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BiBiars - A Robotic System for Realising Cooperative Behaviours of Multiple Sensor and Actuator Agents

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1 Introduction

In the Technical Computer Science research group of the Faculty of Technology of University of Bielefeld, a two-arm robotic system *BiBiars (Bielefeld Biarm System)* is being developed. The general goal of this system is to model and realise human sensorimotor skills for performing manipulation and assembly tasks. This requires a comprehensive set of actuators and sensors, which perform functions similar to those of the human arms, hands and perception channels (i.e. vision, touch, acoustics). To organise the interaction of the complex sensor and control subsystems, sensor data cannot be acquired and processed independently of the movements of the actuators. It is mandatory that both be performed simultaneously and in view of the task to be performed the actuators will work on. This is the reason, therefore, that the three major components of an intelligent robot system, i.e. perception, planning and control, are considered synergetically instead of separately, so that complex, cooperative behaviours involving sensors and actuators can be realised.

The development of the *BiBiars* system is closely linked to the on-going interdisciplinary research program of the project SFB 360 "Situated Artificial Communicators" at the University of Bielefeld. The SFB 360 is aimed at the discovery of linguistic and cognitive characteristics of human intelligence for communication purposes. The results from the project are to be transferred to several application domains, one of which is the emulation of human cognitive principles for information processing systems, [SFB93]. The primary example for demonstrating the usefulness of these newly developed techniques is the robot system mentioned above, whose numerous sensor and actuator modules can be used as an ideal test-bed for investigating the interaction between human "natural" communicators and machine systems in the real-world. Furthermore it will be used for validating the complete concept by integrating different linguistic and cognitive components. As a basic scenario, the assembly procedure of a toy aircraft (constructed with "Baufix" parts) was selected, Fig. 1. A number of separate parts must be recognised, manipulated and built together to construct the model aircraft. Within the framework of the SFB, in each of these steps, a human communicator instructs the robot, which implies that the interaction between them plays an important role in the whole process. Nevertheless, the aim of our work is to fully automate the process of multi-sensor supported assembly by gradually enabling the robot/sensor system to carry out the individual steps in a more and more autonomous fashion. A

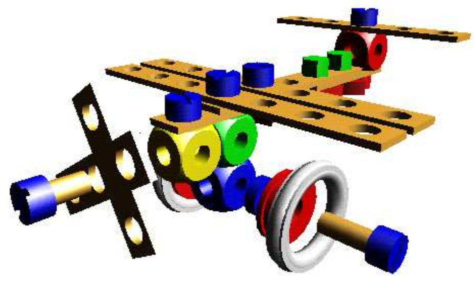


Figure 1: The assembly of a toy aircraft

fully automatic assembly, however, presupposes a precise task description; unfortunately, not much work has been done in this potentially very fruitful area of robotics research.

2 System Overview

The *BiBiars* system has been designed to fulfill the demands of flexible "fixture-less" assembly. Its hardware configuration enables a high-speed of the (partly massive) data flows inside the system and the possibility for adding further actuator and sensor components. The structure of the software was so chosen as to ensure the compatibility of different program modules to make the whole system work without collisions and deadlocks. Robot control architecture combines the functional modules of perception, planning, control and the human interface and cooperate both hardware and software components on each abstraction level.

2.1 Hardware Configuration

The physical set-up of *BiBiars* system consists of the following components:

Main actuators: Two 6 d.o.f. PUMA-260 manipulators are installed overhead on a stationary assembly cell, possessing common work space[1], Fig. 2. On each wrist of the manipulator, a pneumatic jaw-gripper with integrated force/torque sensor and colour vision system is mounted.

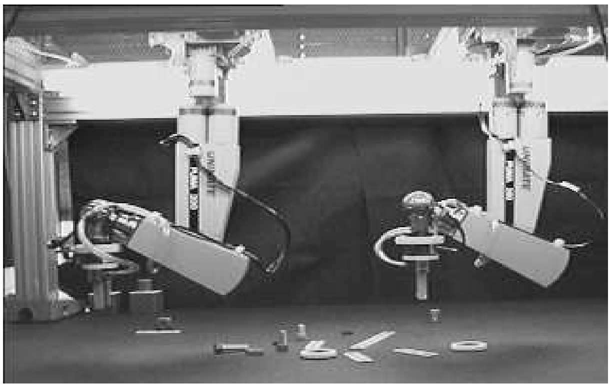


Figure 2: Two-arm configuration in a flexible assembly cell

Computer system: A multi-computer system consists of robot controllers, UNIX-workstations and a VME-bus system for data acquisition and actuator control, Fig. 3.

Sensor systems:

- Two 6 d.o.f. force-torque sensors are installed on the robots' wrists.
- Two miniature colour cameras, each of them is mounted next to the robot gripper.
- Two 3-CCD RGB cameras in a stereo setup for building 3D world models.
- Several compact cameras with controllable zoom, auto-focus and aperture serve as active vision agents.

Other actuators:

- A small mobile gripper system "Khepera" serves as a transportation agent in the assembly area in cooperation with two robot manipulators.
- In the future, several small robot arms with 2 d.o.f. will be installed around the assembly area, carrying the compact cameras to supervise the assembly process actively.

Peripherals: Six d.o.f. space mice are connected to the workstation for teaching robot motion and for tele-operation.

[1] A similar two-arm configuration was used in the KAMRO system, [HR91].

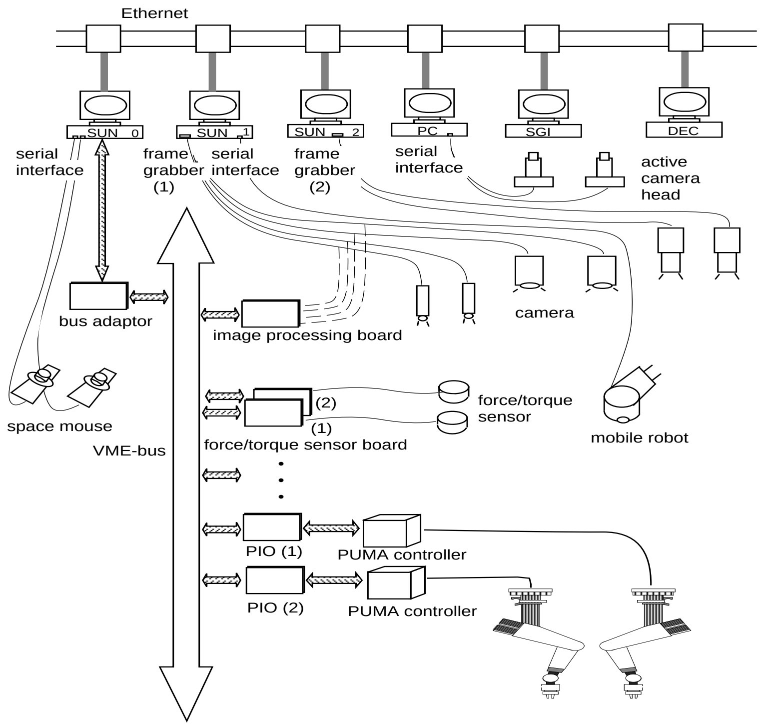


Figure 3: Hardware configuration of BiBiars system

2.2 Software Organisation

On the lowest level, the main actuators of the *BiBiars* system are controlled by Multi-RCCL/RCI (*Robot Control C Library/Real-time Control Interface*), see [LH89]. With this library, the two robots can be synchronised and can run in interpolation cycles as short as 10 ms. The high-speed communication between the sensor systems and the robot task-level control is realised using parallel buses.

Motions of two robot manipulators are controlled by the main control program, which runs on one UNIX-workstation. Sensor processing, control of other actuators and peripherals, and simulation programs communicate with the main control program through sockets or serial interface connection. The generated motion steps of the two manipulators are further sent to the "trajectory generator", which computes the exact joint values for each control cycle. Through the bus adaptor, joint data are further transferred to the joint controllers of the two PUMA-robots. See Fig. 4.

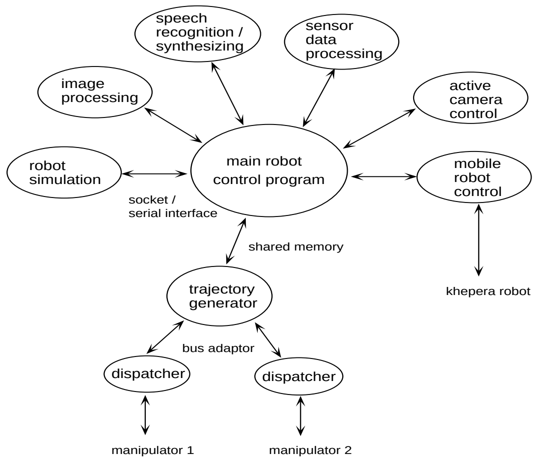


Figure 4: The software organisation of BiBiars system

2.3 Control Architecture

In order to fulfill the main objective described in section 1, the *BiBiars* system adopts an interactive hierarchical architecture[2], Fig. 5. A *Human user* may intervene on each level of the task planning, motion planning and plan execution as well as during the modelling of the knowledge base.

On the task planning level, an assembly task of the toy aircraft or an aggregate of which is decomposed into a sequence of elementary motions, e.g. gross motion, grasping, inserting, screwing, etc. The final decision of the motion sequence depends on the instructions of the human user as well as the automatically generated plan. On the next "motion planning" level, an elementary motion is transformed into a geometrical path which is free of both collisions with obstacles and singularities. The human user can apply his intuitive knowledge to interactively give the motion planner hints. The planning system should not only be able to understand the human instructions, but also to learn from the human guidance and improve its planning abilities gradually. Based on the geometrical path, the component "plan execution" considers the robot kinematics and dynamic constraints, the on-line sensor information, and the human instructions. It then generates the joint values for the PUMA-controllers. On this level, the development of sensor-based motion will be the key work.

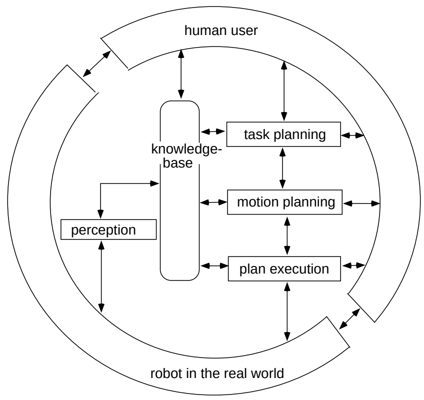


Figure 5: System control architecture

3 Current Work

Up to now, several experiments with *BiBiars* have been successfully carried out:

Visual servoing: The visual feedback from the hand-camera is coupled to the motion process of manipulators. A novel approach for calibrating a "self-viewing" hand-camera (Fig. 6 (a)) is under development. Based on this approach, grasping operation guided by the hand-camera or through a tele-operation mode can be easily realised.

Compliant motion: By on-line evaluating the force-torque sensors on the wrist of the robots, the arm-stiffness can be adjusted for complex operations. This experiment is a starting point for two cooperating arms.

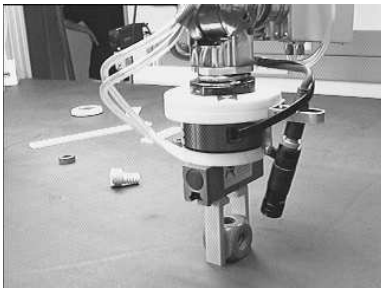
Master-slave movement: Any one of the two robot arms can be used as a master and directly moved by a human user, the other arm then moves as a slave (mimics the movements of the master synchronously). One robot arm can be set to "zero-gravity" status, so that a human user can move it easily. This function is a variation of tele-robotics applications.

Screwing operation with two robot arms: The cooperation of the two arms enables the precise screwing, e.g. of a wood screw and nut, Fig. 6 (b). The two robot arms grasp at the same time and then move to a selected site. This first step for the final construction of the Baufix-aircraft can be now performed if the position of the components to be screwed together is exactly known. Elimination of uncertainties, error recovery, and the necessary sensor-based operations are being extensively investigated.

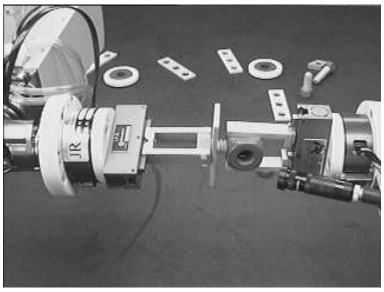
4 Future Research Areas

Future work with *BiBiars* can be summarised as follows:

[2]The pure hierarchical control architecture is used in [Zha95].



(a) Hand-camera guided grasping



(b) Screwing operation

Figure 6: Two experiment examples

Human-robot communication: *BiBiars* will integrate the research results of linguistic description, intention detection, speech recognition, etc. from different partners within the SFB. The robot system should be able to understand not only the simple verbal instructions, but also to detect the context related ambiguity with profound linguistic background and, if in doubt, to ask for the next instruction in natural language.

Force control: The compliant and cooperative motion of the two arms is intended to be achieved by developing adaptive hybrid control algorithms based on the torque/force sensors as well as vision information. With such a force control mechanism, complex manipulations like joining, screwing, carrying a common object can be precisely done under normal environmental conditions.

Multisensor fusion: Information from different cameras, images at the different points in time and data from other non-visual sensors are integrated for dynamic world modelling. Both statistical and fuzzy-set based approaches will be investigated.

Vision-guided manipulation: Through “filtering” of information from hand-cameras, active cameras and the stereo-vision system, useful data will be integrated for guiding the on-line robot motion. Calibrated as well as uncalibrated approaches will be further developed for manipulation tasks.

Active vision: Active vision agents are positioned at the optimal observation viewpoints and supplied automatically with suitable illumination and other optical parameters. Computation of optical flow from complex image sequences will be the main tool for gaining dynamic visual data.

Coordination of multi-agents: Concepts and control architectures are to be developed for delegating distributed sensor and actuator agents to fulfill common tasks. Modularity, flexibility and optimality are the main criteria to evaluate different approaches.

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