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The 3D-Modeller: A Multi-Purpose Vision Platform

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Abstract— **This paper deals with the concept and implementation of a multi-purpose vision platform. In robotics, numerous applications require perception. A multi-purpose vision platform suited for object recognition, cultural heritage preservation and visual servoing at the same time is missing. In this work, we draw attention to the design principles for such a vision platform. We present its implementation, the *3D-Modeller*. In specifying and combining multiple sensors, laser-range scanner, laser-stripe profiler and stereo vision, we derive the required mechanical and electrical hardware design. The concepts for synchronization and communication round off our approach. Precision and frame rate are presented. We illustrate the versatility of the 3D-Modeller by addressing four applications: 3D-modeling, exploration, tracking and object recognition. Due to its low weight and generic mechanical interface, it can be mounted on industrial robots, humanoids, or free-handed as well. The 3D-Modeller is flexibly applicable, not only in research but also in industry, especially in small batch assembly.**

I. INTRODUCTION

Perception is the process of acquiring, interpreting, selecting, and organizing sensory information yielding internal representations of the world. In robotics, there has always been a high need for perception of the environment, especially with the purpose of increasing the level of autonomy of systems. In this work we present the 3D-Modeller, a multi-sensory device for *geometric and visual perception* of the world. Common perception tasks in robotics are object modeling and recognition, visual servoing, exploration, collision avoidance, path planning, and simultaneous localization and mapping to name only a few.

In general, it is not possible to acquire a 3D model of the environment at one single measurement step (be it a laser scan or visual information) due to self-occlusion or object size. The 3D geometrical information gathered from a particular vantage point, limited by self-occlusion of the object, is actually called 2.5D information. Hence multiple 2.5D views are to be acquired in order to subsequently merge them to a single 3D model. Existing system are primarily differentiated according to the way this merging process is accomplished: On the one hand, one can acquire data from unknown positions. The different 2.5D views have to be registered based on overlapping domains (usually 20% of a view). On the other hand, one can measure the position and orientation (i.e. pose) of the sensor while sensing. There is no need for strongly overlapping views and intensive computing, thus the 3D data sets (point clouds) are readily applicable for online visualization and realtime processing.

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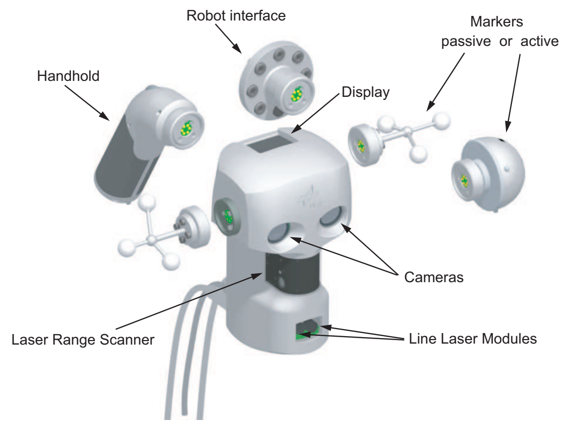


Fig. 1. 3D-Modeller Components

The 3D-Modeller follows the second approach and is next compared to similar systems.

Numerous 3D digitization systems work with turntables, e.g. Reed et al. [2]. A sensor device is precisely rotated around the object (or vice versa) in order to merge 2.5D data sets into a 3D model, using the rotational angle as a reference. However, the size of the objects to be scanned is here physically limited. It is more convenient and versatile to 3D-digitize an object similarly to using a spray can since the object can be more complex. The sensor has to be of low weight in the case of hand guidance by the user. Most of these systems use only one type of sensor assigned to specified use. In [3], [4] a laser-stripe profiler sensor (LSP) is attached to a passive manipulator for pose estimation.

In general the specifications of common systems are most limited and tailored to the desired application: there exist laser-range scanners for mobile robots, sonar proximity sensors for obstacle avoidance, cameras for pose or texture estimation, stereo cameras for 2.5D sensing, etc.. Currently, there is a strong need for perception systems that are applicable for flexible work cells in the industrial robotics domain. The pose and models of objects are to be estimated (inspection), as well as unknown objects detected and autonomously identified (exploration). This plethora of different functions calls for the development of a *highly integrated 3D sensor device*. The development of a robust flexible 3D-Modeller is then of paramount importance to current technological challenges like e.g. automation in small batch assembly (for the reduced setup costs of integrated sensing) or cultural heritage preservation (for the convenient handling and the simultaneous gathering of texture and geometric structure).

The requirements for a multi-purpose vision platform are:

1) Complementary range sensing principles to allow for data fusion and robust acquisition.
2) Extendibility/flexibility in sensing.
3) Synchronization through adaptable measurement clocks.
4) Generic mechanical interfaces and compact, light-weight design.
5) Local computational capabilities (smart sensor).
6) Extensive software suite.

The paper is organized as follows. First, design considerations in the light of the fundamental requirements stated above are elaborated. In Section III these considerations are applied correspondingly – mechanical and electronical implementation is described. Then we focus on the hardware synchronization of the sensors. In order to clarify the high practical relevance of our approach, Sec. VI illustrates different applications of the 3D-Modeller. Additionally, the performance of the 3D-Modeller by means of frame rate is described. Finally, we draw a conclusion and depict future work.

II. Design Considerations

Current commercial[1] and research vision systems [11], [12] are very specialized in one or few applications and therefore not suitable for flexible use in applied research or in SME[2]: First, various applications (hand-guided digitization, robot vision, automatic robot-workspace exploration [7], and more see Sec. VI) have different and conflictive demands concerning sensor range, view angle, lighting, precision and acquisition speed. Second, there is a need for a compact, versatile mechanical platform e.g. for fixating different pose reference sensors, a handhold for hand-guided 3D-modeling or interfaces for robot applications.

These demands can only be met by miscellaneous sensors on the same hardware platform. In the past the *DLR hand-guided multi sensor device* served for 3D object digitization. It was equipped with two miniature camera modules, a line laser module and the *DLR laser-range scanner (LRS)* [1]. Due to a concept of time-synchronization multiple sensor applications were implemented: The laser-range scanner, a texture sensor, a laser-stripe profiler (LSP) [6] and stereo vision. The multisensory concept was first presented in [5] and has potential for a wide field of applications in research and industry.

However, increasing requirements demanded an up-to-date new hardware platform: On the one hand the components (cameras) and the hand-held operation had to be improved, and on the other hand the fields of applications have extended, especially for robot vision [7]. The previous system [5] was not suitable for robot use, due to lack of couplers and large amount of cabling, synchronization clock was provided externally. A higher level of integration and increased robustness of the components was highly desirable.

The 3D-Modeller design should allow for multiple and flexible use for vision applications and research. Furthermore, the system is to support different operation modes (hand-guided, actuated, i.e. robot-controlled) and different 6D pose reference systems, demanding for a modular framework.

Light-weight design of 3D-Modeller is also required, as the system should be used in hand-held operation. The overall weight of the system should not exceed 1 kg, otherwise hand-held operation becomes quite uncomfortable when using the system for a longer time. The center of mass location should also support ergonomics.

Currently, stereo vision, laser-range scanners, and laser-stripe profilers are considered for integration. Sonar's low angular resolution and sensibility to noisy environments argues against integration, radar is not suited for low range data acquisition. Other optical principles like PMD sensors[3] or structured light approaches, e.g. using DLPs[4], are not compact enough for integration, but are concurrently evaluated for their suitability as they compensate prominent drawbacks of stereo vision on unstructured and laser approaches on specular surfaces.

Therefore, only the following sensor principles are considered for integration.

A. DLR Laser-Range Scanner

The DLR Laser-Range Scanner (LRS)[1] uses the principle of laser triangulation. The outgoing beam is generated by a laser diode (670 nm) and focused by a highly refracting micro lens. The transmitted light is dispersed diffusely on the object surface. Some of the reflected rays strike the receiver lens which focuses the light onto a position sensitive detector (PSD). Multiple object surfaces with their widely different reflection characteristics that necessitate a high dynamic adaptability of the sensor are a special challenge. For this reason the transmitted power is adapted to the optical characteristics of the measured surface for each single measurement. As the laser range scanner rotates around its longitudinal axis it can quickly gather a cross section of distance values in a range of 270 degrees. Because of its robust 2D data acquisition and the small dimensions the LRS is used as a high definition short-range sensor. The wide scan angle has advantages in robot vision.

[1]The following companies provide solutions for sensor systems:

- 3D Scanners Ltd. (http://www.3dscanners.com): Laser-stripe profiler mounted on a FAROarm
- Isra Vision AG (http://www.isravision.com): numerous industrial multi-line triangulation sensors
- Steinbichler Optotechnik GmbH (http://www.steinbichler.de/en): T-Scan, optically tracked scanner
- Polhemus (http://www.polhemus.com): Fastscan and Fastrak, hand-held LSP referenced by an electromagnetic motion tracker
- Sick AG (http://www.sick.com): various sensors mainly for industrial use and safety

[2]Small and Medium-sized Enterprises

[3]PMD: Photonic Mixer Devices

[4]DLP: Digital Light Processor

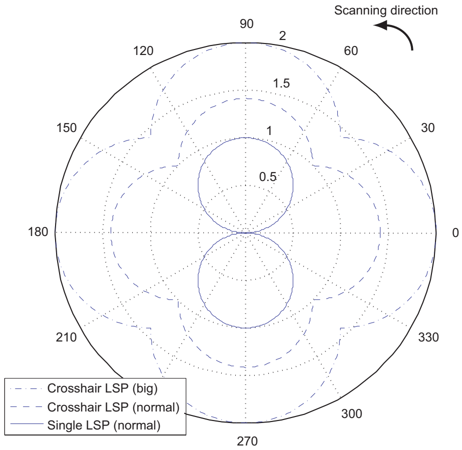


Fig. 2. Directional surface-related information gained at constant speed and range w.r.t. the object in every scanning direction (polar coordinates). The single LSP does not provide any information when sweeping it horizontally. The dual crosshair LSP gains a rather constant amount of information in every direction. Furthermore, the oblique projection of the stripe in the camera allows the extension of the laser stripe. (big) relates to a dual LSP which projection in the images encompasses the same amount of pixel columns than the single LSP.

B. Stereo Vision

Stereo Vision is very efficient for textured environments. A stereo sensor acquires large area of the environment at once. The accuracy is usually low, but the sensor covers a large range. The base distance and the focal length of the lenses of the cameras define the minimal and maximal sensing range. It is desired to cover a range from approximately $250\ mm$ up to $2000\ mm$. Optical filters are not desired, as they would make stereo processing impossible.

C. Textures

Textures should be as photo realistic as possible. Optical filters, except for infrared light cut-off, oppose this demand, and should not be used.

D. Single and Dual Crosshair Laser Stripe Profiler

The single Laser Stripe Profiler (LSP) consists of a laser beam that illuminates a stripe on a surface and a camera that records its reflection. The 3D position of different points contained both in the stripe and on the surface may be readily estimated by means of image processing algorithms followed by triangulation – provided a calibrated system [6].

It is usually said that scanning with this kind of sensor is virtually like spray can painting, particularly if the sensor is mounted on a hand-held device. However, this is not completely true, since you do not have the freedom of horizontally moving in the stripe direction while gaining data, but sweeping up-and-down the sensor. While automatically scanning by a robotic manipulator this fact constraints the movement and entails the waste of one degree of freedom (DoF).

In order to get rid of this constraint with a static LSP we use an additional laser beam that illuminates perpendicularly to the first stripe (from here *crosshair*). Due to construction-related constraints, both laser beams have to be closely placed. Since this arrangement implies an undesired reduction of the basis distances between each laser beam and the camera, we opt for using the second camera of the 3D-Modeller in order each of the cameras to perform single LSP scanning each with their farthest laser stripe (see Fig. 4(a)). We call this configuration *dual crosshair LSP*.

So the addition of a second miniaturized laser beam implies: *1)* the release of a scanning movement constraint, *2)* the increment of surface-related information gained in every direction (Fig.2), and *3)* the possibility to duplicate the sensing rate, since both cameras and laser beams may be triggered in a complementary way at highest speed and limited shutter time.

Robust image processing supports the segmentation of the laser-stripe without the need of optical filtering. The LSP delivers close to mid-range distance measurement.

TABLE I
TECHNICAL DATA OF THE 3D-MODELLER'S SENSOR COMPONENTS

Sensor	Laser-range scanner	Dual LSP	Stereo Camera Sensor
Principle	triangulation	image processing and triangulation	stereo vision
Range $[mm]$	$50 - 300$	$150 - 500$	$250 - 2000$
Accuracy $[mm]$	$0.1 - 2.5$	$0.3 - 2.5$	$2 - 50$
Base distance $[mm]$	20	103	50
Field of view	270°	58°(f'=6mm) 30°(f'=12mm)	58°x 44° 30°x 22°

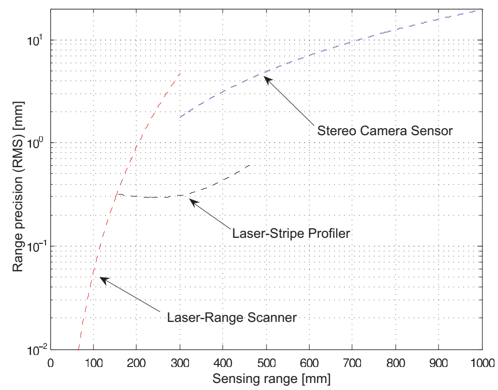
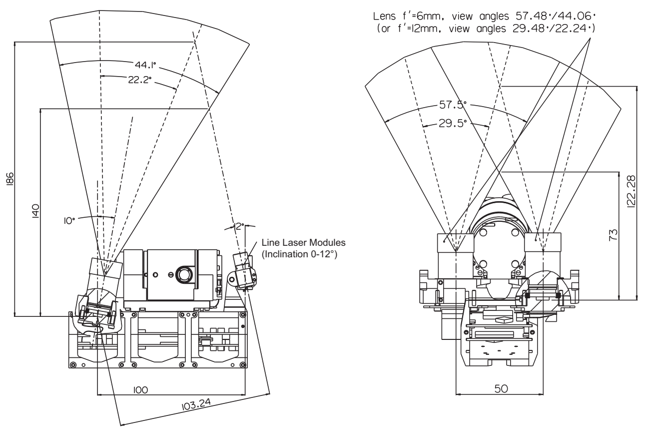


Fig. 3. Range precision of the different sensors. The LRS has smallest range but highest precision, suiting it for hand-guided 3D modeling. The LSP covers the mid-range, most applicable for exploration and 3D modeling using robots. Stereo ranges up to 2m, the relatively low precision is compensated by its large field of view (see Fig. 4(b)).

E. Specifications

The design considerations lead to the following technical specifications of the individual sensors integrated in the 3D-Modeller. Tab. I summarizes the measurement ranges as well as the fields of view. Fig. 3 quantifies the range precision of the sensor, considering geometry and 0.5 pixel noise RMS for LSP and SCS and 12Bit resolution for LRS.



(a) side view: laser-stripe profiler (b) top view: stereo camera sensor

Fig. 4. 3D-Modeller: Field of view and geometric arrangement of the optical components

III. Hardware Implementation

In this section the hardware components and the technical data are described. The elaborated system architecture is shown in Fig. 5. The usability and positions of the sensors were tested and developed on 3D-Modeller variant using optical rails Fig. 7. Design considerations and practical evaluations lead to the following mechanical and electronical hardware layouts.

A. Mechanics

The new 3D-Modeller is designed to arrange all components as compactly as possible with good usability and robustness at the same time. The total weight of the system is $850\,\mathrm{g}$, which suits it for hand-held operation.
It is equipped with three equal easy-to-connect free-of-play couplers. They contain six electrical contacts for active markers[5] and the handhold. The housing is coated EMC-compatible. The 3D-Modeller consists of the following components (Fig.1):

1) DLR Laser-Range Scanner: Except for the synchronization the LRS is not integrated in the FireWire communication nor controlled by the 3D-Modeller electronics.

2) Cameras: Two FireWire cameras from AVT[6] are integrated for stereo vision algorithms [10], texture-mapping and in combination with the line-laser modules as LSP [6]. Allowing for compact design, the cameras are embedded in the 3D-Modeller framework without their original housing and with custom lenses[7]. There are two different adaptable lenses ($f = 6\,mm$ or $f = 12\,mm$). The base distance between cameras is $50\,mm$, derived from base line optimizations, which is a trade-off of between perspective difference and range precision.

3) Laser modules: As LSP one or two line-laser modules with 60 degrees opening angle are used. Due to eye-safety as well as optimal camera sensitivity at that wavelength the laser diodes present $635\,nm$. Because of space restrictions the laser modules are a proprietary development. The laser modules are separately inclinable for different measurement ranges (Fig. 4).

4) Handhold: The handhold is designed for easy use and good ergonomics in hand-held operation. It contains buttons and scrolling wheel of an off-the-shelf USB computer mouse. The handhold is hot-pluggable to the embedded PC Board (see Sec. III-B).

5) Tracking Markers: Optionally two passive or active markers for tracking can be coupled. Changing them does not demand recalibration because of the free-of-play couplers. The arrangement of the markers is optimized both for marker visibility and tracking accuracy.

6) Mechanical Connector: The mechanical coupling on the rear side of the 3D-Modeller is suitable to plug the handhold as well as to connect it to a robotic manipulator, allowing the system to be plug-'n'-play able.

B. Electronics

The concept of the 3D-Modeller electronics was driven by intention of minimizing the required amount of cables. Even though the system is designed as a smart sensor (see Fig. 5), not all processing can be done locally in the 3D-Modeller, therefore an external sensor-PC is needed for computation. Cabling between these systems should be kept minimal. FireWire was chosen as a suitable bus medium for this purpose as it allows for communication and power transmission.

1) Embedded PC and Peripheral Connection: The embedded PC[8] is the core element of the electronic concept. The module is equipped in addition to SDRAM with flash memory to locally boot from and store the operating system and applications. This embedded PC controls the synchronous cooperation of all sensor components and manages the communication with the sensor-PC. The embedded PC is mounted on a mainboard which carries all electronic parts needed for the connection of the peripheral components and interfaces. The mainboard also provides the electrical power for the embedded PC and the peripherals. The mainboard is carried out in flex-rigid technology so that it can be folded into the housing of the 3D-Modeller and connect all components without any jacks.

2) IEEE1394 Interface: A IEEE1394b[9] 3-port physical layer controller and a link layer controller are implemented on the mainboard. A chipset from Texas Instruments is used, wired to the embedded PC through its PCI-Interface. The IEEE1394 Interface has several duties: Two of the FireWire ports connect the IEEE1394a-cameras to the system. The communication with the sensor-PC is done via the remaining FireWire port, which is used as fast IEEE1394b port.

[5]Optical tracking system supports passive retro-reflective markers as well as infrared emitting diodes, so-called active markers

[6]Allied Vision Technologies GmbH, Taschenweg 2A, 07646 Stadtroda, Germany, http://www.alliedvisiontec.com.

[7]For use with Sony NF-mount lenses

[8]Kontron X-board PXA, http://www.kontron.com

[9]FireWire and IEEE1394 are concurrently used throughout this paper. The appendix b denotes the standard allowing for data transfer up to 800Mb/s

3) Synchronization Interface: All components of the 3D-Modeller, the cameras, the line laser modules, the laser-range scanner and the active markers have to work synchronously among each other and with the position reference sensor in order to allow reasonable sensor data fusion. For this purpose a synchronization unit is implemented on the mainboard.

4) Laser Modules Drivers: The two line laser modules consist of laser diodes which can be operated continuously or pulsed. In pulsed operation mode the two laser modules are toggled alternatively by the video frame clock. So the laser stripe can be separated by comparing subsequent video frames. The clock synchronization and the power control of the line laser modules are done on the mainboard.

5) Interface to Active Markers: The 3D-Modeller can be equipped with active markers that are detected by tracking cameras of the 6D pose reference system. The mainboard provides the clock signal and power needed for the active markers.

6) User Interface: The user interface consists of an 1.8” color TFT display with a resolution of 160x128 pixels, direct driven by the XScale on chip LCD controller and an USB root hub. For user input a mouse like button and scroll wheel device, embedded in the handhold, is connected to this USB port in the hand-guided mode. Also, an USB hub to easily connect other USB devices - e.g. a keyboard or a mouse for debugging purposes - is integrated in the handhold.

7) Debugging Interface: An ethernet port and a serial port are usable for setting-up and debugging purposes, e.g. for programming the flash memory of the embedded PC.

8) Power Supply: All components of the 3D-Modeller except the laser-range scanner are powered through the IEEE1394 interface from the sensor-PC. As the supply voltage of the IEEE1394 interface can vary in a wide range, the mainboard must provide voltage control for all needed supply voltages of the embedded PC and its own components. In order to achieve this with a minimum of waste heat, high efficient switching controllers have been used.

9) Laser-Range Scanner: Due to its complexity the laser-range scanner is the only component of the 3D-Modeller that is not fully integrated into the IEEE1394 communication concept yet. For historic reasons the LRS transfers its data to the sensor-PC directly via a CAN-Interface. But nevertheless it is integrated into the global synchronization concept through a separate clock wire. So the rotation of the LRS can be synchronized to the frame sync of the video cameras with any phasing.

IV. COMMUNICATION

The communication concept of the 3D-Modeller brings together the different control tasks. These tasks are to control the laser modules, active markers and the synchronization signal generator, to manage a LCD display and an input device as user interface and to establish an interconnection from the 3D-Modeller to the sensor-PC. In normal operation mode, a low pin count interface using FireWire for both data transfer and power supply is the only connection between the device and the sensor-PC. Using FireWire allows the power

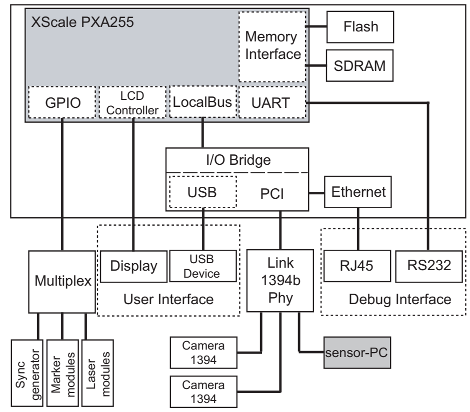


Fig. 5. Communication concept

supply of the device over the same standardized cable and connector as data flows. Also, the specification of FireWire as data link permits a straightforward integration of the two FireWire cameras, communicating via IIDC protocol to the sensor-PC’s software suite. A design guideline for the specified processing system is to use standard hardware and software components where applicable to manage complexity and to reduce design cycle time.

A Linux standard distribution for ARM processors was chosen as operating system. It runs mostly out of the box, only a few adaptations and the device drivers for the sensor interface hardware were necessary to implement. The Linux operating system is bootable from the flash memory and needs no connection to a host computer for start-up. Once running, it uses the IP over FireWire protocol to establish a standard network connection to the sensor-PC.

The stringent adherence to standard software components allows using of well known libraries, interfaces, and services, e.g. Qt embedded for graphical user interface, RPC-based communication services, and simple moving of functionality from sensor-PC to the 3D-Modeller on board. Communication concept supports easy implementation and adaption of required and designated software functionality and represents a rapid prototyping platform for the embedded software.

V. HARDWARE SYNCHRONIZATION

Hardware synchronization is crucial for systems including more than one sensor. It is most desirable to have all sensors acquiring data at the same time, such that e.g. fusion of pose and image data is possible. In previous work [5], the hardware synchronization signal as shown in Fig. 6 was generated using analog video cameras. Digital FireWire cameras do usually not provide such a signal, but can be externally triggered. Therefore, we decided for a flexible strategy to supply all sensors with a common clock signal.
The synchronization unit Fig. 5 can work in two different ways. Either it generates a video clock signal internally and provides it to all connected components. The timing parameters of the video sync signal are freely programmable by software through the embedded PC. In the second mode, the synchronization unit receives an external video signal from

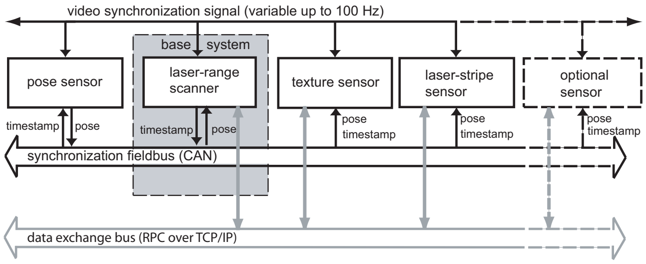


Fig. 6. Synchronization concept: hardware level (video), software level (CAN), data exchange level (RPC)

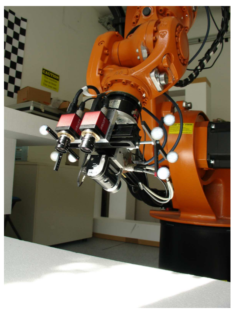


Fig. 7. 3D-Modeller components mounted on a robot to design the final system. Sensors are mounted on optical rails to allow for variable arrangement. This 3D-Modeller variant is used for evaluation of new sensing principles, e.g. based on PMD or DLP technology

Fig. 8. 3D-Modeller as vision system for the DLR humanoid robot *JUSTIN*. The system is actuated with a two DoF pan-tilt unit to allow for head movements. Recognition, and pose estimation, as well as two-handed manipulation of known objects is demonstrated

another source (e.g. an analog camera or an external pose sensor), for example the tracking system, and synchronize the cameras and line laser modules on this external clock.
A single clock signal is not sufficient to fuse information on- and off-line. A common practice is to use timestamps to tag data sets uniquely. Therefore, a two level strategy was designed:
First of all, a *hardware synchronization* is needed to allow for synchronous measurements. This is realized by supplying all sensors with a common video synchronization pulse, as displayed in Fig. 6.
Secondly, data sets need to be merged. This is solved by using the CAN bus as the master *software synchronization bus* for exchanging timestamps and poses.

Integration of new sensors is easily done, therefore evaluation and verification of sensor principles using the 3D-Modeller variant in Fig. 7 is an additional *novelty* of the approach and of importance for future developments.

VI. Applications

The 3D-Modeller is due to its versatility widely applicable in robotics. Exemplarily, the following applications

- online surface triangulation [8],
- robot work cell and configuration space exploration [7],
- texture-based real-time tracking of objects [13], and
- vision system for the DLR humanoid robot system JUSTIN [14]

(a) Hand-held configuration (b) Triangulated and textured 3D model of bust

Fig. 9. The 3D-Modeller applied for hand-held photo-realistic 3D modeling

are presented.
The 3D frame rate is 25 Hz for LSP (212 points per line) and LRS (300 points per line). Stereo processing using SGM [10] runs at 1 Hz with 290x390 range values per data set.
The two operational modes: *hand-held* and *actuated operation* are described in detail below.

a) Hand-held Operation: The handhold with input buttons is attached to the 3D-Modeller (Fig.9(a)), a graphic display provides visual feedback. Direct menu-based operation is possible. Current pose sensors are an optical tracking system[10] and a passive measurement arm for higher accuracy[11].

b) Actuated Operation: For robot vision applications (Fig.7 and Fig.8) the 3D-Modeller is attached to an actuated system, e.g. an industrial robot, the DLR light-weight robot, or a pan-tilt unit, instead of the detachable handhold.
The extensive software suite developed for the 3D-Modeller is presented by modeling of a cultural heritage object, i.e. a bust, in the accompanying video. Here, the 3D-Modeller is used for automatic modeling of an wooden block in the SME exploration cell.

A. Online surface triangulation

Here, the 3D-Modeller is applied for 3D modeling of small objects. The system is used hand-guided, the global pose is measured using optical tracking. Fig. 9(b) was acquired using the 3D-Modeller‘s LSP. The human operator directs the system over the objects surface. The online triangulation algorithm [8] generates a 3D surface mesh of the object. Concurrently, texture information is acquired and mapped on the surface. In future, mesh fusion using multiple sensors as well as automatic inspection with the 3D-Modeller mounted on a robot will be applied.

B. Exploration

In case an articulated robot is installed in partially known work cells [9], exploration to gain knowledge of its surroundings is necessary. This occurs often in service robotic environments as well as in flexible work cells. In Fig. 10 a

[10]Advanced Realtime Tracking (ART) GmbH, Am Öferl 6, 82362 Weilheim, Germany, http://www.ar-tracking.de
[11]FARO Technologies Inc., 125 Technology Park, Lake Mary, FL 32746, http://www.faro.com

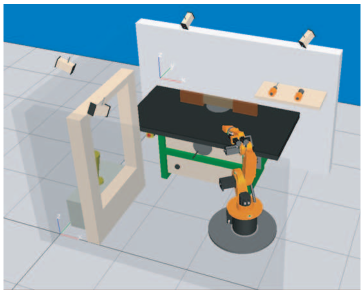


Fig. 10. Scene was designed according to a real wood working cell. The robot (standard industrial robot, type Kuka KR16) is up to explore this environment. The 3D-Modeller is mounted on the robot, and the robot pose is timely synchronized according to Fig. 6.

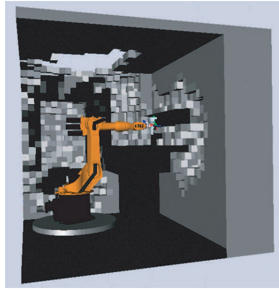


Fig. 11. Explored scene after using the 3D-Modeller in Fig. 7. Grey blocks define unknown areas, black blocks are known obstacles. At this stage, approximately 80% of the configuration space in known

typical workcell for a wood-working application is modeled. Initially, the work cell is only partially known, the robot has to gain knowledge about its configuration space. The 3D-Modeller is mounted on the robot, the pose is measured using optical tracking (in case manual scanning is necessary) and the robot kinematics. Fig. 11 shows results of such an exploration. Sensor results are inferred in a occupancy grid representation (see Fig. 11), LRS and LSP are used for exploration. Simulation and real robot experiments are possible. In the case of simulation, noise models of the sensor are used to integrate sensings as realistic as possible to provide thorough simulation results. Fig. 7 shows a implementation on the real robot system.

C. Tracking

The 3D-Modeller can also be used for tracking objects [13]. Initially, a textured 3D point cloud is acquired using the system. Then, these objects can be tracked using only one camera of the 3D-Modeller in all 6 DoF.

D. Humanoid Robot

In this application, the 3D-Modeller is used as vision system for object recognition (see Fig. 8). The 3D-Modeller is mounted on a Pan-Tilt unit which serves as actuated neck. The system is calibrated on the shoulder frame of the robot. Stereo data is acquired, which is processed using the SGM stereo algorithm [10] to analyze table top scenes. Glasses, bottles and other known objects are placed in front of the humanoid system. Object recognition and pose estimation is performed, enabling the robot to differentiate between objects, e.g. wine glass and water bottle. Path-planning and manipulation is performed to open the bottle or pour water into glasses.

VII. Conclusion

In this paper, we present the design considerations for a multi-purpose vision platform. In research and in industry such a system is missing, therefore the considerations led to the implementation of the 3D-Modeller. Mechanical, electrical and synchronization concepts are elaborated and implemented. The versatility of this system is shown by pointing out four applications: 3D modeling, work cell exploration, tracking and visual servoing, as well as object recognition for a humanoid robot. In 3D modeling and exploration multiple sensors are fused. Extending fusion also to e.g. object recognition, are future fields of interest. Future work will include experiments in real robot work cells on different robot platforms. Additionally, other sensing principles are evaluated for robustness as well as suitability for integration in the mechatronic concept of the 3D-Modeller. Furthermore, modeling of objects, detection of humans in work cells and collision scene analysis are applications for the system.

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