

Semi - Automatic 3D CAD Model Generation of As - Built Conditions of Real Environments using a Visual Laser Radar

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1. Introduction

The development of special, active physical sensor systems for the direct 3D measurement of environment geometry is gaining more and more importance, as it is the basis for realising many applications in the area of automation technology. This is especially true for applications that require an on-line acquisition of geometric environment information, such as the guidance of autonomous robot vehicles, service robots or other assistance systems. In addition to these applications, the capture of the "As-Is" state of certain objects or complete environments ("Digital Factory") is becoming more important in order to obtain further results for the realisation, planning or simulation of certain operations, based on the actual state of the environment. Examples are the inspection and modelling of environmental objects, such as tunnel tubes, buildings or facades or complete industrial plants, such as chemical processing plants, nuclear power stations or single work cells in the area of automobile manufacturing. Here, it is important to guarantee a fast registration of the environment in order to avoid a long down-time of the plant while the measurements are in progress. The basis for the realisation of such tasks is an image of the environment in 3-D, which as accurately as possible reflects the "As-Built" condition of the object or environment. For an inspection or surveying of real environments and additional modelling, the sole use of 3-D geometry is sufficient in many cases. Increasing requirements for the realisation of ever more complex tasks as well as human interaction during a planning, simulation, optimisation or execution phase require the measurement of a multitude of physical parameters (geometry, visual image, colour, etc.) and their analysis and abstraction into the relevant information. A visual laser radar is used for a non-contact and accurate survey of an area which is completely measured in three dimensions and visually imaged within a few seconds. This information forms the basis for the generation of real models of the 3-D environment. This contribution describes the design and function of the developed visual laser radar in detail, adapted to an environmental survey at medium ranges. Robustness as well as a high absolute and relative accuracy enable the deployment in real industrial environments.

Section 2 describes the principle of measurement and two basic modules of the measurement system; the spot laser sensor and the beam deflection unit. Currently two different deflection units are used with the spot laser measurement system. A single rotating deflection mirror is used for profile measurements within long stretches of tunnel tubes. A combination of simultaneously rotating and nodding deflection mirror is used for the survey of local environments and generation of corresponding single 3-D images. Results are demonstrated in Section 3 from the second variation of the visual laser radar, such as survey and generation of a 3-D model of a "plant structure and supply network" and "robot cell" in automobile manufacturing.

Section 4 describes the semi-automatic model generation of spheres and planes. Instead of selecting all points manually, it is sufficient to mark a small region of the object, and the program extracts automatically all points which are measured on the object. In order to generate a global CAD model of the environment and to eliminate hidden areas, local images are registered in relation to each other. Two methods are implemented, either using targets or spheres as registration landmarks or based on the measured objects (natural landmarks) itself. Model generation of surfaces is not only implemented based on geometric primitives but also a meshing technique, approximating free from surfaces.

2. Visual Laser Radar

The developed visual laser radar is an optical measurement system and is based on the transmission of laser light. The environment is illuminated point by point and the light scattered back from the object is detected. The laser radar consists of a one-dimensional (1D) laser measurement system in combination with a mechanical beam deflection system for spatial measurements of the environment. Both components operate independently from each other and are connected via a common control and surveillance unit. Any difference from normal operation results in an automatic shut-down of the entire system.

2.1 Spot laser measurement system

In order to cover measurements at a medium range up to 60 m and simultaneously realise an absolute accuracy within mm-range, a phase difference method is used, based on the transmission of modulated laser light. The spot laser is the basic module for measurement of natural surfaces, from highly reflective to highly absorbing. It is suitable for industrial applications, where an accurate and fast registration of geometry and simultaneous visual imaging of objects is required. An integration of the spot laser measurement system with different mechanical beam deflection units opens additional application areas, since only then a spatial survey of an extended scene in the environment can be achieved. Following, a realised Z+F high-speed imaging system is described in more detail.

2.2. Imaging Z+F Laser Radar System

In order to implement a survey of a local 3-D section of the environment, a 2-D deflection unit is combined with the spot laser measurement system. The deflection unit enables imaging of 360° in azimuth (horizontally) and 60° in elevation (vertically). The deflection of the laser beam is achieved by a single rotating (azimuth deflection) and simultaneously nodding mirror (elevation deflection). The nodding rate and rotational speed of the mirror are set such that the range and reflectance image are measured in approximately 80 seconds. Both images consist respectively of 1400 rows (elevation) with 8000 data points (azimuth) per row. They correspond pixel by pixel. The achieved angular accuracy for this deflection unit after calibration is approximately 0.02 degrees (azimuth and elevation).



Fig. 1: Imaging Z+F Laser Radar

The range images obtained in this way show the geometric relationship between objects in the environment, whereas the reflectance images are used for identification and extraction of objects, visual inspection and also classification of object surface and documentation. Reflectance images are similar to video images, except that they are independent of ambient lighting conditions.

3. Semi-automatic model generation

The imaging laser radar generates a point cloud of the surveyed environment in terms of laser range and reflectance images. Both images are used for model generation, the reflectance images for segmentation and object identification whereas the range images for geometric modelling. In order to convert the point cloud of a range image into a CAD model which can be used by standard CAD software packages a specialised software for model generation was developed.

The software implemented for semi-automatic model generation is based on an interaction between user and the machine. Especially the interface has to be very efficient, in order to generate as fast as possible very accurate 3D CAD models. Therefore, the user marks only a certain area of the respective object to be modelled, and then the software itself extracts all points of the object automatically. This means that the user selects only a portion (“region of interest, ROI”) of the object, and the program

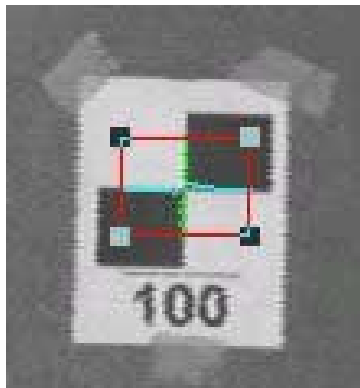
approximates the object by first segmentation of the object (i.e. extracting all relevant points) and then approximation of all extracted single measurement points on the object surface.

Before the semi-automatic model generation process starts, images of different view points taken within a global environment have to be merged, i.e. registered. This registration is based on either artificial (targets) or natural (real objects) landmarks in the environment.

3.1 Registration of images

In order to have full information of relevant objects, they have to be surveyed from different positions due to hidden areas, etc. The different local scans are registered relative to a global coordinate system (global context). In order to transform all local scanning positions (and therefore all measured points within a single image) into the global coordinate system, special targets are used as landmarks. They are positioned in the environment. The precise position of all landmarks is surveyed in the global context using a theodolite. Based on these global positions of the surveyed landmarks and the scanned images including these landmarks, the scans are registered. Position of the landmarks is very important, as only images containing three targets can be registered in all 3D dimensions (translation and rotation in 3D space).

Targets



*Fig. 2: Target "100";
Reflectance image*

In order to guarantee target recognition in the reflectance images of the laser radar, special targets are used similar to the one in fig. 2. The target consists of two white and two black sides, so that the crossing of all different colours indicates exactly the centre of the target. It is also the basis for the registration process, as it indicates precisely the position of the target.

For registration of several images relative to each other, the targets are positioned on walls or objects with even surfaces in the environment. The position of the centre of each target is surveyed precisely using a theodolite. Based on the positions of all landmarks in a global coordinate system, the registration of all scanned images is started. The registration process opens an image and extracts automatically all targets included in this image. For each target it extracts the centre of the target (fig. 2) automatically and asks the user to input the number of this target ("No. 100"). After having extracted all targets within one scanned image, the algorithm calculates the transformation matrix of this image into a global coordinate system. This registration is repeated for all images and at the end all images are registered into a global coordinate system, which is the basis for the model generation.

3.2 Model generation

Model generation normally is based on geometric primitives, like planes, cylinders, pipes or spheres. Only if the environment is not well structured (building facades, sculptures, etc.) these geometric primitives are not well suited for model generation. Here, meshing techniques are more useful in order to have a precise approximation of the environmental objects.

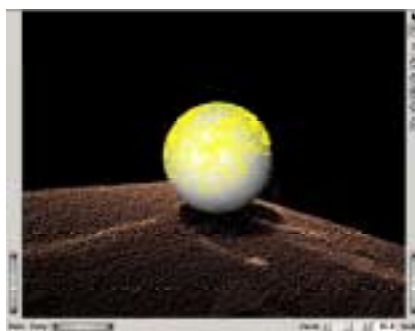


Fig. 3: "Sphere" and point cloud

Geometric primitives

Geometric primitives like cones, spheres etc. are stored in a library. Model generation of these geometric objects, is performed automatically. The user selects a certain region (ROI) of the object to be approximated. After having marked the ROI in the image the type of primitive has to be selected. After this manual interaction of the user, the algorithm fits the primitive and determines the parameters of the primitive. Having extracted all corresponding parameters, the program

tries to match the primitive to a standard primitive stored in the respective object library. If there is an appropriate object in this library these parameters are used. If not, the user has to determine if the extracted parameters are ok and if they should be added to the library. Having modelled all geometric primitives in the image, these parameters and positions are stored within a new file. This file can be interfaced to most standard CAD programs. Figure 3 shows a point cloud of a sphere and superimposes the modelled sphere.

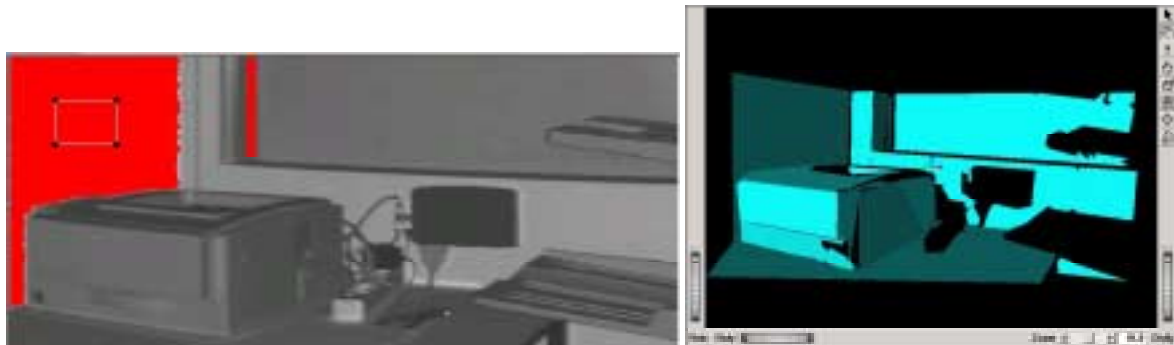


Fig. 4: Semi-automatic plane modelling
a) Segmentation of planes

b) Extracted Planes

Planes are modelled in a similar way. The user selects a small part of the ROI to be approximated by a plane. After this initialisation, the program extracts - within an area defined by the user - all single points which might be potential candidates of points representing part of this plane. Due to this automatic search, all small parts of the plane in the image are extracted, even if the plane is interrupted by some other objects (hidden areas). Figure 4a shows the plane fitting process in detail. The input of the user was the small rectangle and as a result all parts of this plane have been extracted. As a result of plane fitting, the corners of each plane are detected. In the example of figure 4a, ten corners are extracted: six corners of the larger plane and four of the smaller plane in the background. After this detection, these points are projected to the adjusted plane so that the plane really represents a flat surface. Figure 4b shows the result of the semi-automatic plane fitting algorithm applied to the scene of figure 4a. All important planes are modelled automatically and stored as 3D-objects. They can be processed in CAD-programs.

The implemented algorithms for semi-automatic fitting of geometric primitives is very useful and leads to the generation of a very precise CAD model of the environment without involving the user for each single step. This leads to an effective model generation and guarantees a very high quality of the resulting models.

Meshing

Meshing is used for modelling of free form surfaces, like statues. The meshing algorithm segments the image by means of detecting discontinuities in the objects. After this, a mesh is generated by connecting the adjacent points. After generation of the mesh, it can be manipulated with different filters like smoothing or changing the width (subsampling).

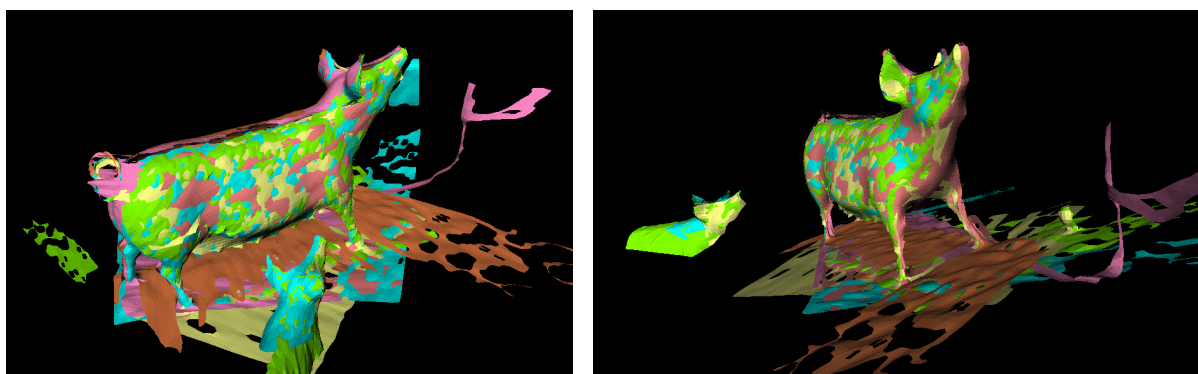


Fig. 5: Mesh consisting of different scans
a) View 1

b) View 2

Meshing can be applied to local and global contexts. Therefore, registration of the images is also very important. This can be done by either using targets but also fully automatic, without any artificial target. The algorithm merges the scenes in a way to best fit them [15]. This is done very effectively using several modules out of Artisan by CMU University, USA within less than one minute computing time. Fig. 5a and 5b show the result of a mesh of a famous statue "pig in Wangen, Germany" where several images (different colours) are registered automatically and then used to generate a complete mesh of the pig.

Models based on both geometric primitives as well as meshing are interfaced to standard CAD-programs (AutoCad, Microstation, CATIA, etc.) in order to support further data evaluation and processing based on standard tools.

4. Applications

The unique characteristics of the laser radar and the developed software for model generation support a large variety of different application areas. Next to the classic guidance of service robots [6,7,12,25] for the execution of locomotion and manipulation tasks, the visual laser radar and the software are deployed in the following applications:

- Survey and as-built modeling (CAD model) of miscellaneous objects such as machine parts, production facilities [11], industrial plants, airplanes, ship plates.
- Inspection of dangerous areas which are off-limits to humans (Nuclear power stations [11], contaminated environments, etc.) as well as tubes (tunnels [13], sewers, etc.)
- Virtual Reality applications in the area of movies, planning of interior building design up to the virtual visit of museums, etc., via internet.

Following, obtained results using the visual laser radar and the model generation software as described before are discussed for two different applications in industrial manufacturing environments.



Fig. 6: Reflectance image (Section: field of view 360° horizontal x 60° vertical)

Industrial manufacturing environment

An important application area of the visual laser radar is the generation of "as-built" 3-D models of industrial manufacturing environments. Such models are generated by surveying the environment with the laser and further model generation. Here, results from a survey with the laser radar and model generation software for both a "plant structure including supply network" and a "robot cell" in an automobile manufacturing plant (high degree of dirt, partially metallic surfaces) are described.

Figure 6 shows one of several reflectance images of the plant measured by the laser radar which are - together with the range images - the base for generating the as-built CAD-model shown in figure 7a. In this model not only the existing building structure, but also water, air and oil pipes as well as electrical power connections are represented precisely. These objects are the basis for planning and designing new work cells or assembly lines in the plant, as these production equipment must be adapted to the existing building and connection structure. Objects like robot pedestals or closings are not modelled separately, as they are not part of the building structure.

Figure 7b shows a robot cell and its environment. The robot was not modelled, but imported from an existing library. As all robot manufacturers have precise models (incl. kinematics) of their robots in a library, these models are then used to complete the CAD model of the environmental structure of the cell measured by the laser radar. The robot in this cell transports elements from the conveyor belts on the ground and puts them on one conveyor belt located under the ceiling. Furthermore, some new

robots have to be placed in this cell, and therefore the cell with pedestals were modelled carefully as the user is interested in the free space within this cell. All objects were modeled from measurement data of the visual laser radar and can be well recognized.

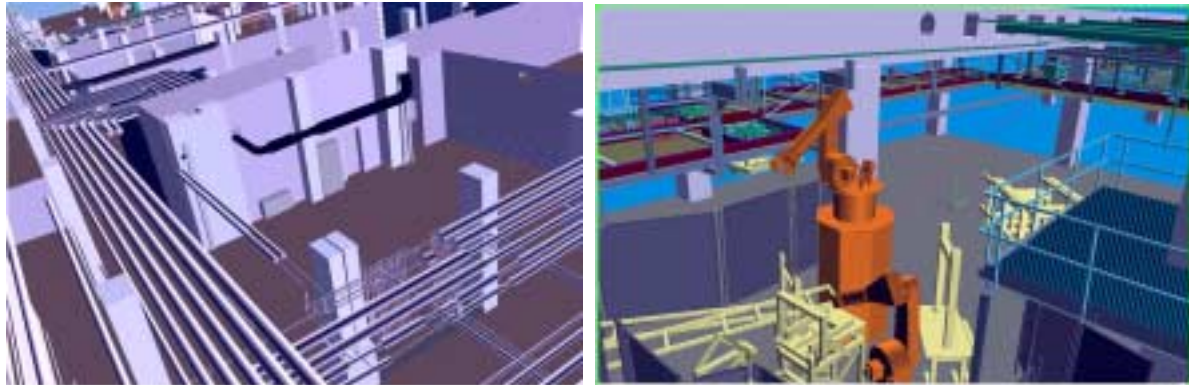


Fig. 7: CAD Models from laser range images

a) Plant, including supply network

b) Robot cell, incl. robot and conveyor belts

With the help of geometric models like these and a CAD library of known parts and machines, entire production runs can be simulated and optimized. For this purpose, software packages are used which already contains a direct interface for importing data of our system.

5. Summary and Outlook

With the developed visual laser radar and the software for model generation, very powerful tools are available that are suitable for industrial surveying tasks. The developed laser radar offers high accuracy measurements in conjunction with a high sampling rate and large dynamic range in reflective properties of object surfaces (highly reflective to absorbing). The semi-automatic model generation is integrated for the standard geometric primitives sphere, tube and plane. Together with the meshing, a broad variety of industrial environments can be modelled semi-automatic already.

Next steps will be auto-tracking with segmentation and model generation especially for tubes, as they are often very long and extensive and therefore difficult to model. Furthermore, improvement of the library management is essential as it exists now only for meshes, but not for object primitives.

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