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A Remote Measuring System for the Mapping of Hazardous Environments

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Abstract

Close range photogrammetric measurement is a proven method for the mapping of industrial structures and has been widely employed within the process plant and nuclear industries. Unfortunately the radiological conditions encountered within active parts of many nuclear installations may severely constrain any measurement system which depends on photo–chemical imaging.

This paper describes the development of the HAZMAP photogrammetric system, developed under the European Commission TELEMAN project initiative, which is intended to operate within hazardous nuclear environments. The system utilises a remote measurement/inspection unit which is coupled via a photogrammetric module to a process plant design and management system (PDMS). Accordingly 3D CAD plant models can be constructed from digital images acquired photogrammetrically. A number of trials of the HAZMAP system are also described. These have demonstrated the feasibility of the system for constructing accurate 3D CAD plant models which can be used both for conventional engineering purposes and for planning and simulating robotic entry.

1. BACKGROUND

The Hazmap system has been developed under the TELEMAN project initiative which is sponsored by the European Commission in Brussels. The technical objective has been to strengthen the scientific and engineering base for the design of remote equipment for use throughout the nuclear industries in Europe. This is to be done by providing new solutions for manipulation, material transport and mobile surveillance in nuclear environments and by demonstrating their feasibility.

The HAZMAP project was started by University College London (UCL), Department of Photogrammetry and Surveying. They wanted to exploit the proven techniques of close range photogrammetry onto a realistic model of the nuclear environment. UCL appreciated that photogrammetric techniques might match well with 3–dimensional (3D) Computer Aided Design (CAD) modelling technology. Accordingly UCL approached CADCentre with a view to working together on this project.

2. HAZMAP DESCRIPTION

HAZMAP is based on a merging of 2 technologies, close range photogrammetry and 3D CAD modelling, supported on a common UNIX CAD workstation. This workstation acts as a software development environment and also possesses a powerful 3D graphics capability. The philosophy was to closely integrate photogrammetrically–acquired digital images with 3D CAD models of nuclear plant. The technique of close range photogrammetry has already been widely employed within the process plant and nuclear industries for the mapping of industrial structures. It also offers a more flexible approach to 3-dimensional measurement than conventional photogrammetry. The other important reason for choosing digital images is that conventional photo–chemical imaging processes may not be stable in an active hazardous nuclear environment.

The original HAZMAP system is fully described elsewhere (1). However in overview, the system comprises three modules.

The first module is for remote acquisition of digital images. The prototype unit utilises off–the–shelf components. It consists of a pair of standard CCD video cameras mounted on a motorised theodolite pan/tilt unit. This hybrid camera configuration can also be operated remotely via an RS 232 data link to the CAD workstation. Its resolution is 768 x 575 pixels. The first camera carries a wide field of view and a wide angle lens allowing the operator to visually inspect a number of plant components at once. The second camera uses a narrow field of view to enable the high resolution image acquisition of close range details of individual plant components. The operator is thus able to build up and store a number of discrete digital image tiles on the screen of the CAD workstation. Overlapping stored image tiles can then be assembled to build up a complete panoramic photo–mosaic of the wider field of view of the plant. Since the prototype system is built up of off–the–shelf components it is not radiation hardened.

The second module is the photgrammetric module which is resident on the CAD workstation, a Silicon Graphics SG 4D/20. Sophisticated bundle adjustment software is used for localisation of the separate camera viewing points. This determines the exact 3-dimensional positions of the camera at each image acquisition location.

Manual identification of homologous points by the operator interactively on a number of image tiles on the CAD workstation screen enables real–time intersection of key plant components to be established and the corresponding 3-dimensional coordinates to be determined and made available for 3D plant modelling.

The third module is the 3D CAD plant modelling module and the interface into it from the photogrammetric module. The plant modelling system used is the Plant Design and Management System (PDMS) from CADCentre Ltd. This system uses an intelligent engineering database and has the potential to construct a detailed layout of a process plant model. This will now be described.

PDMS DESCRIPTION

PDMS is a sophisticated, configurable 3D design engineering system for the process plant, oil, gas and power related industries. PDMS creates an accurate full colour 3D computer engineering model which can be accessed by designers, engineers and project managers. The heart of the system is a powerful multi–user project database directly coupled to a full scale 3D solid modelling system. This modelling system is based on the construction of 3D solid model primitives e.g. cylinders, cones, pyramids etc.

Piping isometrics, general arrangement detail drawings, bills of materials and other engineering data project reports can be produced quickly from PDMS. A particular feature is that piping components employed in the design may only be selected from engineering piping specifications stored in the database. These specifications consist of predefined lists of all permissible piping components for that engineering project. This ensures design integrity and enables powerful automatic checking for piping data consistency.

PDMS is particularly appropriate for piping–intensive design applications in hazardous environments. In particular these include North Sea oil platform topsides, conventional and nuclear power stations, and nuclear fuel reprocessing plant.

4. 'PROOF OF CONCEPT' TRIALS AND FURTHER DEVELOPMENTS

Initial trials were carried out on a mock–up (i.e. non–hazardous environment) of the core of a British nuclear reactor of the Magnox type. The item selected for modelling was a restraint clamp. Firstly, the exact positions of the HAZMAP camera viewing points were established in the process of localisation mentioned above. Then image tiles were acquired and stored on the CAD workstation from these viewing points. Thereafter, homologous points on the clamp were identified in separate image tiles and 3-dimensional coordinates of these points established. Then a 3D model of the restraint clamp was made in PDMS by generating the constituent 3D solid model primitives.

This trial proved that a single component could be modelled to a precision of 1:5,000 over a range of 1 to 50 metre stand–off distances. However the actual construction of the 3D CAD model itself was not optimal and it highlighted the need for an improved interface between the photogrammetric and 3D CAD modules. Also the trial had not included any pipework which is a particular strength of PDMS.

Although it had been quite a simple trial, 'proof of concept' had been established. It was also clear that this technology had further potential. So it was decided to extend the HAZMAP contract and carry out further trials under more realistic conditions in nuclear installations.

However, before these trials were carried out the HAZMAP system was further enhanced. One development was an improvement in the sophistication of the layout of the photo–mosaic of the digital image tiles on the screen of the CAD workstation. A second development was a closer interface to PDMS to enable the intelligent creation of engineering components within the 3D plant modelling database rather than just building up a simple solids model with little or no engineering design intelligence. Continuous developments were also carried out on the bundle adjustment software to improve the accuracy of the 3D coordinates measured.

5. BENEFITS FROM AN ACCURATE INTELLIGENT ENGINEERING MODEL

Until recently the benefits of such 3D CAD models for process plant have been restricted to the design phase of engineering. The use of HAZMAP, as well as an increasing awareness of using the 3D CAD model as an 'as–built' database record for the benefit of plant operations and maintenance (3), suggest that this intelligent model is about to be used much more widely.

Within the engineering design phase of process plant, the PDMS 3D CAD model with its clash detection capability can be used to manage the space volume of the plant and accordingly help coordinate the different engineering disciplines working on plant design. The data consistency of the piping design can also be checked quickly and engineering drawings, based directly on the 3D model, can be produced automatically with the rule–based draughting package. The 3D 'walk–through' capability can also be used to carry out design reviews and project progressing.

On completion of detailed design, piping isometrics can be produced automatically from the database to assist in the construction of the plant. These isometrics can be separately manipulated within the PDMS environment to produce fabrication, erection and spool isometric drawings with annotation as required. 3D coordinate information can be passed to pipe–bending machines if appropriate. Also erection sequences can be easily prepared to assist in construction. These can be produced as a number of colour shaded images and retained as hard copy or made into animation sequences on video.

During the operational phase of the plant, as described above, the accurate 'as–built' 3D CAD model can be developed from the 'as–viewed' HAZMAP digital images. The 3D plant model can also be used to assist in planning plant maintenance. For example, a removal and installation sequence of a turbine or pump can be simulated. With the benefit of on–line clash detection optimal routes can be established within the 3D CAD model preventing costly mistakes on site. The 3D model can also be used to plan, simulate and execute robotic entry.

To add to this, the 3D CAD model is now being interfaced into existing plant maintenance databases. In this way, the 3D CAD model becomes a pair of eyes into maintenance databases that up until now were not accessible through a graphical interface.

6. TRIALS IN A CONVENTIONAL PLANT ROOM

Before going out to real nuclear plant to validate the HAZMAP system on site, a trial run was carried out to test the HAZMAP enhancements and produce a more intelligent engineering plant model. The site chosen was a hydraulics laboratory at UCL, the environment of which was non–hazardous. The laboratory consisted of a single room 7 metres by 4 metres with associated pumping, equipment, pipework and other plant items. This is described more fully elsewhere (2).

The HAZMAP camera was deployed at a number of fixed locations on a stable tripod. Remote operation was not used on this trial. A photo–mosaic of the plant room was generated interactively on the CAD workstation. Then a 3D plant model was generated off–line in PDMS as now described.

The plant model was made up from three types of engineering items. Firstly, standard pieces of engineering equipment like tanks, pumps and vessels were modelled. They were then correctly positioned and orientated within the 3D space of the plant model. Equipment items were created by building up appropriate 3D solid model primitives. Once created these standard pieces of equipment can be stored in the PDMS catalogue and can be reused again for repeated instancing when necessary. It is also essential to model 'nozzles' attached to the equipment. The particular significance is that nozzles are the attachment points on the equipment, to which pipework is connected within the PDMS system.

Secondly, pipework runs were modelled by establishing centre lines, by locating the centre points of flanges at each end of the straight pipe. PDMS then managed the creation of pipework using a pipework specification to select the appropriate nominal bore. Bends with the same bore and from the same piping specification were then created as appropriate between straight length pipework. Thus quite complex pipe runs could be constructed by the combination of accurate determination of the orientation and single point measurements of flange pairs.

Also valves were placed within the pipework at the correctly measured positions. These valves were selected from the PDMS catalogue. These predefined valve definitions contain adequate geometry to represent the valve graphically for engineering purposes rather than replicating exact photographic detail. One flange measurement is sufficient to position the valve but an additional measurement of valve handle location and extent is necessary to set the orientation relative to the pipe centre line.

Thirdly, other non–standard plant items were built in the model by creating solid 3D primitives, and combinations thereof, that could be manipulated to fit the viewed position. This was also done as a sensible engineering approximation.

The building of this small but representative plant model to an accuracy of $\pm$ 3mm in a static non–hazardous, non–remote control environment with on–line acquisition of digital images, and off–line 3D CAD model generation proved that the technology was now ready for testing in a realistic nuclear environment.

7. TRIALS AT A NUCLEAR POWER STATION

Two separate trials were carried out at a French nuclear power station which was still under construction. This gave the opportunity to carry out real data collection under realistic conditions but in a non–hazardous environment.

The first trial took place in an auxiliary building inside a room of size about 15 metres by 4 metres. It contained much regularly spaced medium bore stainless steel pipework with connected pumps. The camera was operated remotely from the engineering workstation in an adjacent room. Good image acquisition was achieved.

The second trial involved image acquisition and 3D modelling of the heat exchanger bowl at the base of the steam generator building. The bowl acts as a heat exchanger between the primary and secondary water systems and contains a high concentration of small bore piping. The immediate surroundings of the bowl in the base of the building were also modelled. This included floor, walls and other adjacent pipework. In this case the 3-dimensional precision of the HAZMAP measurement system was checked against the proven techniques of industrial photogrammetry and conventional theodolite measurement. This was done with the assistance of theodolite targets which were placed in the bowl environment. These checks confirmed that HAZMAP was achieving accuracies around $\pm$ 2–3mm.

8. TRIALS AT A NUCLEAR REPROCESSING PLANT

The trial was conducted at a BNFL plc facility. The facility was nearing completion of construction prior to becoming active. The HAZMAP equipment was both tripod and gantry crane mounted. On–line acquisition was obtained remotely observing (theoretical) radiation restrictive practices (i.e. all cables were fed through overhead wall plug and shielding with no human intervention). The gantry crane was operated remotely to reposition the camera during the data acquisition stage.

Once on–line digital image acquisition was completed with the construction of the relevant photo–mosaics, the camera was retracted. Then the 3D CAD model consisting of vessels, pumps, building structure and pipework was built up off–line.

The 3D CAD model thus assembled was transferred via an existing program interface to the IGRIP robotics simulation package. The characteristics of the robotic device to be used had already been programmed. Thereupon simulation trials were carried out for robotic intervention.

9. FUTURE DEVELOPMENTS

The HAZMAP system with its 3D CAD model is now set to be at the heart of a continuation phase of the original European initiative. This phase is intended to integrate a number of new emerging technologies into systems that can be transported by a mobile platform into a hazardous nuclear environment. As part of this it is intended to incorporate radiation hardened camera equipment into the system when it becomes available.

The overall objective is to develop and test a light mobile robot in a number of configurations with different sensors/devices/navigation systems for a variety of inspection and surveillance tasks. These are intended to cover a range of maintenance, repair, replacement, post–accident and decommissioning situations.

One such configuration is to mount the HAZMAP camera equipment on–board the mobile platform and drive it remotely from the engineering workstation. A second configuration will mount a separate sensor systen. to HAZMAP on the mobile platform for rapid inspection. Information collected from this separate multiple sensor system is expected to include temperature and radiation levels as well as range data. It is intended thereafter that information acquired from both the HAZMAP and the rapid inspection configurations will be merged together such that temperature, radiation levels and other sensor results obtained can be mapped onto the HAZMAP 3D CAD model.

Practical project trials on these and other configurations are expected to be carried out separately for maintenance tasks and decommissioning work in hazardous areas. They are planned to take place under realistic operating conditions in nuclear plants over the next three years.

10. CONCLUSION

These trials have demonstrated both the feasibility and practical engineering application of HAZMAP as a new form of photogrammetry which is used in close association with PDMS 3D CAD plant modelling. The HAZMAP photogrammetry system can be used for remote acquisition of digital images on–line in a hazardous nuclear environment with satisfactory precision to generate a 3D CAD plant model for remote operation and engineering purposes. The plant model thus constructed is a highly intelligent engineering model which can also be made available to plan and simulate robotic entry.

From a wider context for conventional process plant, this technology will also enable the practical capture of 'as–built' engineering models which hitherto has not been possible cost–effectively. A CAD engineer can be quickly trained to operate this technology and use it as a 3D 'digitiser'. He can also make sensible engineering judgements as to the extent of modelling needed to capture the 'as–built' engineering model. Accordingly not all plant has to be 100% faithfully modelled.

Also the separation of on–line digital image acquisition and storing from off–line 3D plant modelling has two important benefits. Firstly, in a hazardous environment, the 3D plant model can later be constructed away from the hazardous area minimising exposure of the equipment to the hazardous environment. Secondly, digital imagery of a complete plant can be acquired without the immediate need to construct the whole 3D plant model. The 3D plant model, or part of it, need only be constructed as and when required e.g. for the refurbishment and redesign of part of the plant.

11. REFERENCES

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