Imaging Ladar Camera for Washing Robots

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Abstract

Imaging sensor systems are inevitable components of intelligent and automated machinery. Imaging sensor systems based on the laser radar (ladar) principle are proposed to provide advanced machine capabilities such as collision avoidance, obstacle detection, object recognition and position determination. This paper describes the adaption of a 3-d ladar camera to the requirements of a large computer-assisted telemanipulator (CAT) for aircraft washing.

1 Introduction

Aircrafts are cleaned overnight or during daytime (wide bodies) at regular intervals from 1 month to 3 months. Up to date humans are needed to clean aircrafts and the manual washing of planes is very labor intensive and time consuming. For example, a B 747 is washed by manual work in approximately 8 hours with 12 people [1]. Taking into account economic factors it is quite attractive to cut down the downtime of the planes. For a partial or complete automation of such tasks manipulators with intelligent vision systems are required.

At Dornier the development of 3-d vision systems technology started about 15 years ago [2]. Based on the light pulse time-of-flight measurement principle a laser radar sensor with biaxial beam deflection, the so-called ladar camera, has been adapted to the requirements of large computer-assisted telemanipulators (CAT).

In a joint project of different industrial partners and a scientific research organization it was planned to increase the efficiency of the machinery by automating certain tasks, such as motion or manipulation. Automatic motion requires knowledge of the manipulator position with respect to its environment. Similarly, manipulating objects requires classifying these objects and recognizing their position and orientation. The ladar camera provides the necessary input for determining relative positions and orientation of manipulator and environment and this information is supplied to the control unit of the CAT for further processing.

2 The SKYWASH System

The principle of the CAT has been implemented in a large robot for aircraft washing 'SKYWASH'.

The project was carried out by:

- Putzmeister as manufacturer for the mechanical hardware; brush system; as system integrator with the background of construction machinery
- AEG as supplier of the robot control
- Dornier as supplier of the 3-d ladar camera

Figure 1: Washing robot at the Aircraft

- FHG/IPA-Stuttgart, responsible for the scientific research and the off-line programming approach
- Lufthansa as enduser (specifications) and leading customer

The operation of a prototype started early in 1993 and since then several thousand hours of operation time have been realized. In 1994 an order for two serial machines (SW 33) was placed by Lufthansa.

The SKYWASH SW 33 mechanical hardware consists of the following main components:

- Standard on-road chassis from Mercedes-Benz, five axles, specific sound protection features, Diesel engine with EURO 2 standard regarding emissions
- Large multi-section manipulator boom; main axes with 6 d.o.f.; wrist axes with 3 d.o.f. and two adaption axes (telescopic and revolute joint)
- The brush, divided into four sections, measures the pressure onto the plane and is able to distinguish between position and orientation errors.

For precise positioning of the boom and accurate washing SKYWASH is equipped with sensors and control components:

- Robot control systems: AEG Robot Control IRC 250 for operation in programmed task execution mode and very precise for the fast movements required
- On-board PC system acting as MMI and tool for comfortable diagnostics
- Position measuring system for the axes (nine multi turn resolvers, one ultrasonic system for the translatory axes)
- A ladar camera: position and orientation of the manipulator in reference to the plane can be determined with high accuracy.

The SW 33 has been developed and optimized in computer simulation to cover a high percentage of the B 747 surface and other large aircrafts for perfect and quick washing operation. The washing programs of most common aircraft are programmed off-line as well. They define the sequence of the brush washing path on the aircraft surface.

3 The Ladar Camera System

A range imaging sensor system applicable to a washing environment must be rugged, simple to operate and fault tolerable. It also requires sensors with a high detection probability and at the same time, with low false alarm rates.

Active sensors, which are independent of ambient light, satisfy these basic requirements. The Dornier 3-d imaging sensor is an active sensor and based on the light pulse time-of-flight measurement method. This method provides unique range data for each measurement and range accuracy is range independent. The function of the ladar camera is simple. [3].

With the aid of a two-dimensional deflection unit (scanner), objects, scenes or areas within the range of vision of the ladar camera are illuminated with short laser pulses. For each orientation of the scanner, the distance from the respective scanning points on the objects is determined by light pulse time-of-flight measurements. The realization of the camera and its main components are shown in Figure 2, the parameter of the camera are given in Figure 3.

Thus, a matrix of digital range values, the so-called range image, is generated. The corresponding data are particularly suitable for further processing in a computer. Therefore, the entire process is often called 3-D computer vision.

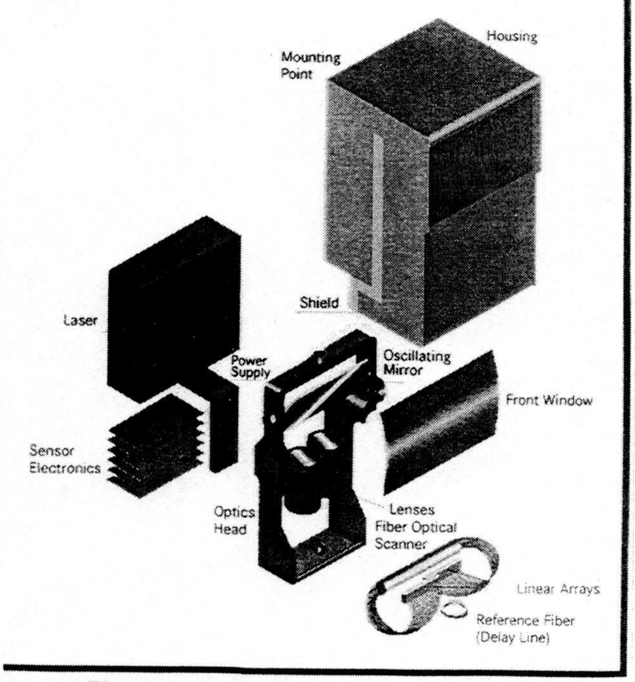

Figure 2: Main components of the camera

A graphic representation of this digital data is also possible. If the range values are for example color-coded, the spatial information, i.e. digital data can be displayed on a monitor by the computer (Figure 4).

More important is the processing and evaluation of the measured values in accordance with the washing robot application. With this system (i.e. ladar camera plus evaluation computer and suitable evaluation software), processes such as the initial coordinate determination during aircraft washing can be performed automatically and autonomously.

Type	Scanning LADAR, biaxial optics, pulse time-of-flight
Laser wavelength	910 nm
Optical peak power	10 W
Acquisition range	typical 5 m - 50 m
max. range resolution	± 0.05 m (single pulse)
Image refreshing rate	1 image / sec.
Field of view (FOV)	31 ° x 60 ° (vertical x horizontal)
Image format	63 x 128 pixel, raster scan
Beam divergence	0.2°
Laser protection class	class I, IEC 825 and DIN VDE 0837
Built in test, abs.calibration	with firmly integrated reference measurement section,b.i.t. in each image
Operating voltage	24 VDC (18 V - 28 V)
Power consumption	110 W
Weight	approx. 15 kg
Dimensions	30 x 28 x 27 cm
Protection class	IP65
Data Interface	RS 422 , 20 Mbit / sec.

Figure 3: Ladar camera parameter

For this reason, the software is an integral part of the ladar system, as it determines the system's performance. On account of the geometric information content of range data, robust real-time information processing methods permitting a direct and fast computerized representation of the environment can be developed.

For the measurement and classification of objects, a software is used to compare the ladar image data with one or several geometric object models stored in the computer (Figure 5.) In the SKYWASH project, the CATIA data records of the aircraft manufacturers concerned serve as geometric models.

The use of geometric data for the comparison of image and model data allowed the development of a particularly robust and efficient software. The process sequence is schematically as follows. When a range image of the object to be measured has been taken a hypothesis with

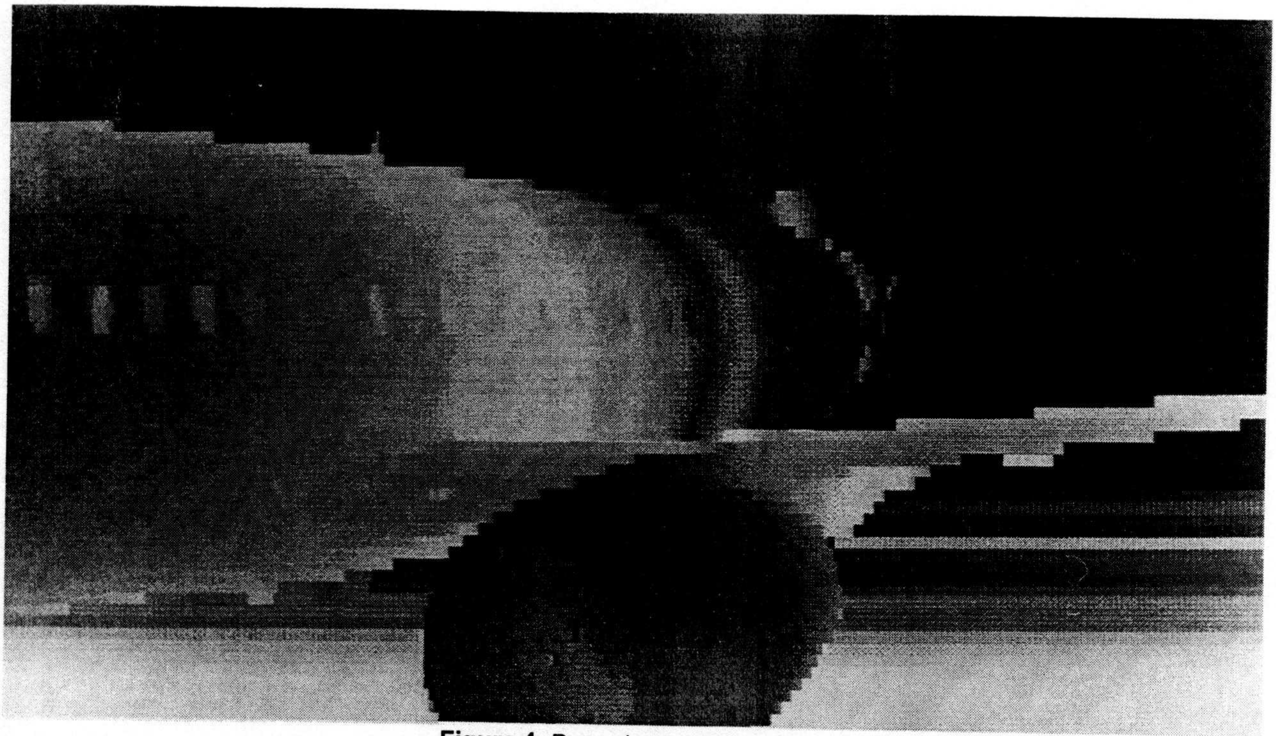

Figure 4: Range image, greycoded

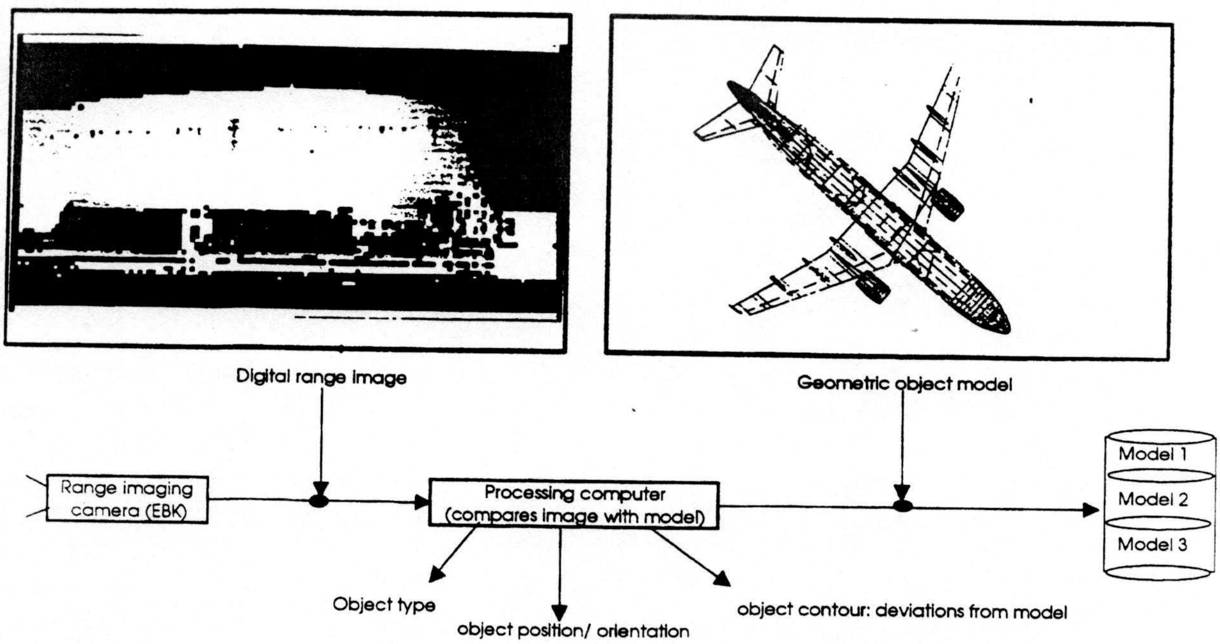

Figure 5: Principle of object classification

regard to the object type is established in the first step. In the subsequent position and orientation determination, the geometric model that corresponds with the hypothesis is brought into accordance with the range image data as far as possible in an optimization procedure. This method is performed in two phases:

(1) rough positioning and
(2) fine positioning

The rough positioning is carried out by the software program TRY. TRY is a navigation aid for the user and helps with simple routines to find the washing position. The program allows the determination of position/orientation by combinatory correlation of horizontal object contour of model and image. When the rough positioning method provides a solution i.e. TRY converges, the fine positioning is carried out by the software program SKY. This program is based on the processing of averaged range images for high accuracy, so the calculation time is in the order of minutes. The position/orientation determination is done by minimizing the main distance between pixels of the range image and the reference surface. This allows the highly precise determination of all 6 positions and orientation coordinates of the manipulator in reference to the plane to approximately 8 cm.

4 Operation of SKYWASH

For a chosen aircraft the stepwise operation of the SKYWASH system is as follows:

- Drive to the position
  Each of the two SKYWASH systems takes position in the center between wing tips and fuselage, front or rear. With the ladar system and the navigation-aid TRY the manipulator can be located in a predetermined circle of approx. 1 m.
- Adjustment of the system
  SKYWASH is stabilized with the outriggers on ground. The precise measuring of orientation and position of the aircraft relative to the manipulator is started with the ladar system and the program SKY, the program for folding out is loaded.
- Folding out
  During this procedure the existing washing programs are shifted onto the new location by the onboard PC and loaded onto the robot control unit.
- Washing of the plane
  The sensor washing brush at the boom-tip touches the surface of the plane and the manipulator moves in automatic mode under human supervision. The programs can be repeated, backward and foreword.
- End of the program
  Downfolding of the boom and outriggers. Movement to the next washing location.

5 Outlook

Advanced robotic systems like SKYWASH require vision systems for safety and efficiency. 3-d imaging, high resolution ladar systems meet all requirements of the robots in practice, and partially or fully automated manipulator motion have become feasible.

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