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Special Contribution

Innovative management system for infrastructure by utilization of 3D point cloud data based on GIS platform

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In recent years, much of the infrastructure that was constructed in the high-economic-growth period in Japan has begun to age. At the same time, the number of maintenance engineers for this infrastructure has become insufficient due to a decrease in working-age population as well as budget deficits. With respect to the large change in the social environment as described above, the advanced maintenance system of the infrastructure should be developed and required to improve efficiency and accuracy of maintenance works on roads and other structures, based on the platform utilizing GIS (Geographic Information System) and the point cloud data. By using this innovative system, a variety of data related to structures such as drawings, inspection results and repairs or reinforcing records are managed easily through a digital map on the GIS. This developed system also offers the function to create 2-D and 3-D CAD data or FEM models, and simulations of inspections and repair works, utilization of the 3D- point cloud data measured by an MMS (Mobile Mapping System). In addition, the deformation of structures detected by using the 3D-point cloud data has been examined and the accuracy of deformation verified. This paper describes the innovative management system based on the GIS platform to support maintenance work on infrastructures using the point cloud data.

Keywords: infrastructure, maintenance, point cloud data, GIS, MMS (Mobile Mapping System)

1. Introduction

In recent years, much of the infrastructure such as roads, bridges and tunnels that was constructed in the high economic growth period in Japan has begun to age. In addition, the number of inspection and maintenance engineers for this infrastructure will become insufficient based on the estimation of future working-age population by the Ministry of Internal Affairs and Communications, as well as the issue of budget shortages. In order to solve the above issues, an innovative management system for infrastructure based on the GIS platform has been developed.

The computerized system named as “InfraDoctor” which is a core technology of the innovative management system, will be able to improve efficiency and accuracy of maintenance works on roads and structures, utilizing GIS and the point cloud data. By using this system, a variety of data related to structures such as drawings, inspection results and repair or reinforcing records can be handled on a digital map of GIS. This system also has the ability to create 2-D and 3-D CAD data and FEM models for structural analyses and deterioration prediction analyses, and to simulate the inspection and repair works with utilization of the point cloud data measured by an MMS. Furthermore, inspection work can be carried out efficiently with accuracy by detecting the change in displacement or damage of structures using point cloud data measured over a certain period. In this paper, various functions of the “InfraDoctor” are introduced and innovative management system for infrastructure named “i-DREAMs” (intelligence-Dynamic Revolution for Asset Management system) which has been implemented by the Metropolitan Expressway Co., Ltd. since August 2017, is described.

2. Outline of InfraDoctor

The “InfraDoctor” has been developed to improve efficiency and accuracy of maintenance works on structures such as roads, bridges, tunnels, buildings and so on, utilizing the GIS platform and 3D-point cloud data. This computerized system consists of the following elements.

2.1 GIS platform

The “InfraDoctor” is based on the GIS platform. In the portal of the system, a digital map is shown in the browser on the computer screen. Through this digital map on the GIS platform, any data such as various ledgers can be searched for easily and quickly.

The “maintenance ledger” has the information concerning the number, dimension and material of structures and appendages. The “inspection history ledger” has inspection-result records. The “repair history ledger” has records of repair and reinforcement works carried out based on the inspection results. All data in these ledgers has the coordinates and is connected to the digital map. This data can also be searched by using various keywords such as the name, type, material and so on, of the structures. Using other information connected to the searched data, they can be sorted easily and quickly for various purposes, such as confirming the quantity and locations of same-type structures or members, comparing between inspection results or repair work history, for example.

The point cloud data and the all-around video data which is described later, are also managed on the GIS platform and can be shown on the computer screen by specifying the location from the digital map on the browser shown in Figure 1.

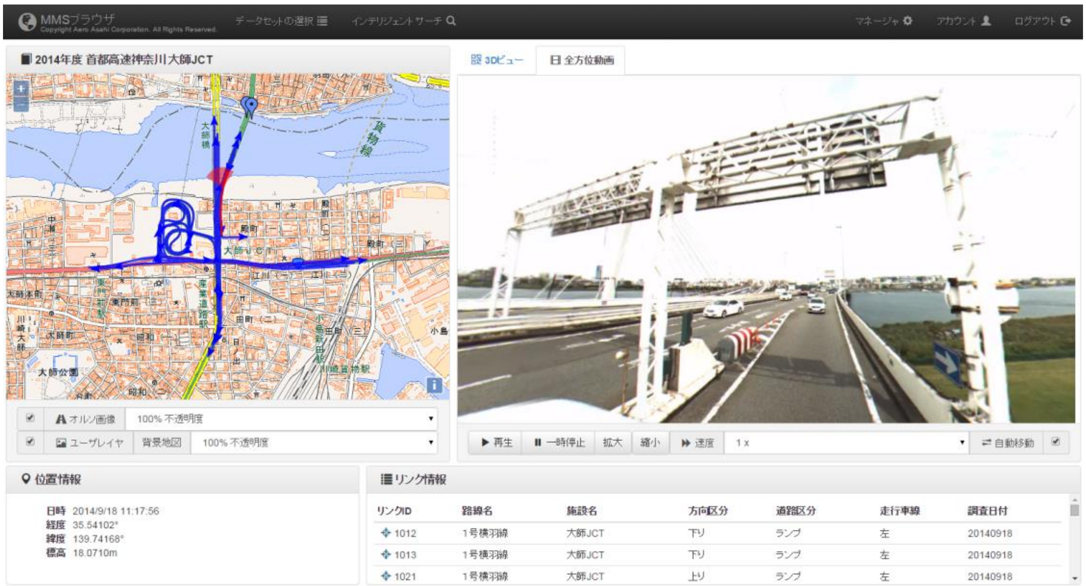

Figure 1 GIS browser with all-around video image

2.2 All-around video

All-around video images are captured using a vehicle called an “MMS” shown in Figure 2, while travelling. All-around video is recorded as still images at every 4m of interval when the vehicle with an MMS is travelling at 60 kilometers per hour. The resolution of an image is about 12 mega pixels.

Figure 2 Mobile Mapping System (MMS)

Using this all-around video, the condition of structures and their surroundings can be confirmed on a computer screen without an actual investigation at the site. Because the all-around video enables objects on a road to be seen from not only the direction that the MMS is moving ahead but also any direction from the point of the MMS, the condition of the site can be grasped quickly and precisely at the office. Even the back of a sign board can be looked at, as seen in Figure 1, for instance.

2.3 Three-dimensional point cloud data

Two laser scanners are installed on the MMS described above, and three-dimensional point cloud data are obtained while the MMS is travelling at a speed of 40km/hr. These laser scanners emit a million of the laser beams for a second and capture the position of an object which reflects the laser beams from the scanner. A laser beam can usually reach an object about 800 meters away from the MMS. The MMS also equipped with a GNSS antenna and an IMU, which stands for “Inertial Measurement Unit”, and the error of measured coordinates due to vibration or rotation of the vehicle are revised using those devices. In general, the degree of an error for coordinates of an object is about 10 centimeters for absolute value of position with respect to the surveying coordinate and a few millimeters for relative errors regarding the position of each point recorded in one measurement if the target is an expressway road bridge with a height of about 10m from the surface road. The degree of an error, however, is changed depending on the distance between the target object and the laser scanner, velocity of the MMS, the condition of road surface which affects the vibration of MMS, existing tall buildings or structures which interrupt or reflect radio waves for GPS antennae from satellites, and so on.

When a structure is modelled in three dimensions using the point cloud data, the vehicle with the MMS should be driven several times around the target structures to cover its blind spot. Therefore, registration is required to integrate those point cloud data groups measured separately. It has been confirmed that an error of a few tens of millimeters may occur during a registration work. In order to solve this problem, a program which can carry out the registration work while correcting the error automatically, is now under development and being prepared for commercialization.

The MMS is also equipped with some HD digital cameras and the color data of the image captured by those cameras can be exported to each point in the point cloud data. As a result, the point cloud data look like a video image as seen in Figure 3 and this makes it easier and more precise to recognize the shape and positional relationship of structures.

When the structures such as bridges are spanning over a wide river or existing in a mountainous area without roads available for the MMS, all the necessary point cloud data of a target structure cannot be captured. In these cases, a portable scanner fixed on a tripod, a human carrying type scanner or drone equipped with a scanner can substitute and the point cloud data captured by those different scanners can be integrated with that from the MMS.

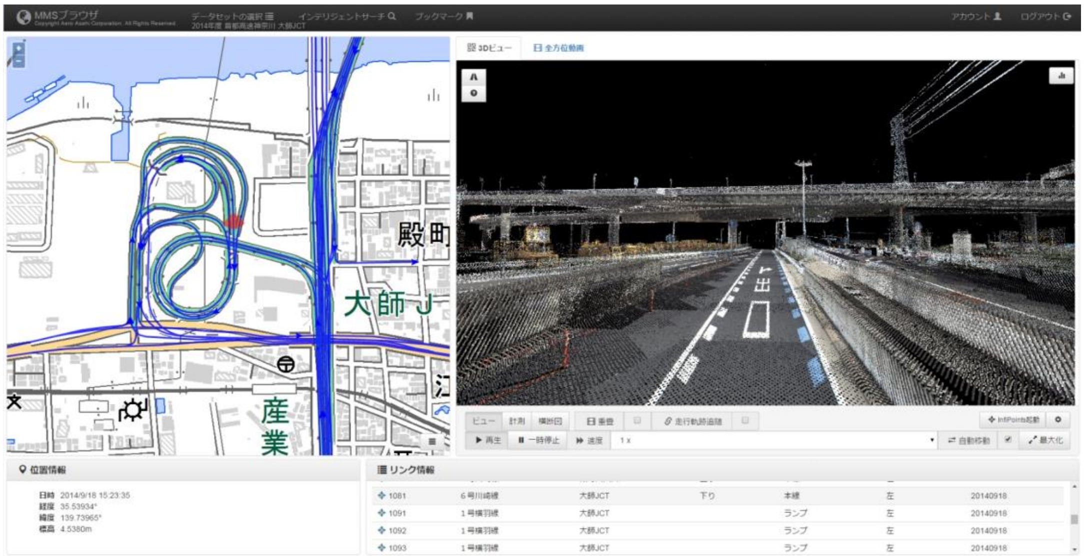

Figure 3 GIS browser with point cloud data

3. APPLICATIONS OF POINT CLOUD DATA

3.1 Detection of damage and displacement of structures

Since viaducts are above those intersections with heavy traffic or railroads, a remote inspection technique to detect damages where a close visual inspection is difficult is highly recommended, especially in urban areas to protect people from injury and cars from damages due to spalling and delamination of surface concrete. Therefore, a technology to detect spalling and delamination on the surface of concrete structures has been developed using the point cloud data, by taking the difference of positions between the measured points and a "reference surface" which is an average plane of the concrete surface created from the point cloud data. In addition, it is expected that the propagation of the damage will be also detected by comparing the point cloud data measured in time series.

In a trial measurement, some delamination on the concrete surface with 3 or 4 millimeters of protrusion were detected when measured by a scanner on the MMS about 10 meters away shown in Figure 4. In this trial, the point cloud data measured in one measurement was used to eliminate the error induced by the registration. A further study is still necessary to obtain higher accuracy with this remote inspection method. Moreover, it is also possible to find displacement, deformation or lack of the appendages, structural members or the structure itself when subjected to a large external force, such as a large earthquake or tsunami, by comparing the point cloud data measured after the event with the one formerly recorded.

3.2 Three dimensional measurements

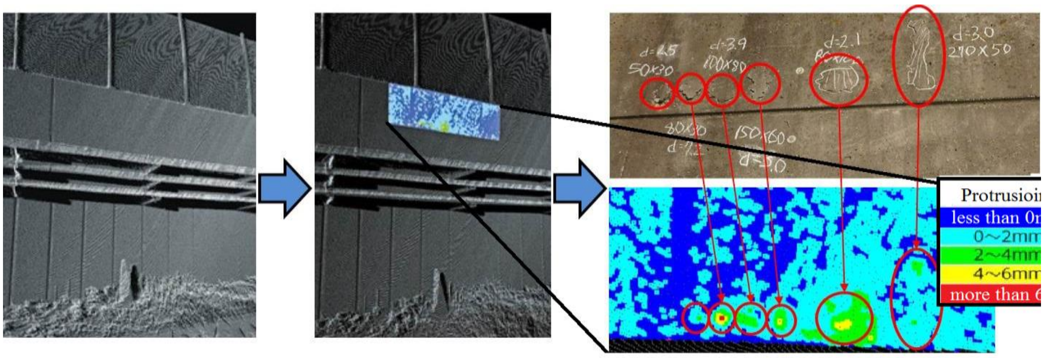

Figure 4 Detection of damage on concrete surface

It is possible to measure the dimension of and distance between structures in the 3D space created by the point cloud data on the GIS browser of the “InfraDoctor”. Using this function, it is possible to confirm the positional relationship between structures where the traffic regulation is needed for measurement, and where inspectors cannot easily reach, or different organizations own. All the existing structures that are not described on the same drawing can be integrated and the construction space can be checked three-dimensionally for inspection, repair and reinforcement work, as well as both clearance between structures and the traffic clearance in this 3D space shown in Figure 5.

This digital platform also has a function to create a contour map by providing a color to each point sequentially different depending on its position in the height direction of the pavement for instance. From this contour map, the inclination and rutting depth on the pavement surface will be measured as shown in Figure 6, and the location of a ponding place or flooding range can be confirmed. As a result, these data show a reference for determining whether the road surface is required to be repaved or not and are stored in the inspection database corresponding to the GIS map information.

Figure 5 Clearance check in the space by point cloud data

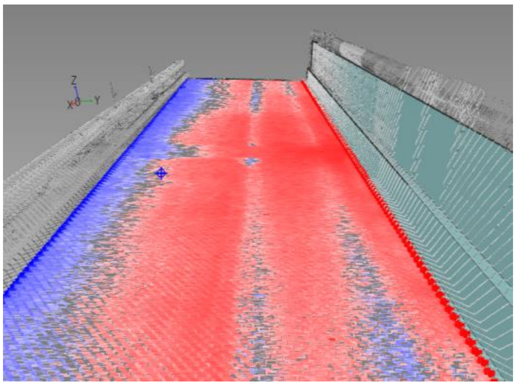

Figure 6 Contour of rutting depth on pavement surface.

3.3 Creation of two-dimensional CAD drawing

By extracting the point cloud data in each direction of the cross-section, it is possible to create a CAD drawing in two-dimensions. In conventional applications, a drawing is created by manually tracing the outline of the cross-section of the structure on the point cloud data. On the other hand, the “InfraDoctor” can automatically generate outlines of the cross-section of the structure and complete a drawing much easier and faster than the conventional method. Since each point of the point cloud data has a value in x, y, z-coordinates, the dimension and the distance of structures can be obtained at any section and a general drawing of a structure with the dimensions, as shown in Figure 7, can be generated semi-automatically in a short time.

In Japan, there are about 700,000 bridges with a length longer than 2 meters. However, it seems that the original drawings of approximately 300,000 old bridges among them may have been lost. This current situation is surely hindering maintenance work for bridges. In addition, since the appendages and the reinforcing members are installed on a structure after the construction is completed, these drawings are not often well conserved. In these cases, creating drawings of the current state of the structure using this computerized system will greatly contribute to the repair or retrofit design and efficient maintenance work.

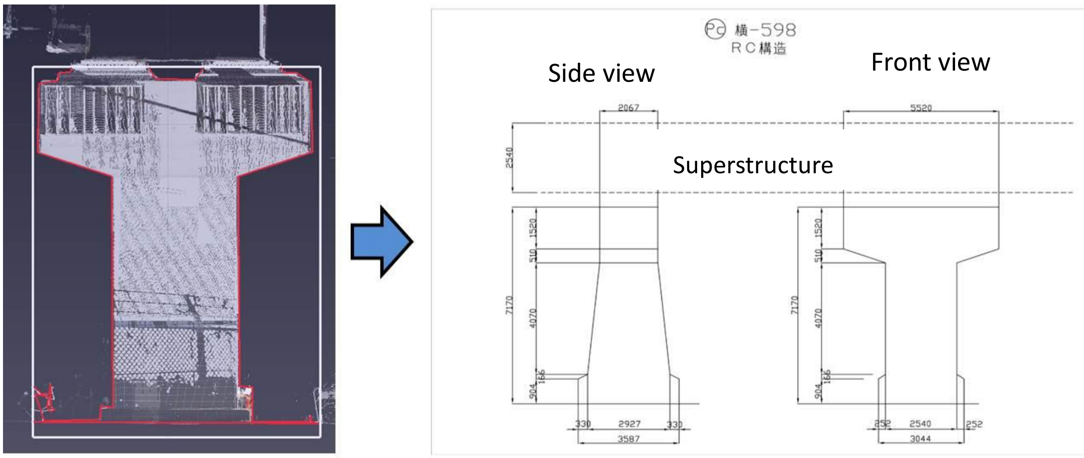

Figure 7 2D-CAD drawing created from 3D-point cloud data (bridge pier)

3.4 Creation of three-dimensional CAD model

Three-dimensional CAD model can be also created in a short time by automatically generating the planar or curved surface of a structure from the 3D-point cloud data, using the "InfraDoctor" as shown in Figure 8. This model will be used for three-dimensional structural designs and analyses. In addition, a three-dimensional FEA (Finite Element Analysis) model can be created from the three-dimensional CAD data by meshing automatically. Currently the development of three dimensional FEA is remarkable and it would be possible to estimate residual or ultimate strength, and degree of damage of structures. Combining with the inspection results which are used as the boundary condition in the FEA analysis, evaluation of the structure with high-precision can be carried out. Therefore, this function will be a great help to analyze the strength of a structure effectively and to carry out a design of repair, retrofit or reinforcement, using the obtained structures in the current situation with the damage or deformation caused by deterioration, natural disasters or other external loadings.

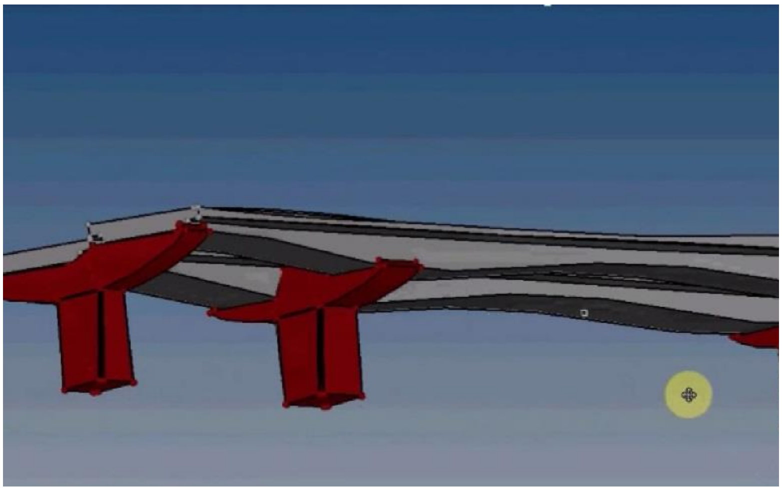

Figure 8 3D CAD model created from 3D-point cloud data

4. Smart Infrastructure Management System, *i*-DREAMs

To achieve the effective maintenance work with accuracy, various data made or obtained at the stage of survey, design and construction such as design statements, drawings, material data, methods or conditions of construction work, inspection results including construction errors, repair records before operation, are very much required. Combining the Construction Information Modeling (referred to as CIM) with "InfraDoctor", the initial data required for the maintenance work will be transferred continuously from the design phase to the maintenance phase shown in Figure 9. As a result, comprehensive evaluation of deterioration and damage of the structures will be carried out based on the accumulated data of the platform. In addition, it is possible to integrate the database of inspection, repair and reinforcement into the use of ICT and IoT technologies on this platform.

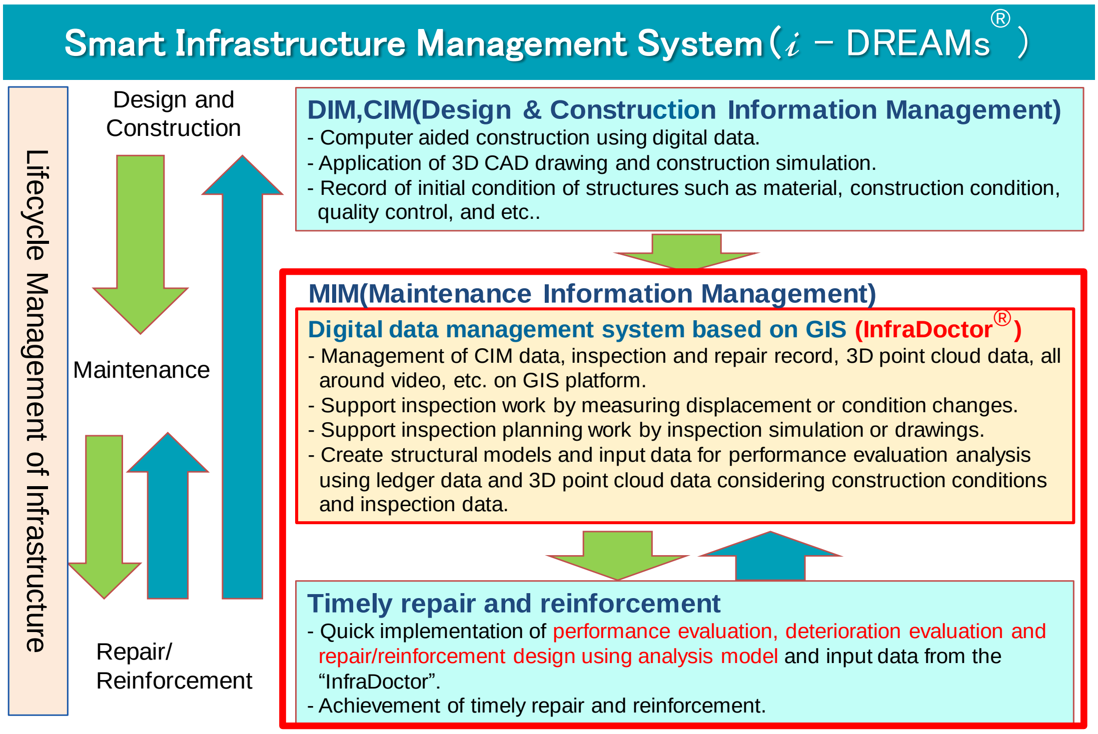

Figure 9 Future development for smart infrastructure management system

Making use of this initial data from CIM and the boundary condition obtained by inspection, a deterioration prediction, deterioration diagnosis and performance evaluation of structures with high-precision can be determined by making use of this initial data from CIM and the boundary condition obtained by inspection, and even by the structural analysis with FEM models generated by "InfraDoctor". Consequently, it is expected that proper repair and reinforcement at an appropriate time will be carried out, and efficient and smart maintenance work on infrastructure can be achieved. These experiences of infrastructure management can be applied not only to maintenance work but also to better design and construction. Furthermore, by processing the big data such as integrated data of traffic volume, axle weight and environmental conditions as well as inspection data, sensing data with the use of IoT (Internet of Things) utilizing AI engine, the innovative platform of *i*-DREAMs (intelligence Dynamic Revolution of Asset Management system) makes it possible to evaluate the damage and performance of structures efficiently with high accuracy shown in Figure 10.

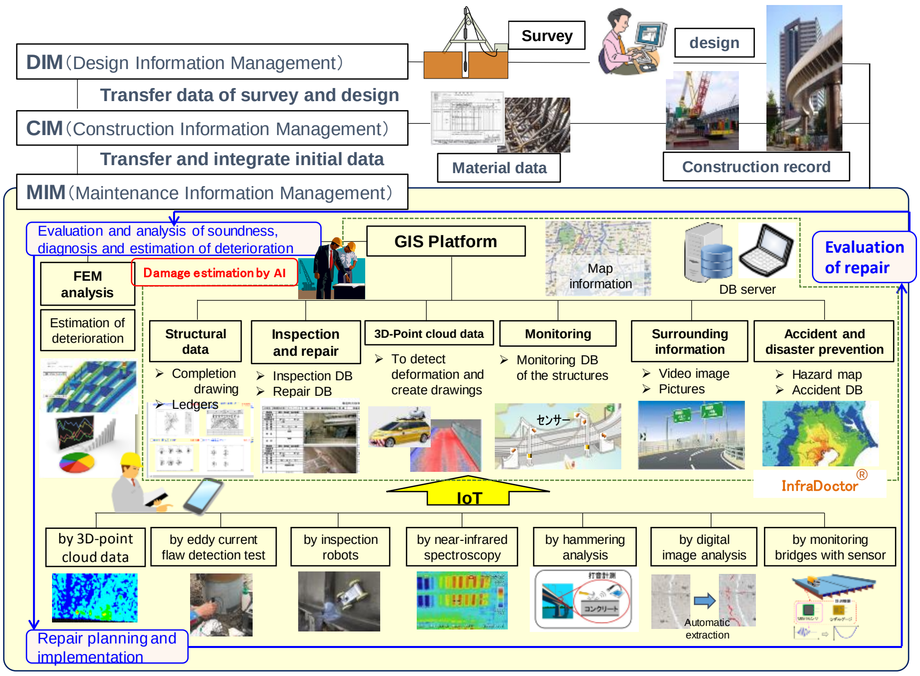

Figure 10 Innovative infrastructure management system (*i*-DREAMs)

5. Summary

Maintenance work of infrastructure has become increasingly important due to ageing, deterioration and severe use of structures. Periodical close visual inspection of road structures with every five years was legalized four years ago by the Japanese Government. However, there still exist areas where inspection is very difficult, and the number of inspectors is still limited due to a decrease in population, especially the working age population. Therefore, development of the advanced and innovative inspection technologies is required for accurate and efficient inspection as well as for education and training of inspectors.

For this reason, "InfraDoctor" has been developed as an advanced database system based on the GIS platform to support the maintenance work on road and structures, integrating various ledger data, the inspection data, and repair and reinforcement records of structures, all-around video and point cloud data. By utilization of this platform, the operation and maintenance work will be more efficient and laborsaving without sacrificing accuracy. In addition, the seamless infrastructure management system such as i-DREAMs combining with "InfraDoctor", CIM and numerical analyses such as FEM, is a more integrated system which enables efficient maintenance of infrastructure. As a result, timely and appropriate repair and reinforcement of structures following deterioration diagnosis and prediction connecting with the initial data, the boundary condition such as inspection results and FEM analyses will be achieved.

The group companies of the Metropolitan Expressway Co., Ltd. are carrying out a trial operation of this platform to verify applicability and accuracy for the maintenance work in practical use. With the results of trial operation, the system will be further improved and implemented in the actual maintenance work. It is expected that this innovative GIS platform will contribute to efficient management of infrastructure not only in Japan but also in various countries around the world in the near future.

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A brief CV of Dr. Hiroshi DOBASHI

Dr. DOBASHI is a director, Maintenance and Traffic Management Department of the Metropolitan Expressway Company limited, Japan. He is currently in charge of maintenance work and traffic management service of the Metropolitan Expressway. He has developed an innovative infrastructure management system to achieve comprehensive management of infrastructure. Especially he specializes in the field of tunnels. He has developed the shield tunnel enlargement method, the first of its kind in the world.