fukui City and 3D forest maps for Kyoto University are to be generated based on the Land Survey Act, Cadastral Survey Work Regulations and the Forestry Agency Measurement Regulations, realizing world-standard satellite surveying and photogrammetry in AutoCAD. Japanese cadastral map is reviewed, certified, and sent to a registry based on Article 19 of the Land Survey Act, and becomes the title of the map based on Article 14 of the Real Estate Registration Act, and the land is registered in a registry. The forest basic map and forest plan - compartment map are to be transformed as a 3D forest map with 3D topographical map (airborne laser survey elevation model: point cloud, contour lines), combined with GSI-Japan-5m DEM and TLS( Terrain Laser Scanner) 3D point cloud data, for a 3D-DX (Digital Transformation Initiative) map to be displayed, measured, and stored as a 3D-CAD map. In forest areas, due to the constraints of the tree canopy, the airborne laser topographic data will also be supplemented with DGPS satellite surveying ground surface data, to create a 3D forest map of Fukui City (150 km2). Aerial photographic images taken by Fukui City (2023) , provided to the laboratory of Professor Toshihiro Tsukihara, Faculty of International and Regional Studies, University of Fukui, generated at GeoNet , Inc. (Osaka City), which shares the Summit Evolution (AutoCAD version) digital stereo plotter.



## １．From 3D mapping to 4D Image Map Archive Designed Aerial Survey

Aerial photo digital images (2400dpi) of the entire Fukui Prefecture, taken in the 1970s (Fukui City: owned by University of Fukui) were generated as the first 3D topographical maps, under the concept of 4D Image Map Archive in the World Geodetic System, compatible with the Echizen Joh-Ri Restoration Maps (first Japanese landownership maps since 650s A.D. owned by University of Fukui), of "the History of Fukui Prefecture (1996)".

For the 2024 National Tree-Planting Festival in Fukui Prefecture, we proposed advanced specification for cadastral mapping for the National Land Survey Act and the Basic Survey of Boundaries of Disaster-Affected Areas of the Noto Peninsula Earthquake – with Accuracy Verification, as the following new aspects;

1. Basic triangulation point (electronic control point) - single parcel survey
   - tilt-compensated GNSS satellite survey pole mounted on forestry machinery
2. Automatic bundle aerial triangulation – stereo-matching point search method DEM
   - ortho-mosaic-image - creation - CAD globe display, forest road design
3. Cadastral survey work regulations and standards - satellite image photogrammetry

Basic procedures are based on authentic Photogrammetry and Satellite Geodesy, with translated textbooks and installed modern software as references.

Starting from national photogrammetric mapping of the Saudi Arabian Kingdom in 1977 with analogue stereo plotter and mechanical triangulation, digital mapping was developed with analytical / digital stereo plotter with 3D CAD. Now with 3D display for 3D stereo measurement with AutoCAD image maps, the current 3D-DX mapping is established with public survey specifications, as the title of cadastral map for land registration in 3D map.

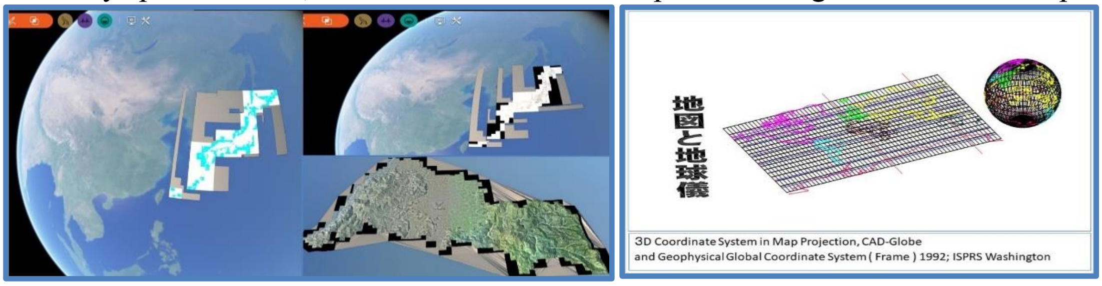



**Fig. 1-1 CAD-Globe-Fukui City(2008) : CAD Map and CAD globe(1992)**

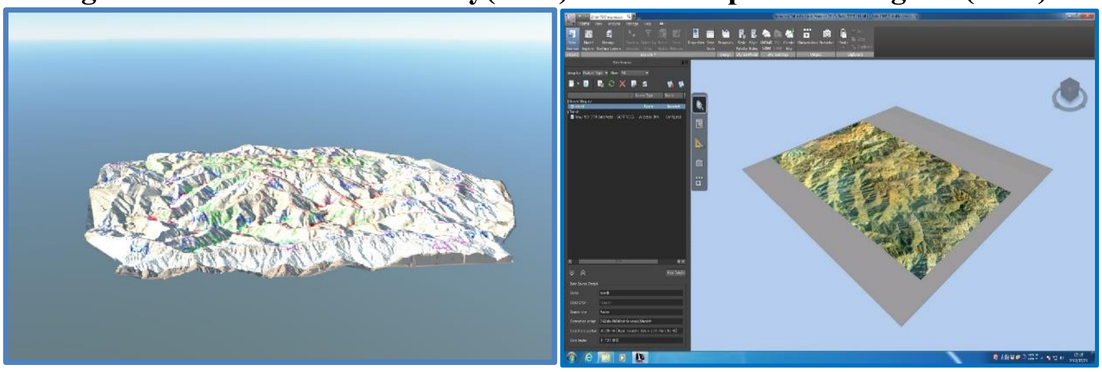


**Fig. 1-2 Kyoto University Ashu Research Forest 3D forest map and 3D Diorama Model**

## 2. 3D-DX Mapping (3D Forest Map, 3D Cadastral Map) - Standard Process - Objectives and Deliverables

3D-DX(digital transformation initiative) map is derived from a 3D topographical map (topographical map showing the terrain before afforestation), using Aerial photogrammetric 3D image modeling for the title of the Land Survey Act and Real Estate Registration Act.

3D forest facilities and forest road facilities are mapped by 3D-CAD image modeling as photogrammetric 3D image measurements. Forestry Agency measurement regulations, forest road regulations, mapping feature regulations must be complied with. 3D topographical map (airborne laser survey elevation model: point cloud, contour lines) are complemented with terrain surface data by DGPS, like Garmin GNSS, receiver for forest road, work road and ground surface points, as 3D topographical mapping. Terrestrial laser point cloud model synthesis of forest road is formed to the 3D diorama model version - 3D forest map.

Fukui City 3D forest mapping (1970; University of Fukui-aerial photo version) was completed in Apr. 2024. Fukui City photographed images (2005) after 2004 Asuwa river flood were mapped to Orthoimages, 3D image models, diorama models. Fukui City aerial images (2023) are now adjusted by automatic bundle triangulation for Orthoimages, 3D image models, diorama models on digital stereo plotter: Summit Evolution (AutoCAD version) of University of Fukui, as 3D cadastral and forest maps with regular map grid system.

For DX - oriented forest land register of forest management system, Forest environment tax, forest management law, and forest land register law, 3D forest maps are the title of the land ownership and land registration, as well as 3D cadastral maps on digital stereo plotter with 3D display supported by 3D-CAD(AutoCAD), alternating 2D paper maps.

3D diorama model is used for growth simulation of small plots and forest stands, and creation of point cloud data model of individual trees (each tree) is linked to forest asset register according to the Forest Management Act（2023） as Forest Land Register Map.

Construction of 4D forest archive (forest register) based on forest asset register would refer to the specifications of University of Göttingen, Germany and University of British Columbia, Canada as world standard.

## 2.1 3D-DX maps (3D forest maps, 3D cadastral maps) – Definition

Compliant with the Forestry Agency's measurement regulations, cadastral survey work regulations and the German Land Registration Act, we define the concept of 3D-DX maps (3D forest maps, 3D cadastral maps) as follows;

1) A 3D-DX map is a 3D topographical map based on Aerial photogrammetric 3D image modeling, for the title of the Land Survey Act and Real Estate Registration Act.
2) 3D forest and forest road facilities are to be mapped by 3D-CAD measurement, compliant to Forestry Agency measurement regulation, forest road regulation and mapping regulation. Essential components of 3D maps are as follows;
    1) 3D photogrammetric model parameter: Camera IO (Interior Oriented) image (TIF)
    2) Camera EO (Exterior Orientation) parameters by bundle triangulation
    3) 3D-display combined 3D-CAD drawing, referring to 3D digital stereo plotter, like Summit Evolution; DATEM international (AK, USA)

We could orient and adjust the photogrammetric models in 1940s with primitive fiducial marks around the photo print images. These photogrammetric models are now combined with old national maps of 1930s of Burma Republic (established on 1943.8.1) nationwide. Old aerial photographs are to be reconfigured as the title of 3D maps for 4D Image Map Archive Designed Aerial Survey (IMADAS), showing the Historical Reality (HR), like Virtual Reality in CG business world. Osaka city and its sister city: Hamburg city have a lot of aerial photos before the bombing during WW II, to be revised as 3D cadastral maps.

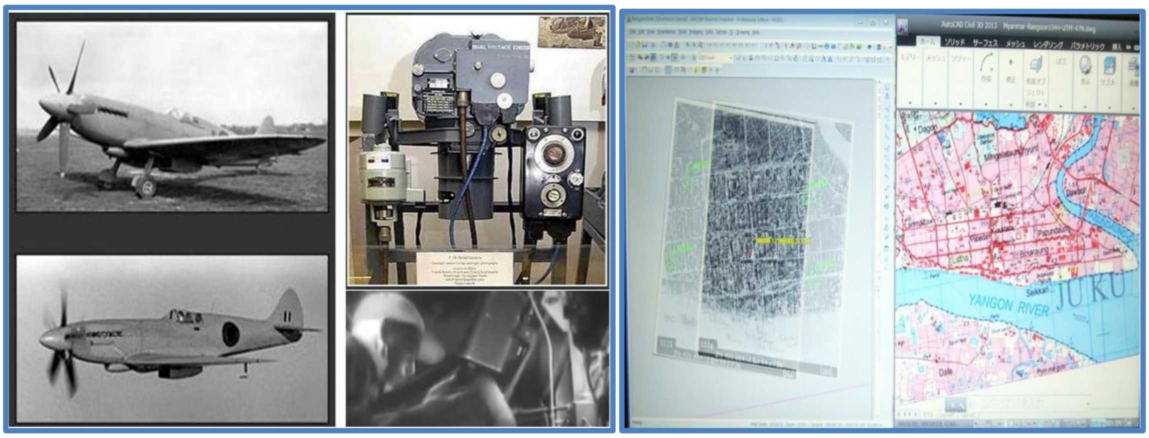



**Fig. 2-1 British Royal Air Force Spitfire-MK8 camera-1944**
**: Rangoon - Yangon -1944-3D image model- CAD map**

Forthcoming status of photogrammetric 3D mapping system is configured by new generation 3D display with 3D CAD, without polarized glasses (under development).

**Fig. 2-2 3D-displays without and with Glasses (GeoNet, Inc.)**

3D topographical map (airborne laser survey elevation model: point cloud, contour lines) is combined in 3D forest map, using 3D CAD modeling, like GSI-Japan-5m DEM.
3D CAD mapping is based on Geocentric GNSS geodetic networking and Satellite/Aerial photogrammetry, especially bundle triangulation, to provide basic geocentric/ellipsoidal/map-projected coordinates, for the title of landownership of cadastral registration system.

### 2.2 Historical Reality of old maps and photogrammetric 3D models based on 4D-Image Map Archive Designed Aerial Survey (IMADAS)

Having configured in WGS84 coordinate system and map projections, old maps since 1890 and aerial photos in 1942 are generated as 3D diorama map as historical reality.
3D DX (cadastral / forest) maps are displayed, measured and stored in 3D CAD(AutoCAD) as the title of 3D cadastral / forest maps, realizing the Historical Reality of the landownership at that time of photo exposure and map generation.

### 2.2.1 CAD-globe and Map projections on 3D CAD

CAD-globe was conceptualized and represented on AutoCAD in 1992 by the author. In 3D CAD we could realize the relationship between earth-globe and map projection. We could define the location of the ground points according to geocentric coordinate system and projected map coordinate system consistently. Nowadays global sea level rise indicates the importance of equipotential surface: geoidal model worldwide. This aspect would be considered with ITRF definition, based on International GNSS service (IGS).

### 2.2.2 Map projection and Global rectangular coordinate system

Coordinate transformation and map projection could be consistently applied on 3D CAD system, utilizing 3D rectangular coordinate system and spatial similarity transformation, commonly used in Geodesy and Photogrammetry, showing 3D maps and CAD globe in the united 3D CAD coordinate system, as the object of display, measure and store in an archive.

### 2.2.3 4D- Image Map Archive on World Geodetic System with Datum transformation

4D- Image Map Archive on World Geodetic System with Datum transformation is already realized with old maps from 1820s, in Japan, Myanmar, Bhutan, Cambodia, Indonesia and Tanzania, using AutoCAD-Infraworks and old image maps.
In a similar way, we could organize Forest 4D Image Map Archive for tree growth analysis.

### 2.2.4 KOSMOS- Physikalischer Atlas (1848): Ellipsoid and map projections

Since 2017, I have been translating “KOSMOS” by Alexander von Humboldt, which includes a separate atlas called “Physikalischer Atlas”. The border between Japan and Russia is shown in red, the reference ellipsoid is Bessel 1841, and the map of the Japanese archipelago was introduced by Philipp Franz von Siebold.

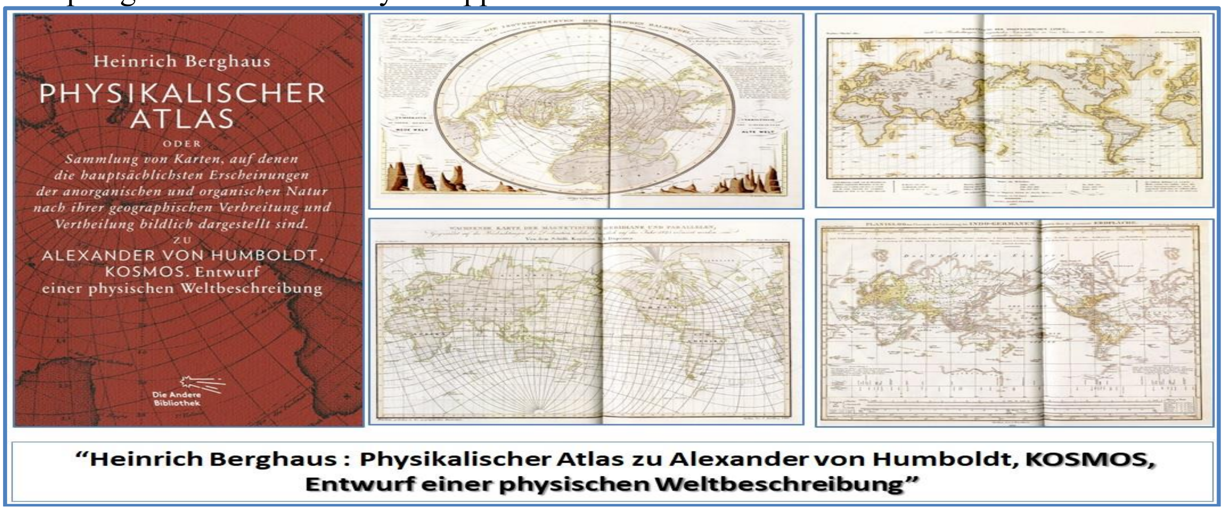



**Fig. 2-3 „Physikalischer Atlas“ zu Alexander von Humboldt, „KOSMOS“, Entwurf einer physischen Weltbeschreibung**

### 2.2.5 3D Photogrammetric Image Modeling and measurement in AutoCAD

3D Photogrammetric Image Modeling and measurement is operated nowadays with digital stereo plotter with 3D display in AutoCAD vector/ raster maps. The entire process of 3D photogrammetric mapping and 3D cadastral / forest mapping is shown as follows;

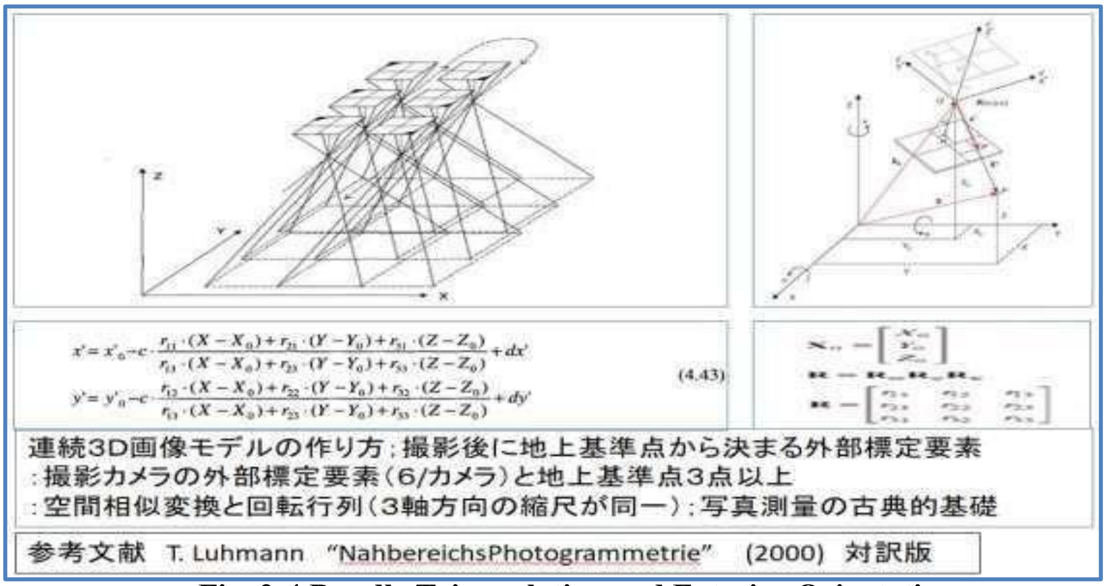



**Fig. 2-4 Bundle Triangulation and Exterior Orientation**

3D image modeling is mechanically, analytically and digitally generated with 3D CAD coordinate system on 3D display with stereoscopic vision. The basic concept is the spatial similarity transformation from camera coordinate system to the reference coordinate system. The current authentic photogrammetric textbooks were translated from English/German into Japanese for daily operations, evaluating the accuracy for archiving as title of land ownership. The accuracy in planimetry and altimetry are schematically shown as follows;

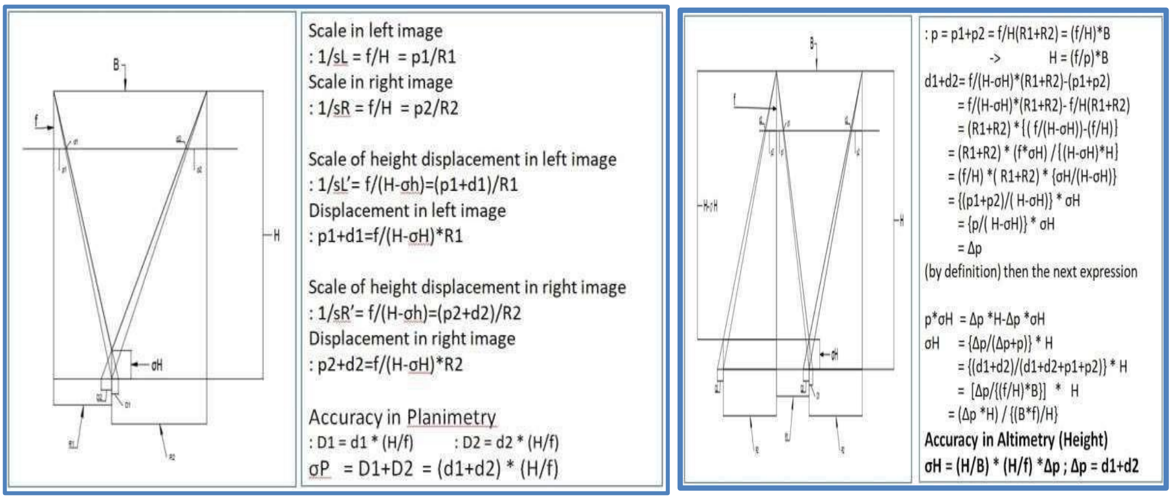



**Fig. 2-5 Planimetric accuracy: Altimetric accuracy of 3D image model**

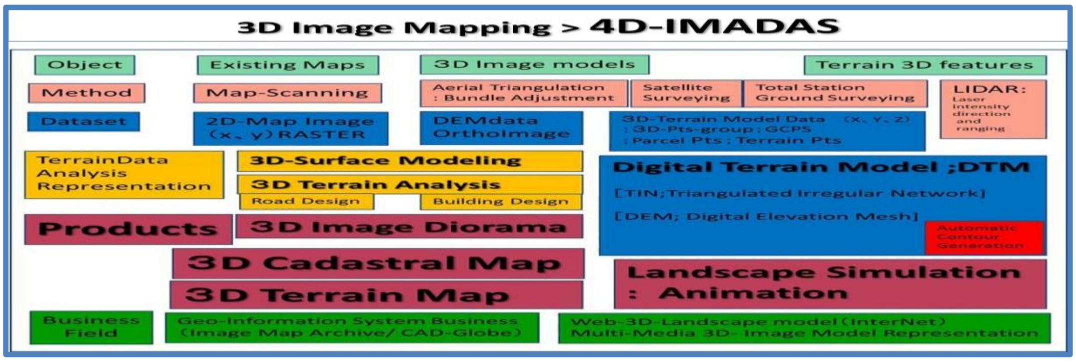



**Fig. 2-6 3D Image Mapping to 4D IMADAS**

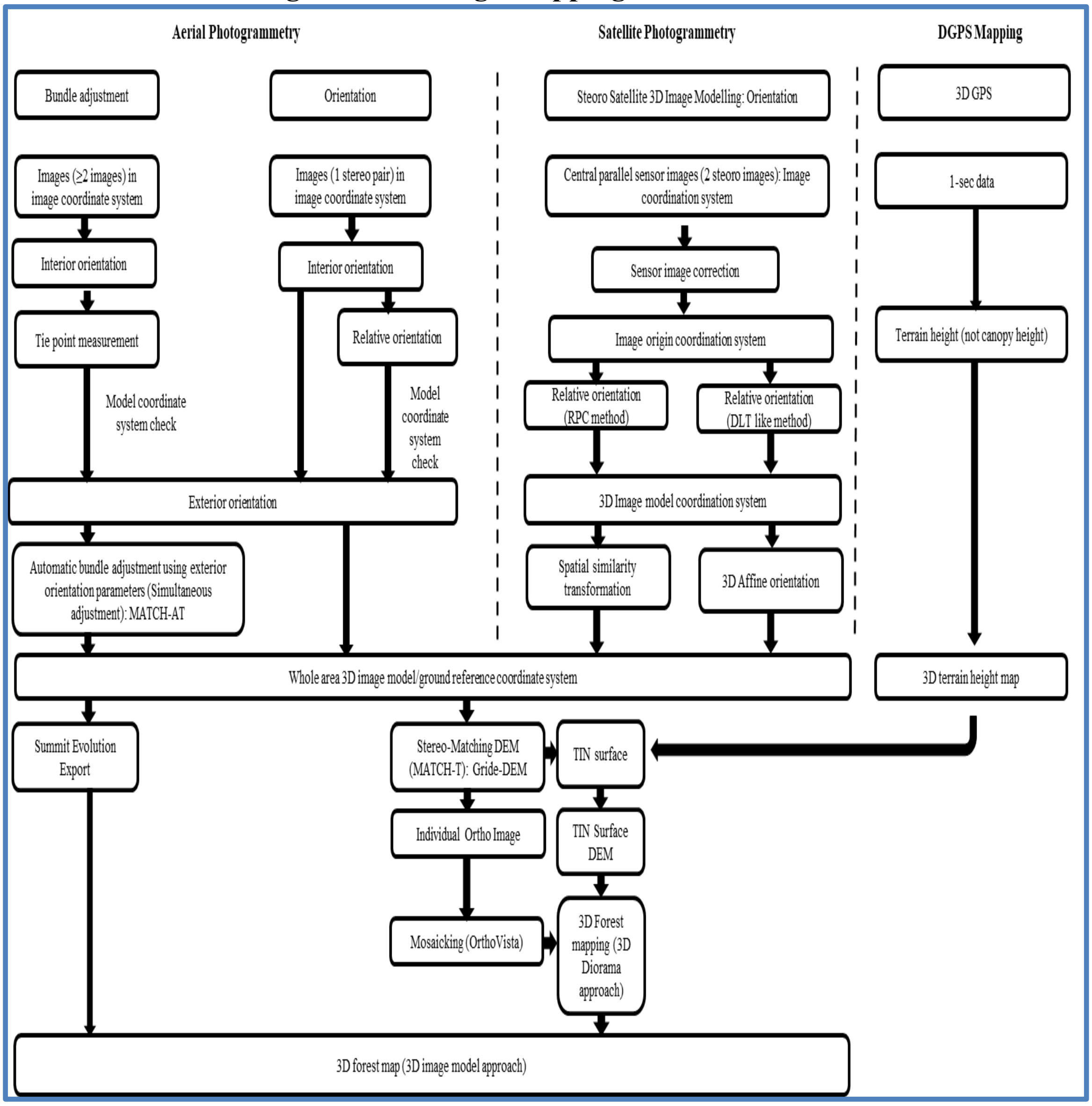



**Fig. 2-7 Orientation and bundle triangulation : 3D forest mapping (3D cadastral mapping)**

# 3. Fukui City - 3D-Cadastral Map and Kyoto University - 3D-Forest Map

## 3.1 Fukui City - 3D cadastral mapping in the national map-grid system

Japan National basic maps are designed to the Transverse Mercator projection with 19 origins and scale factor (0.9999) along with the central meridian through the origins of so-called plane rectangular map projections, and applied map scales are 1/250, 1/500, 1/1,000, 1/2,500 and 1/5,000 for urban planning and forestry planning.
Fukui city is in the 6$^{th}$ plane rectangular map projection zone, which has the coverage of 7 prefectures; Ishikawa, Fukui, Shiga, Kyoto, Osaka, Nara and Wakayama prefectures, with the origin of 136ºE and 36 ºN and the central meridian 136 º E.
Since the map grid system is not yet well defined by the Land Survey Act, Cadastral Survey Work Regulations, as a registered surveyor, the author defined the cadastral map-grid system as follows:

**Fig. 3-1 Fukui City 4D-IMADAS in Univ. of Fukui**

3D cadastral / forest map is now realized on AutoCAD, according to the National Map Grid and Cadastral Map Grid with the origin of plane rectangular coordinates No.6 system.

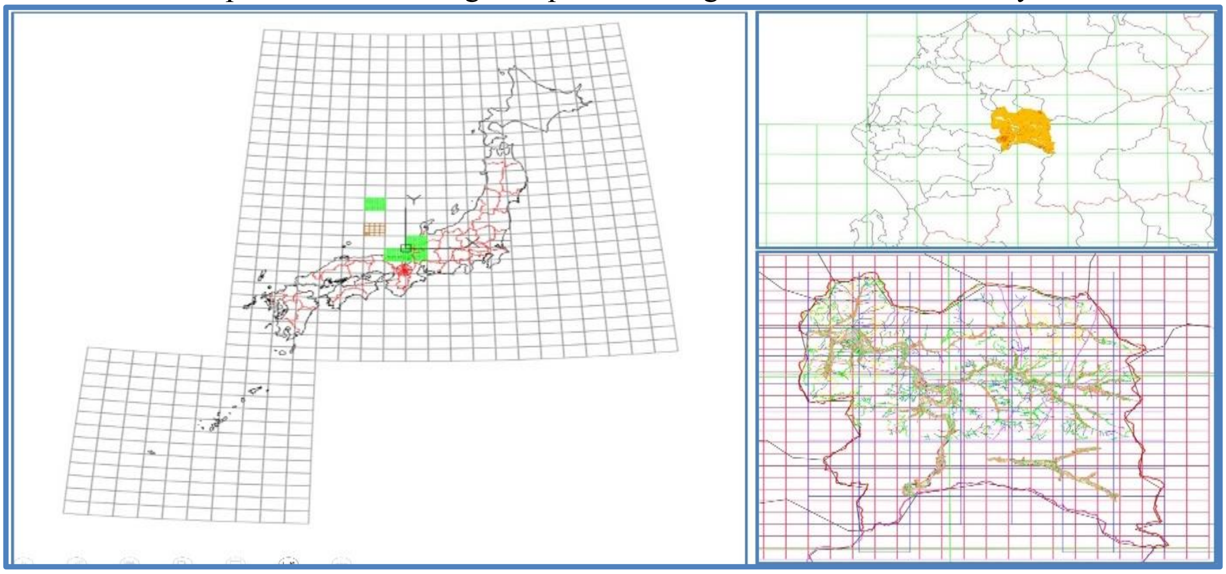


**Fig. 3-2 National Map Grid-Cadastral Map Grid: Fukui City-Miyama Cho**

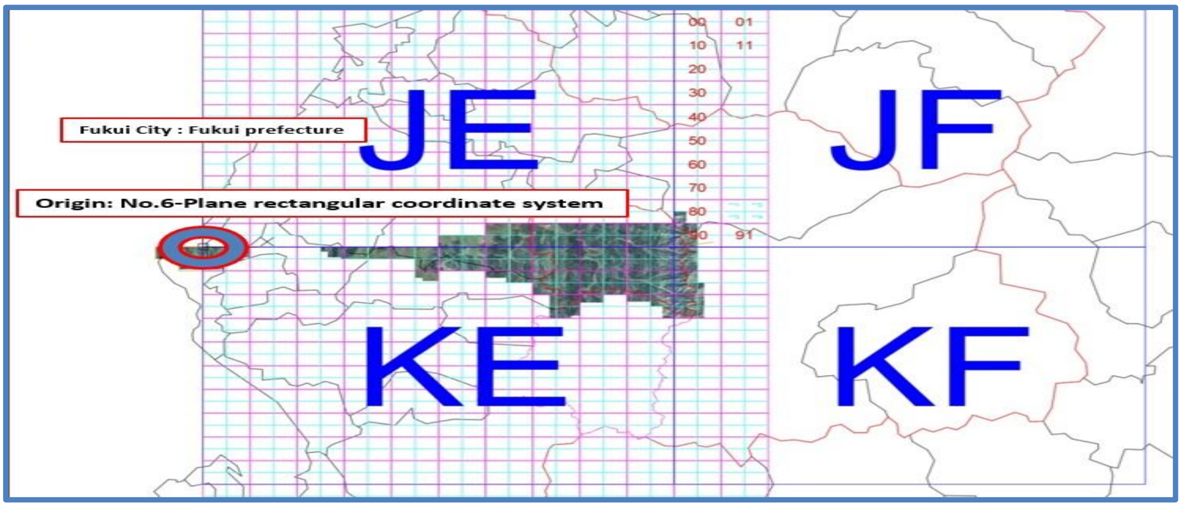



**Fig. 3-3 Origin No.6- Plane rectangular coordinate system**

The cadastral map grid is not well defined and designated by Japan Land Survey Act, since the designated dimension is A3 paper size and the area of 35cm x 25cm as the basic grid. According to the origin of No.6 coordinates system, the campus area of university of Fukui has the following 3D cadastral map grid numbers, based on the above description.

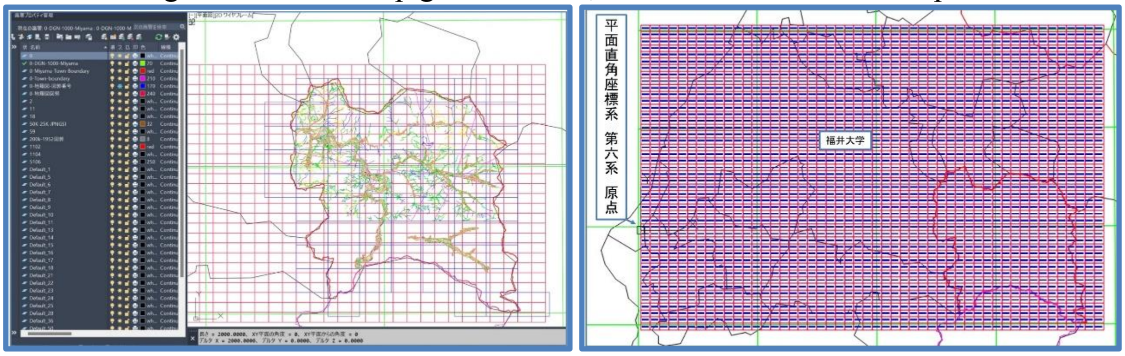



**Fig. 3-4 National Map Grid-Numbering : Cadastral Map Grid-Numbering**

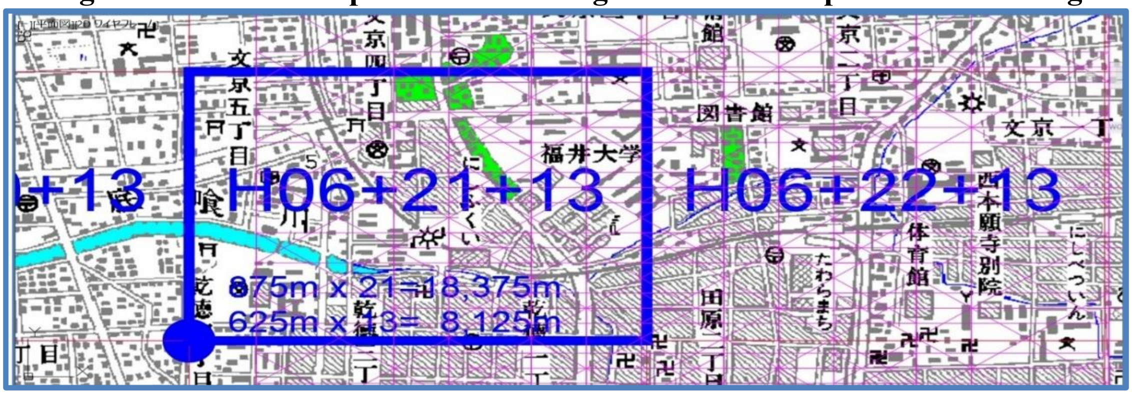



**Fig. 3-5 Cadastral Map Grid-Number- Univ. of Fukui**

Using the aerial images of Fukui City (Administrative Digital Transformation Promotion Division) in 2023, we have now generated 3D cadastral map on digital stereo plotter(Summit Evolution-AutoCAD version) with 3D display(like 3D PluraView | Schneider Digital).

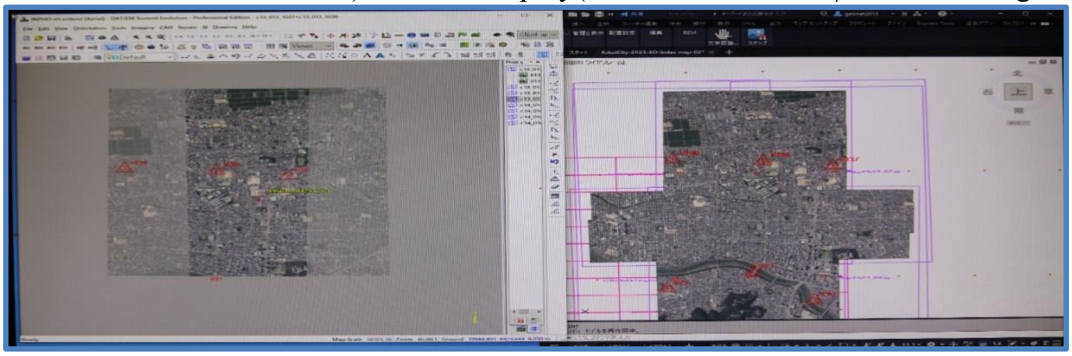


**Fig. 3-6 SummitModel-1039-1038-OrthoMosaic-AutoCAD-Image map**

## 3.2 Kyoto University - 3D-Forest Map

Kyoto University – Ashu research forest was established in 1932, among Kyoto, Fukui and Shiga prefectures, and is one of the representatives of university research forests.
In 2015, we generated 3D forest maps of aerial photographs in 1989 and forest boundaries and utilization maps(2D).

### 3.2.1 3D forestry mapping – procedure and products

Using aerial photography planning map and photo prints and GCP coordinates in 1989, we could generate 3D image models on digital stereo plotter (Summit Evolution-AutoCAD version), and produced stereo matching DEM, ortho-mosaic image of the area.

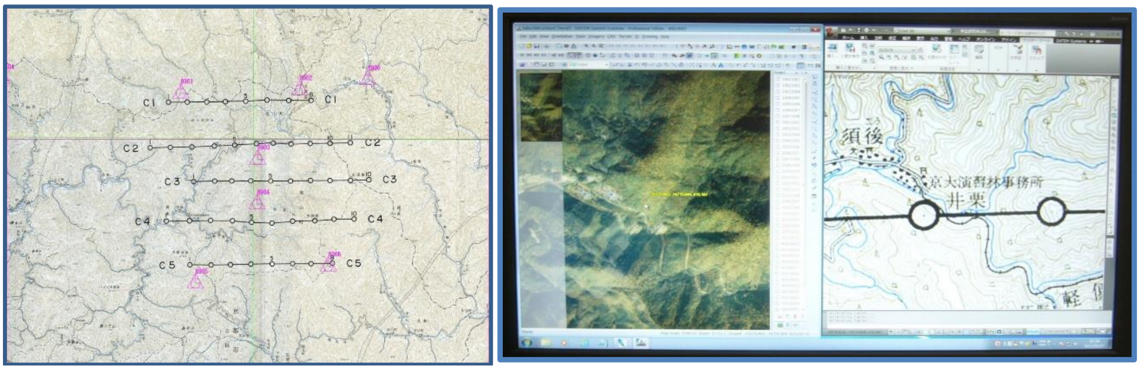



**Fig. 3-7 Aerial Photo Index map (1989) and 3D image model as 3D forest map**

Stereo Matching of overlapped images produce regular interval spot heights (Digital Elevation Model) , and generate TIN (Triangulated Irregular Network) surface of the terrain. Civil3D of AutoCAD is to form 3D diorama network basic data for Infraworks, which is the platform of CAD Globe (ellipsoid) in AutoCAD.

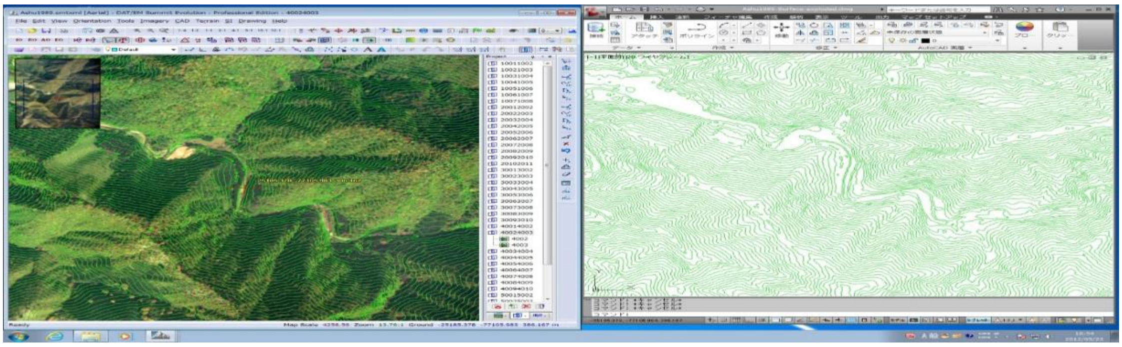


**Fig. 3-8** Contour lines from TIN surface model, on 3D forest map

The important applications of 3D forest map- 3D diorama version are as follows;

1) 3D forest compartment boundary points: display, measure and store in an archive
2) Forest road design - Compliant with Road Structure Act:

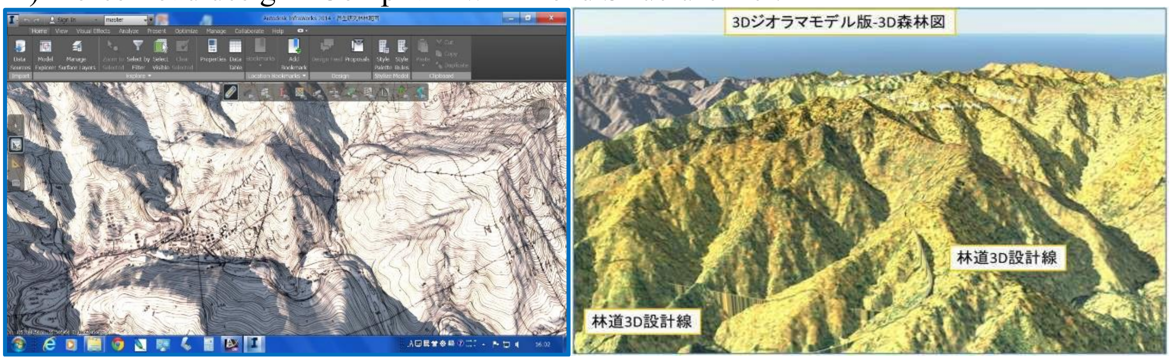



**Fig. 3-8 3D forest compartment boundary: Forest-road design**

### 3.2.2 3D forest mapping and Forestry Inventory Management

3D forest mapping could reconstruct the terrain surface and individual trees. DGPS mapping gives us 1 second 3D coordinates on the human cap or car roof continuously, with suitable accuracy (2-3 m) for 1/5,000 forest maps. Along the logging road and working road, Harvester's arm (10m extension from the vehicle body) could be used to acquire the terrain spot 3D coordinates, with RTK- INS tilt-compensated antenna receiver.

Terrain Laser Scanner could also acquire 3D point cloud data combined with 3D forest mapping. These 3D data terrain surface points are the essential contents as the title of cadastral registration. Komatsu Forest GmbH started to manage forestry machine in daily work process, combined with 3D CAD display and machine control system.

**Fig. 3-9 DGPS-accuracy test-2006 : DGPS-accuracy test-2007**


**Fig. 3-10 DGPS and GNSS survey(2023) and Harvester 3D mapping with TL-Scanner**

For 3D forest mapping, Forestry Agency - Measurement regulations, forest road regulations, map regulations are now introduced in AutoCAD mapping layer templates.

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 法令指定地域 | 保安林 | 01 | 水源涵養 | 土砂流出防備 | 土砂崩壊防備 | 飛砂防備 | | 水害防備 | 潮害防備 | 干害防備 | 防雪 | 防霧 | 雪崩防止 | 落石防止 | 防火 | 魚付 | 航行目標 | 保健 | 風致 | | |
| | 指定地区 | 02 | 保安施設地区 | 砂防指定地 | 国立公園特別保護地区 | 国立公園第1種特別地域 | 国立公園第2種特別地域 | 国立公園第3種特別地域 | 国立公園地種区分未定 | 国立公園普通地域 | 国定公園特別保護地域 | 国定公園第1種特別地域 | 国定公園第2種特別地域 | 国定公園第3種特別地域 | 国定公園地種区分未定 | 国定公園普通地域 | 県立自然公園第1種特別地域 | 県立自然公園第2種特別地域 | 県立自然公園第3種特別地域 | 県立自然公園地種区分未定 | 県立自然公園普通地域 |
| | | 03 | 特別史跡名勝天然記念物 | 史跡名勝天然記念物 | 世界遺産 | 鳥獣保護区特別保護地区 | 鳥獣保護区 | 原生自然環境保全地域 | 自然環境保全地域特別地区 | 自然環境保全地域普通地区 | 都道府県自然環境保全地域特別地区 | 都道府県自然環境保全地域普通地区 | くぼた山崩壊防止区域 | 急傾斜地崩壊危険区域 | 特別母樹・特別母樹林 | 育種又は普通母樹・母樹林 | 歴史的風土特別保存地区 | 歴史的風土保存地区 | 緑地保全地域 | 風致地区 | |
| | | 04 | 分収造林契約に基づく分収林 | 分収育林契約に基づく分収林 | 薪炭共用林野 | 放牧共用林野 | 森林生態系保護地域保存地区 | 森林生態系保護地域保全利用地区 | 森林生物遺伝資源保存林 | 林木遺伝資源保存林 | 植物群落保護林 | 特定動物生息地保護林 | 特定地理等保護林 | 郷土の森 | 緑の回廊 | ふれあいの森 | 木の文化を支える森 | | | | |
| | | 05 | 自然休養林:自然観察教育 | 自然休養林:森林スポーツ | 自然休養林:野外スポーツ | 自然休養林:風景ゾーン | 自然休養林:風致探勝 | 自然観察教育林 | 森林スポーツ林 | 野外スポーツ地域 | 風景林 | 風致探勝林 | その他レクリエーションの森 | | | | | | | | |
| | | 06 | 遊々の森 | 社会貢献の森 | 多様な活動の森 | モデルプロジェクトの森 | ボランティアの森 | 公衆保健共用区域 | 精英樹保護林 | 遺伝子保存林 | 試験地 | 検定林 | 次代検定林 | 展示林 | 施業指標林 | 巨樹・巨木 | 保護樹帯 | 更新困難地 | 係争地 | 森林施業モデル林 | |
| | 附帯地 | 07 | 苗畑数 | 採穂園数 | 採種園数 | 建物数 | 貯木場数 | 防火線数 | 区画線数 | 林道数 | 作業道数 | 歩道数 | レクリエーションの森施設数 | ふれあいの里施設数 | | | | | | | |
| | 貸地 | 08 | 軌道用地 | 農耕用地 | 鉱業用地 | 道路用地 | 水路用地 | 電気事業用地 | 温鉱泉用地 | 学校用地 | 採草放牧地 | 建物用地 | レクリエーションの森施設貸付地 | その他貸地 | | | | | | | |
| | 雑地 | 09 | 官地民木地 | [illegible] | [illegible] | [illegible] | [illegible] | 岩石地 | 崩壊地 | 荒廃地 | 湿地 | 草生地 | 高山帯 | 温泉湧出地 | 池沼 | 水路数 | 沢数 | [illegible] | 笹生地 | 砕石地 | 河川数 |

**Fig. 3-11 AutoCAD mapping layer template for 3D forest mapping**

In Japan, forest areas are often located in steep mountainous areas, a 3D terrain model is required for the design of forest roads and work roads.

The Forestry Agency's forest-road regulations are compatible with the Ministry of Land, Infrastructure, Transport and Tourism's Road Structure Ordinance, so AutoCAD's Road Structure Ordinance design module can be applied.


**Fig. 3-12 Forest-road design (Japan Forestry Agency) and German Harvester vehicle**

In a forestry machine, like harvester cabin, operator could have area image display for machine location at site and/or operating center via internet connection. Satellite image could be latest backdrop of working area with forestry machine, like harvester or forwarder.
In 2016, we have already evaluated the accuracy of stereo satellite images for 3D forest mapping in Kyoto city and presented the results to Asian Conference for Remote Sensing 2017 New Delhi, applying World View2 images from 3-line sensors.

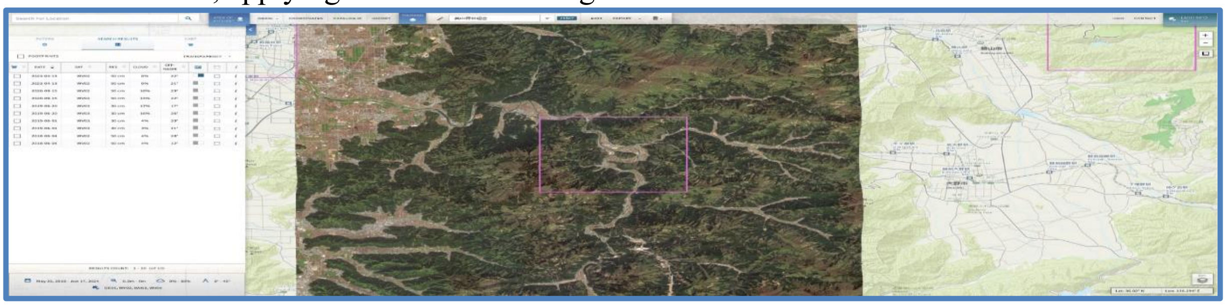

**Fig. 3-13 Forestry machine viewer: satellite image (Fukui City : Miyama Cho)**

## 4. 3D cadastral map/forest map and 4D-IMADAS oriented CAD-Globe

By nature, 3D cadastral map/forest map shows Historical Reality of 3D photogrammetric image models and 3D contour line maps. Historical events in chronological order are the prevailing authority or title to provide the basis for land ownership. To represent the land ownership, 3D CAD Map and CAD Globe are used as the platform for the title of land ownership.

### 4.1 3D CAD maps and CAD-Globe in the same CAD coordinates system

To define and designate 3D CAD maps and CAD Globe in the same CAD coordinates system, AutoCAD is simultaneously able to display, measure, and store coordinate systems and various map projections that represent the entire solar system at the same time.

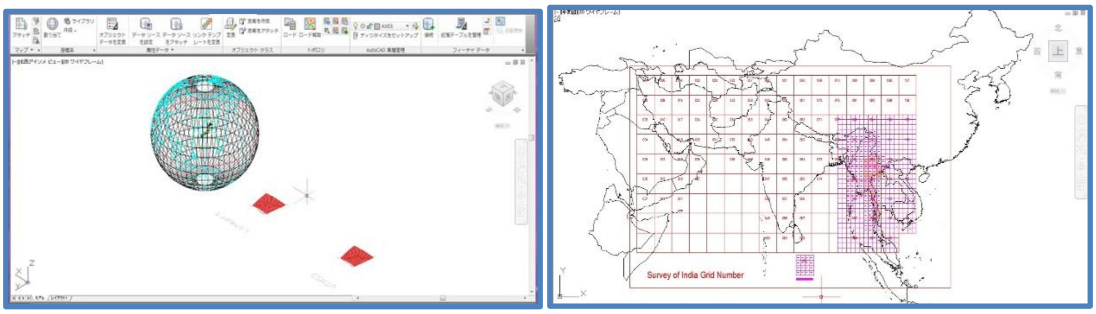


**Fig. 4-1 CAD Globe and CAD Maps：Survey of India - Grid Number**

### 4.2 3D CAD maps as UN-GGIM platform, based on UN-GGRF initiatives

United Nations Member States lead ECOSOC to establish the Committee of Experts as the apex intergovernmental mechanism for making joint decisions and setting directions, regarding the production, availability and use of geospatial information within national, regional and global policy frameworks (The United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM)).

UN-GGIM aims to address global challenges regarding the use of geospatial information, including in the development agendas, and to serve as a body for global policymaking in the field of geospatial information management

Under UN-GGIM, for global geodetic reference frame, UN-GGRF is now organized worldwide, and GNSS networking involves the integrated geodetic network adjustment of GNSS reference points, leveling points, and gravity points, with the Earth's center of gravity as the origin.

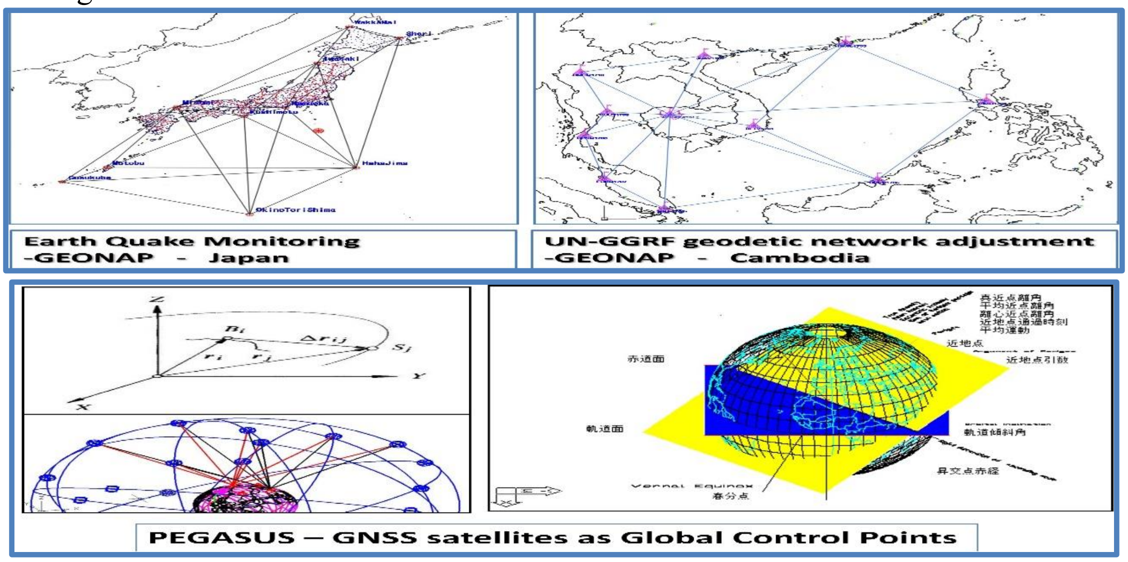


**Fig. 4-2 UN-GGRF – GEONAP -Japan – Cambodia**
**Parameter Estimation Gnss Assisted SUrveying System(PEGASUS)**

**Acknowledgements**

This research paper has been supported by achievements of German authentic satellite geodesy. The author would like to express deep gratitude to Dr. Guenter Seeber and Dr. Gerhard Wuebbena, in the theoretical and practical sense. New practices will be reflected to Japanese forestry specifications, which would be applied to forestry administration and national land survey project nationwide.

**References: all are now translated in Japanese**

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**BIOGRAPHICAL NOTES**

Hiroyuki Hasegawa obtained a BA in Human Geography in 1971 from Kyoto University, Japan. In 1976 he was graduated from ITC, The Netherlands as Photogrammetric Technologist. From 1971 until 1999 he worked at PASCO Corporation in Tokyo, Japan. From 1999 until now he is working in GeoNet, Inc. in Osaka, Japan.
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From 2014 to 2015 he was the representative of common research project of CSEAS (Center for Southeast Asian Studies Kyoto University): "4D IMADAS for Williams Hunt Collection". In FIG Working Week 2019 Hanoi, 4D-IMADAS with 3D mapping of Kyoto (Heian) – Angkor (Khmer) capitals was presented. In Southeast Asia Survey Congress 2019 Darwin, 4D-IMADAS 2019 - 3D cadastral mapping was presented.

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