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VolksBot - A Construction Kit for Multi-purpose Robot Prototyping

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1. Introduction

The development of mobile robotic systems is a demanding task regarding its complexity, required resources and skills in multiple fields such as software development, artificial intelligence, mechanical design, electrical engineering, signal processing, sensor technology or control theory. This holds true particularly for soccer playing robots, where additional aspects like high dynamics, cooperation and high physical stress have to be dealt with. In robot competitions such as RoboCup, additional skills in the domains of team, project and knowledge management are of importance.

Having participated in RoboCup Middle Size League since 1998, Fraunhofer IAIS and FH Bonn-Rhein-Sieg have developed six generations of different mobile robot platforms. Like many other teams we faced several difficulties. These systems were often monolithic, highly integrated prototypes that took a long time to develop, they were high in costs and hard to maintain. Also robots tend to grow old quite quickly when used frequently, put under high physical stress or when the robot's hardware simply gets outdated after a few years. Fluctuation of people combined with long training times for new team members and loss of knowledge are other difficulties we frequently experienced.

In this chapter, we present methodologies to cope with such diverse difficulties by using modular, component-oriented design approaches for mobile robot prototyping. The approach should enable developers to focus on their specific domain, still being able to have a clear understanding of the entire system by help of different levels of abstraction and well defined interfaces to hardware and software modules. Furthermore, (re-)usability should be maximized by having well documented system components of manageable size.

A concrete implementation of such an approach will be presented by way of the VolksBot concept (Wisspeintner et al. 2005). This project was started in September 2002 with the goal to create a multi-purpose, cost-effective and robust robot construction kit for advanced research, education as well as for application oriented prototyping.

Originally being applied to indoor scenarios like RoboCup Middle Size, since 2004 the concept was extended to fulfil the demands of more real-life applications like outdoor use, higher payload, velocity or scalability in morphology and hardware configuration of the platform.

Source: Robotic Soccer, Book edited by: Pedro Lima, ISBN 978-3-902613-21-9,
 pp. 598, December 2007, Itech Education and Publishing, Vienna, Austria

Component-based prototyping concepts have been applied successfully in developing robots mainly for indoor applications or in the field of education some of them using a construction kit. The advantages of using a kit are quite obvious as this usually reduces development time and costs by fostering reuse of existing components. On the other hand, universal modules are not specialized, thus one loses in performance. There is always a trade off between the general applicability and the performance in modular approaches. Significant work has been done in the field of rapid prototyping of robots in the past. (Won et al., 2000) have shown that rapid prototyping is a viable method to create articulated structures of robotic systems. (Reshko et al., 2002) have illustrated methods to quickly produce prototypes of desired quality in considerably small time by using ready-made components such as servo motors, sensors, plastics parts and Lego blocks.

Examples for robot construction kits mainly used for education and edutainment are Lego Mindstorms (Ferrari et al., 2001), Fischertechnik Mobile Robots (Fischertechnik), Tetrix (Enderle et al., 2000) or the CubeSystem (Birk, 2004). Though aspects of modularity are addressed well by these systems, they are limited in onboard computational power and focus on miniaturization and low-cost hardware. As a consequence the aspect of application-oriented rapid prototyping of fully autonomous robots is hardly provided in these approaches and on-board perception is limited. On the other side, several robot platforms with higher complexity in sensors, actuators and higher processing power are usually specialized for a certain field of application or a certain scenario (Evolution Robotics) (K-Team) (ActiveMedia). Besides, many of such systems are specific in their morphology, their mechanics and hardware does not follow a construction kit approach. One exception is presented in the MoRob project with a focus on educational robotics (Gerecke et al., 2004).

This chapter structures as follows. After having motivated the use of such component-based construction-kit approaches, we summarize the resulting design goals. Then we derive concrete design criteria from these goals and show the interrelation between them. In the next section we show how applying these criteria have lead to a component pool in hardware, software and mechanics forming the VolksBot robot construction kit. In the following we illustrate how we used these components for prototyping of various robot platforms for different applications ranging from robot soccer to autonomous transportation, robot rescue and service robotics. The chapter ends with a conclusion and an outlook on future work.

2. Modular Design

With the aim to develop an approach for multi-purpose robot prototyping, several design goals in hardware and software can be defined which are illustrated in the following. The goals are labeled in brackets (G1-G12) for later reference.

One of the major goals is to reduce costs, time and resources needed to conduct mobile robotic projects (G1). This should motivate more research groups from various backgrounds to start or continue activities related to mobile robotics in education and research. Also it should help to generate interest and open the market for new robot applications with more companies being willing to invest in robot technology and prototyping projects.

The complexity of recent robotic systems grows constantly with the complexity of the applications they are designed for. Modern mobile robots usually require a variety of

different sensors, actuators and controllers but also algorithms and methods for signal processing, sensor data fusion, planning, localization, navigation and control of the robot, especially when being used in real world environments. The approach therefore should support the developers to manage this constantly growing system complexity (G2).

The system should allow the exchange and reuse of existing components in hardware and software (G3). For example it should not be necessary to start a system development from scratch every time a new robot needs to be built.

Also, an already existing robot platform should be easily reconfigurable and extendable by use of these hardware and software components (G4).

Reconfiguration and maintenance of the platform should be efficient and should not require special tools or machinery (G5). This way, developers are independent from having access to special facilities and experts and have more time to spend on research and development.

Often, groups already have worked in the domain of mobile robotics in the past. Therefore they should be able to efficiently integrate already existing technology into the system (G6).

The approach should help to foster the exchange and distribution of knowledge (G7). The design of such systems usually requires the interplay of many different individual skills which are distributed over a group or multiple groups of people.

The mechanics of the kit should be robust and scalable and allow for high payloads and high dynamics (G8).

To offer a wide range of possible applications, the kit should allow for diverse robot variants for different scenarios (G9).

The training periods for new users should be short (G10), so that they can produce results more quickly.

Synergies should be achieved by help of standardization (G11). Setting standards in mobile robotics projects to foster synergy between different research groups is an active research topic (OMG). Recently, Microsoft has introduced Robotics Studio (Microsoft) to foster exchange and synergy on the software level. The RoboCup 4-legged league has given excellent examples how using a standardized platform in combination with consequent code sharing can accelerate research and development in this domain.

Here is a summarization of the design goals:

- G1. Reduce costs, time and resources in mobile robotics projects
- G2. Be able to manage system complexity
- G3. Allow exchange and reuse of existing components
- G4. Allow easy reconfiguration and extension of the systems
- G5. Allow simple and efficient maintenance
- G6. Allow efficient integration of existing technology
- G7. Foster exchange of knowledge
- G8. Robust and scalable mechanical design
- G9. Allow for a wide range of robot variants and applications
- G10. Allow for short training periods of new users
- G11. Achieve synergies by standardization

From these goals, we derived various design criteria for the construction kit in hardware, software and mechanics.

To reduce the costs and efforts for manufacturing and design of special components, standardized, available industrial components should be used if applicable (D1).
To keep the system complexity low and to be able to maintain the construction kit, the amount of components should be kept minimal, yet offering a high grade of reconfigurability. (D2)
Components should posses a fine granularity and should be universal to ensure reuse (D3).
A comprehensive mechanical component library should be built up using standard CAD software tools (D4). Before actually building the robot, a complete design and simulation should be done in CAD avoiding major design errors and allowing fast iterations during the design phase.
The same holds true for software development, where a software library should be built up using state-of-the-art software development standards regarding architecture, documentation and coding conventions (D5).
Besides development of own software, existing software and frameworks should be used and integrated into the approach (D6).
When developing a component in hardware or software, documentation standards for developers and users should be applied (D7).
Different layers of abstraction should be provided during system integration and development in hardware and software (D8). This should help to reduce training times and allow a wide range of people from different technical background to work with the system.
Clear interface definitions for hardware and software components have to be defined and maintained (D9).
Furthermore to keep the number of possible variants high and the system complexity low, dependencies between components should be avoided (D10).

Here is a summarization of the design criteria:

- D1. Extensive use of standardized, industrial components
- D2. Small number of different components with high reconfigurability
- D3. Fine granularity of modules to ensure reuse
- D4. Build up mechanical component library in CAD
- D5. Build up software library with documentation and coding standards
- D6. Use and integrate existing software and frameworks
- D7. Apply documentation standards for components
- D8. Introduce multiple abstraction layers
- D9. Clear interface definitions for hardware and software components
- D10. Avoid dependencies between components

The following table gives an overview of the relations between the design goals and the design criteria mentioned above:

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
G1	X	X	X	X	X	X				X
G2		X						X	X	X
G3	X	X	X		X	X			X	X
G4	X	X	X	X	X			X	X	X
G5	X	X		X			X			X
G6	X					X			X	X
G7					X	X	X	X	X	X
G8	X		X							
G9			X							X
G10		X			X	X	X	X	X	X
G11	X					X				

Table 1. Relations between design goals and design criteria

3. Component Pool

Having applied the design criteria mentioned in the previous section, a set of standard components in mechanics, hardware and software has been developed to form the VolksBot construction kit. Fig. 1 shows how different components were assembled to form the first version of a VolksBot Indoor robot. Here, a differential drive unit, a catadioptric vision system, batteries, a control notebook and a motor controller are mounted on the central base frame consisting of X-beams. A modular software framework is used for the robot control.



Fig.1. The first VolksBot Indoor variant

3.1 Mechanics

All mechanical components are modeled in SolidWorks (SolidWorks), a commercial CAD software tool, building up a common component library in CAD. This library helps to reduce mechanical design efforts enormously as new robot variants are designed mostly by recombination and adaptation of existing parts.

3.1.1 Frame elements

In accordance to the design criteria listed in the last chapter, we decided to use standard aluminum machine construction extrusions (X-beams) of 20mm width and proper connectors to build up the robot's main frame. They provide high rigidity, are light weight and offer a variety of different connections.

Size and shape of the robot's main frame can be adapted individually to the needs by simple mechanical processing, i.e. cutting and screwing. By using pluggable t-nut-connectors, it is possible to establish new connections without having to decompose the frame. All sides of the X-beams can be used to connect to additional elements. In our design, all hardware components are connected to the main-frame. Therefore only geometrical dependencies between the component and the main-frame occur, not between the components themselves. All components like batteries, motor controller, drive units and sensors are connected to a rectangular single layered main frame. With this, the repositioning of components and scaling of the platform can be easily done.

3.1.2 Drive system

Fig.2 illustrates the frame construction for the first VolksBot Indoor versions with differential and holonomic drive.

The differential drive unit consists of a 20W DC motor, a claw coupling and a bearing block. The holonomic drive consists of three units which can directly replace the differential drive without any further modification of the robot. The unit itself is built up the same way as the differential drive, except for using stronger motors for higher speed and acceleration and using "Cat-Trak" Transwheels allowing a movement in X, Y and ϕ . A triangular aluminum adapter block is used to attach the two front drive-units to the main frame by simple screw connection, providing an angle of 120 degrees between the wheel axis. The third wheel is being directly attached to the main frame.

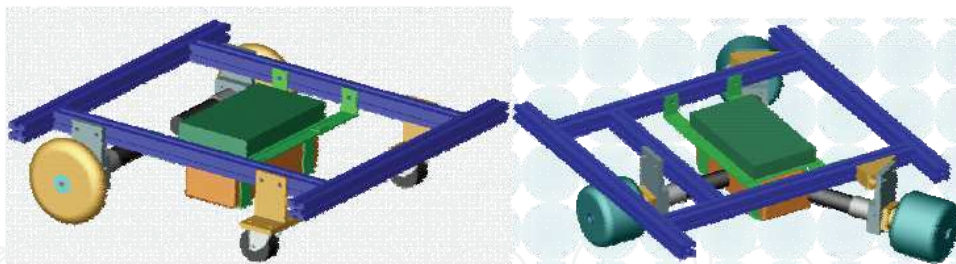


Fig.2. Main frames for differential (left) and holonomic drive (right) of VolksBot Indoor

3.1.3 Universal Drive Unit

The indoor base platforms presented above use a single 40x40cm frame which allows a light-weight construction, but limits the kinds of possible applications. To account for increased rigidity, payload and larger size of the robots, we introduce a double layered main frame consisting of 2 parallel X-beams and a new Universal Drive Unit (UDU). This resulted in the development of VolksBot RT (cf. section 4.1)

The wheels on each side of the VolksBot RT robot are driven by a single 150W DC motor. The force transmission to each wheel is achieved by using the Universal Drive Units (UDU),

a component to establish flexible chain-drive systems. In Fig. 5 (left), a closer view with the wheels removed, shows that a simple repetition of these units in an assembly can create drive systems with a varying number of actuated wheels.

The UDUs (Fig. 5 right) can be mounted with screw connection at various positions along the double layered base frame, which makes it possible to customize the wheel distances easily. The steel shaft of 10mm diameter is supported by two aluminum bearing blocks which allow for payloads of up to 80kg. The shaft can be directly driven by a motor (direct drive) or driven indirectly by belt or chain via the attached sprockets. We use a chain driven system for compactness reasons. The entire drive unit can be encapsulated within the span of 20mm, i.e. the thickness of one X-beam. This allows a complete housing of the transmission.

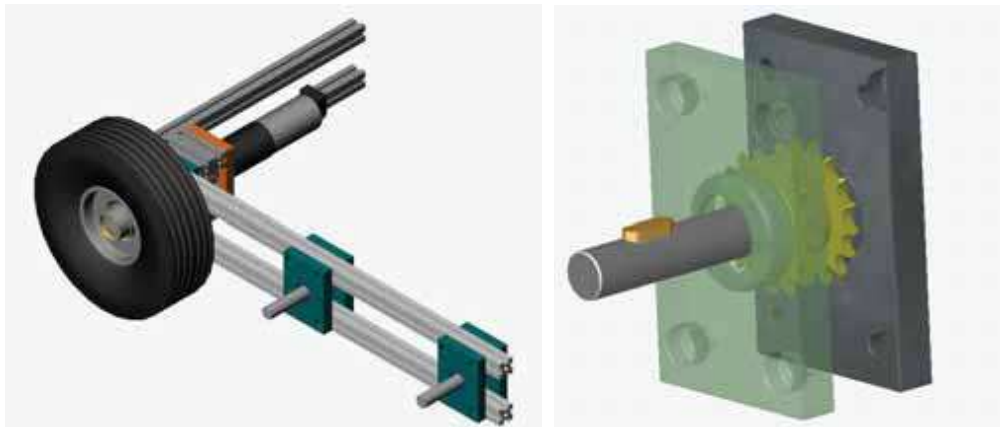


Fig.5. Double layered main frame with attached UDUs (left) and detailed view of UDU (right)

Furthermore, a set of air-filled tires with various diameter and profile provide proper mobility, ground clearance, grip and damping of the robot.

In order to drive the shaft, it is connected to a motor block through a claw coupling. Once assembled, it can be used to either drive other UDUs via chain transmission or drive the wheels directly. In case of different motors only the motor block needs to be modified. A chain transmits the possibly high torque from the 90W or 150W DC-motor which can be equipped with a planetary gear of various ratio ranging from 1:14 to 1:150. It can transmit forces of up to 3000N. The connection of the various tires, ranging from 18 to 40cm diameter, to the shaft requires only one standard hub connector.

3.2 Hardware Components

Also in hardware, a component library has been built up and is constantly being enlarged. The library holds commercially available products as well as own developments. Already integrated commercial components include (D)GPS, laser range finder, inertia sensors, industrial and barebone PC's, compass, stereo and regular cameras and manipulators.

After the selection of new hardware, the component is tested and interfaces are defined. Providing a demo application and documentation for each component allows efficient testing and integration when a new platform is being built.

In the following an overview of hardware components developed for the construction kit is given.

3.2.1 Motor controllers

A specially designed motor controller TMC200 is connected via serial interface to the control PC. The controller offers odometric data analysis, thermal motor protection, battery voltage monitoring, velocity and current PID control for three DC-motors up to 200 Watts power.

In 2006 a new version called VMC was developed with improved properties in hardware I/O and thermal dissipation. It can be easily exchanged with the old component, and neither mechanics nor software require any structural modifications.

The component integrates also well in other robot platforms. For example, three of the four most successful teams in the RoboCup Middlesize League in the World Championships 2006 in Bremen used it in diverse robots.

3.2.2 AISVision

As a requirement for the soccer robots used in RoboCup Middle Size League a catadioptric vision system AISVision was developed. The vision system includes an IEEE1394 CCD camera and a hyperbolic mirror as shown in Figure 6 (left). Before construction, the system was designed entirely in simulation using the ray-tracing software POV-Ray (POV-Ray). In an iterative process, all relevant geometry parameters of the system were optimized for the use on a RoboCup Middle Size field. These include height of the mirror with respect to the camera, height of the entire vision-system above the ground, diameter of the mirror, focal distance of the camera and especially the two parameters a and b of the mirrors hyperbolic surface equation (1) with r being the radius and z the dimension along the optical axis.

$$\frac{z^2}{a} - \frac{r^2}{b} = 1 \quad (1)$$

The criteria for this optimization were full visibility of all landmarks from any position in the field, including goals and corner-posts, and a good visibility of the close region. The rendered and the real camera image are depicted in Fig. 6 (center, right). The optimization can be repeated for any other scenario with the described method. Different cameras have been already integrated, ranging from cheap webcams to sophisticated industrial cameras.

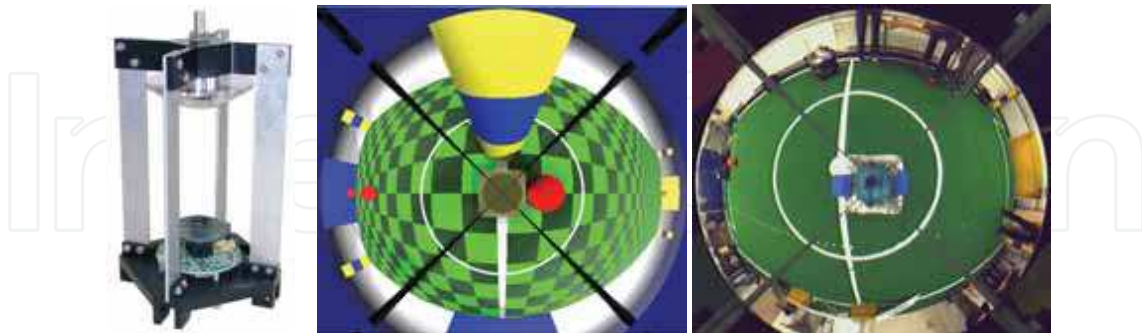


Fig.6. AISVision system (left), rendered (center) and real camera image (right)

3.2.3 3D Laser Scanner

A new continuously rotating 3D laser scanner was developed by extending the concept of the existing tilting 3D scanner (Surmann et al., 2001). Mounted on the robot, it is used for 3D mapping, navigation and localization in particular being useful when applied to outdoor scenarios. Two industrial laser range finders rotate around the vertical axis of the system, acquiring depth and intensity information for a 360° field of view.



Fig. 7. CAD drawing of the new 3D Scanner

The system consists of 2 SICK LMS 291-S05 laser range finders mounted on an angular adjuster plate. The scanners have an apex angle of 180 and a resolution from 1 to 0.25. The maximum range of the scanners is 80 meters. Being able to adjust the angle of the scan planes allows us to increase the scan resolution or to increase the rotation speed while cutting off the irrelevant top and the lower part of the scanned sphere. The system is equipped with an RS232 and a CAN interface, inputs for the hall sensors and some general purpose digital inputs. Contact rings are used to power the laser scanners and to transmit

the sensor data via RS485 from the scanners. The entire system is IP65 water resistant, weighs 13kg and has a size of 90×330×250mm. The scan resolution depends on the rotation speed and the angular adjustment of the scanners. At an angular adjustment of 60 and a rotation at 0.45Hz we obtain a vertical resolution of 0.5 and a horizontal resolution of 1.7 with an update frequency of 0.9Hz. A separate control PC is used for post processing of the laser scanner data.

3.2.6 Kicking device

For participating in RoboCup, a new simple but effective pneumatic device for lift-kicking a ball was designed and built up within 2 days. The kicking device mainly consists of two X-beams, the same kind already used for the main-frame of the VolksBot. The X-beams form a vertical, adjustable lever mechanism, actuated by a pneumatic cylinder. By adjusting the cylinder-lever attachment, the parabolic path of the kicked ball can be tuned. Having an initial angle of 45° and speed of 7 m/s, a flight over a distance of 5 m can be reached. In spite of the short development time, this component has been in use with only minor modifications for years now. A structural similar, but bigger variant has been built for the goalkeeper robot.

3.3 Component based Software Design

As valid for mechanics and hardware components, also in software, a clear framework concept with well-defined components is being used. We use ICONNECT (Sicheneder et al., 1998) as framework for the visual composition of signal flow graphs. A main advantage of ICONNECT compared to similar approaches (The MathWorks, Inc.) (Kalman, 1995) is a unique feature that allows to execute module graphs on a PC in real-time without recompilation of the whole module graph and without extra hardware needed. A module in ICONNECT consists of a compiled DLL and has a visual black-box representation with input and output pins in the graph editor. For each module, relevant parameters can be entered in a parameter dialog or can be changed during run-time via separate input pins. In Fig. 3 the ICONNECT programming environment is depicted, including an example of an easy to build graphical user interface.



Fig. 8. ICONNECT programming environment with graph, GUI and module library

The existing module library of ICONNECT already contains a lot of functionality needed for controlling a mobile robot including signal processing of sensor data, image processing, control, hardware IO, logic, neural networks, network communication, data visualization and GUI design.

Except from recombining already existing modules, own modules can be written in C++ by use of existing module templates which can be filled with user-specific code. With this method, we extended the ICONNECT framework and added more robot-specific software modules to the library such as: the color vision library AISVision, integration of OpenCV (OpenCV), an interface to Matlab (The MathWorks, Inc.), a corba server (OMG), a module for integration of Dual Dynamics behaviors (Jäger & Christaller, 1997) or a simulator module based on ODE (ODE). For each new module, a HTML documentation has to be written, and a compact, self-explaining example graph has to be built. Combined with the aim to build only modules of fine granular functionality, this fosters reuse and reduces work-in time when new team members enter the project. With this approach, loss of knowledge is being reduced and even people with background other than computer science are able to program the robot on this abstraction level. This approach is especially beneficial for projects with many people of different background working together, like e.g. in RoboCup - as compatibility between modules is ensured by this clear interface definition and all people can have a clear and quite intuitive understanding of the entire robot control software.

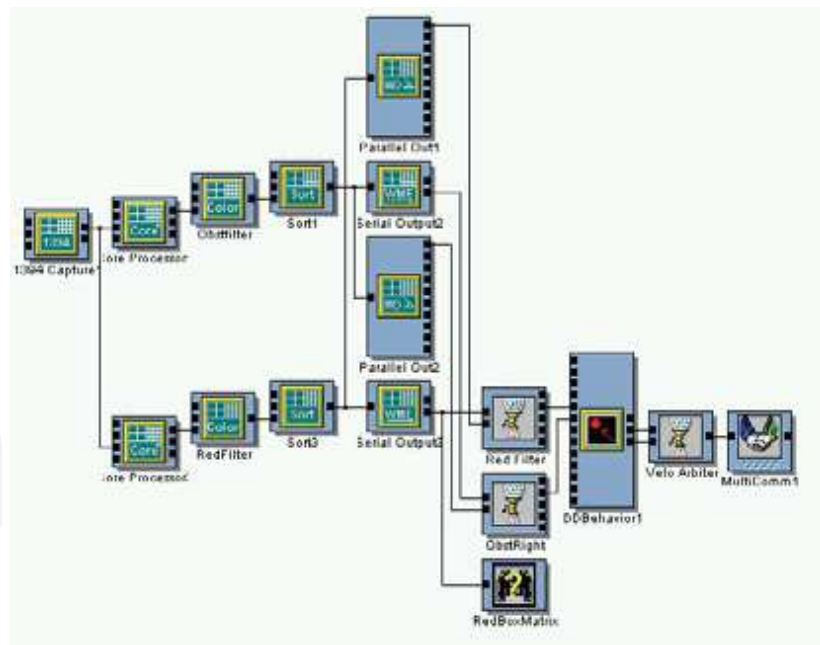


Fig. 9. A robot control graph in ICONNECT including data acquisition, signal processing, behavior and motor control

Combined with the advantages mentioned above, the use of such a framework sets some restrictions to the developer as it limits the choice of possible methodologies when developing software. Another aspect is the use of a particular operating system, such as Windows, which is required for the ICONNECT framework. An approach to overcome these limitations is the use of a more general software library which does not provide all the advantages of a differentiated framework like ICONNECT but may be appealing to a wider group of users.

This way, we started to standardize our inhouse software developments by building a new C++ software library called FAIRLib (Fraunhofer Autonomous Intelligent Robot Library). Here various algorithms and methods in the context of robot navigation, localization mapping, sensor processing and also hardware I/O are being integrated to make them more interchangeable and usable.

The FAIRLib offers multiple abstraction levels with the low level consisting of basic I/O functions, data types, and a math library. Here, dependencies on specific hardware and operating systems are tolerated as they are unavoidable. The higher levels contain more sophisticated algorithms. Here the described dependencies can and should be avoided which allows to use the same set of methods for different hardware and operating systems.

The integration of the FAIRLib with the ICONNECT framework was another demand which has been met. Now, before programming an ICONNECT module, the functionality is first implemented into the FAIRLib which ensures even more universal use and reuse by a larger group of users.

4 Application oriented prototyping

Using the described component pools in hardware, software and mechanics various robot platforms have been designed for different scenarios. To show the feasibility of the construction kit approach, some of them are described in the following.

4.1 VolksBot variants

After the development of the first VolksBot Indoor variant (Fig. 1) mentioned in chapter 3, the idea had risen to extend the VolksBot concept to fit to the needs of rough terrain environments and real life applications. As a consequence new demands have to be set for the system including high payload, mobility, ground clearance and rigidity.

The recombination of the UDU and the double layered main frame enabled us to build 3 different RT (Rough Terrain) variants in a very short amount of time. This is due to the fact that we mainly reused existing VolksBot components combined with available standard parts. Only four different parts had to be machined to build up the Universal Drive Unit. Equipped with two 150 watt DC-Motors the 6-wheeled variant (Fig. 10) is able to climb a slope of 43 degrees and has a maximum speed of 1.3m/s. As the motor gears can be exchanged as easily as for the indoor version, the maximum speed can be adjusted according to the demands. So with little effort different variants in size and wheel configuration of the VolksBot RT can be built. The 3-wheeled, 4-wheeled and 6-wheeled variants are depicted in Fig. 10.



Fig.10. 3-wheeled, 4-wheeled and 6-wheeled variant of VolksBot RT

After the RT development, the original indoor version has been redesigned to take advantage of the improved rigidity and payload of the RT as well as to maintain compatibility between the systems. The redesign included the use of the double-layered frame and the UDU. 90W DC motors and larger wheels with 180mm diameter were integrated. With its compact size, and high payload this platform allows for various indoor tasks as e.g. the use in the RoboCup@Home domain (see section 4.2) or the use as an educational platform for mechatronics in vocational schools called ProfiBot (ProfiBot).

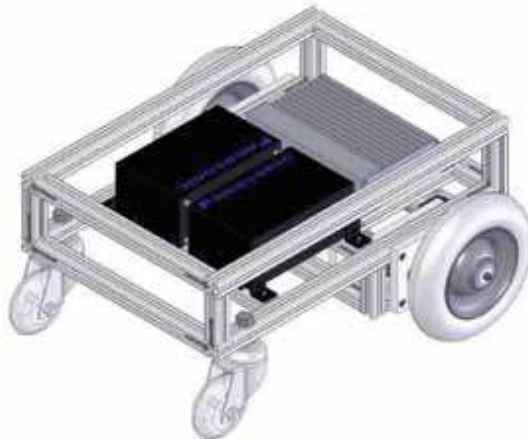


Fig.11. New indoor variant on the basis of RT

All previously described platforms still have limitations with respect to mobility due to their fixed body structure. An interesting approach to overcome these limitations with a wheeled robot platform is shown by the Shrimp Rover from EPFL (Estier et al., 2000) which uses a parallel bogey mechanism to passively adapt the wheel position on uneven terrain. We remodeled and simplified the parallel bogey as a component compatible to the RT kit. The direct drive for the wheels was replaced by a strand of a central hinge unit mounted to an upper and lower horizontal lever unit connecting two vertical leg units. Legs and levers build a parallelogram. Levers, hinge and legs are double bared such that they can accommodate an inlying chained transmission line. All in all we use four chain drives and eight UDUs (see Fig. 12 left). The new component offers various advantages compared to the original design. It only consists of standardized parts and easily allows for variation and expansion of the design.

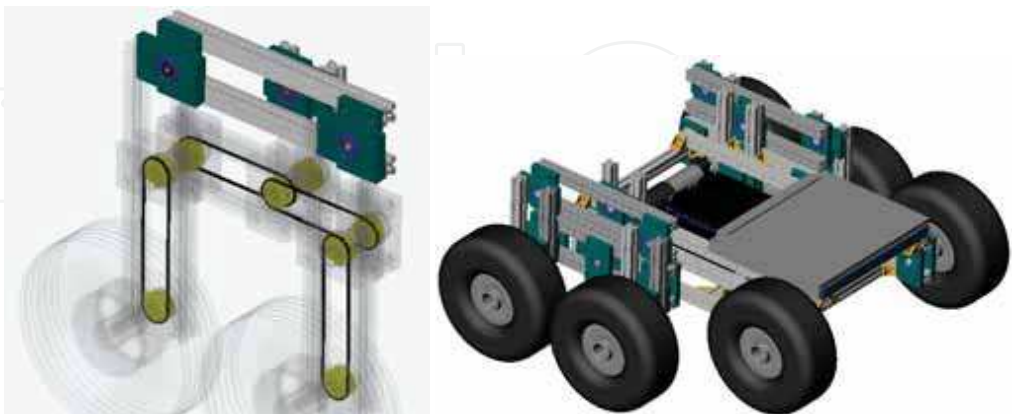


Fig.12. CAD drawing of the parallel bogey component (left) and the complete assembly of VolksBot XT (right)

The indirect chain drive system uses only two actuators and hence can be easily scaled according to motor power and payload. Furthermore, the entire drive system including the motors can be encapsulated and hence protected inside the robots frame. We have modeled an enhanced 6-wheeled variant which we called XT (Fig. 12 right), using the new parallel bogey component and tested its performance in ODE, a physical simulator. An increase of the mobility performance was achieved by use of a genetic algorithm which optimized a set of the robots geometrical parameters in ODE (Wisspeintner et al., 2006). Fig. 13 illustrates the result of this optimization with the robot being able to climb different kinds of stairs and moving over a random step field as used in RoboCup Rescue.



Fig. 13. VolksBot XT climbing mildly inclined stairs outdoors, a steep staircase indoors and moving over a random step field

4.2 RoboCup

Various development projects with VolksBot have been conducted in the context of the RoboCup competitions since 2004. We as well as other teams are using different VolksBot platforms and components to participate in the MiddleSize, Rescue and @Home league. Some of these platforms are presented in the following.



Fig. 14. VolksBots in RoboCup Middle Size (left), Rescue (center) and @Home league (right)

4.2.1 Middle Size League

In the beginning of 2004 an international student-team (AIS/BIT) using VolksBot was built up to participate in RoboCup Middle Size League (MSL). The main demands on MSL robots are quite different from other scenarios, requiring higher dynamics, superior motion control and real time color vision. To meet these demands the team had to introduce only a few additional plug-in components to the existing system. Participation in MSL demanded better image quality especially in high dynamic situations. Therefore the web-cams were replaced by Sony DFW-500 IEEE1394 cameras with very few adjustments.

All of these modifications in hardware required only minor software changes due to the component-based structure of ICONNECT. As each hardware component is directly related to one module, only the module itself had to be changed, without affecting the entire system. This also holds true for the behavior architecture itself, where we focused on the use of Dual Dynamics [14], an architecture based on dynamical systems. We extended the DD-Designer tool to directly generate ICONNECT modules, which made the behavior become an easily interchangeable component.

An important aspect of the development process is simulation. A module incorporating physical simulation of robots based on the ODE engine was developed. It has the same interfaces as the hardware, so the development of behaviors can be done without any special treatment, just by replacing the simulator with the corresponding hardware access modules in the graph.

Later developments included the integration of the holonomic drive unit, the new motor controller VMC as well as a more compact frame. Further developments in the soccer domain include the design of an Outdoor soccer variant (Fraunhofer IAIS).

4.2.2 Rescue

The 6-wheeled version of VolksBot RT was used as base platform at the RoboCup Rescue Workshop 2004 in Rome. There, within 15 hours of lab-activities, two groups of three and six persons - with no prior experience of the system - worked together to build a functional rescue robot with autonomous behavior which has been demonstrated at the end of the workshop.

The task of one group was to build up the entire control system on the robot including, signal processing of laser-scanner data, image-processing, compression and WLAN transmission of the AISVision image stream, interfaces for teleoperation and manual override, autonomous behavior and motor-control. An obstacle-avoidance method was modified to achieve the desired (semi-)autonomous behaviors.

The task of the other group, dealing with human-robot interfaces, was to build an interface for the operator including visualization of the robots state, camera image and laser-scanner data. Further on it was required to set the robots state e.g. from manual to autonomous and build an interface to joystick and throttle for proper tele-operation.

The two groups worked together well, first defining the interfaces then testing the results iteratively. In summary it can be said that the VolksBot concept of rapid system development worked out resulting in a running system within very short time.

4.2.3 @Home

For the RoboCup World Championships 2007 in Atlanta a VolksBot robot was prepared to take part in the @Home league about 3 weeks before the tournament. Thanks to the modular design, it was possible to integrate two laptops and various sensors on the robot within the short time limit by a small team consisting of only two persons. With reuse of existing MSL and FAIRlib software, it was possible to participate in 3 different tests and the Open Challenge, almost reaching the finals. Fig. 15 shows the CAD design of a new @Home robot with integrated laser range finder, stereo camera, pan-tilt unit and a Katana arm from Neuronics. The robot construction is will be finished in autumn 2007 and will be used in future @Home competitions.



Fig.15. CAD model of the @Home VolksBot with integrated laser range finder, stereo camera and a Katana arm

4.3 Real World Applications

Besides application in RoboCup, the VolksBot construction kit has been applied to various other domains like autonomous transportation, surveillance or even underwater robotics.

4.3.1 PeopleMover

The PeopleMover is an extended version of the three-wheeled RT variant introduced in section 3. By selecting a high gear ratio, elongating the base frame, adding additional sensors and a few mechanical components, it is capable of autonomously transporting a person on a predefined track while avoiding obstacles. The reuse of software developed for the RoboCup Rescue workshop 2004 helped to build this prototype used for demonstration purposes within only 1 week.



Fig.15. PeopleMover, a prototype of an intelligent vehicle on VolksBot basis

4.3.2 MarBot

In cooperation with the Alfred-Wegener-Institute for Polar and Marine Research (Alfred Wegener Institut) we are developing an autonomous underwater robot for marine seabed analysis on the basis of the VolksBot kit. Instead of providing a complete housing for the robot's, only the robots sensitive hardware parts like the motor, the motor controller, the batteries or the control PC had to be shielded from the surrounding salt water. Besides the underwater environment the robot was designed for, various other demands had to be met regarding the design of the MarBot. Payload and size of the platform had to be increased to allow the installation of additional sensors and actuators like a mass spectrometer for advanced soil analysis which is mounted on a three-axis manipulator. Therefore an exchangeable center frame was designed carrying the additional hardware. Also the ground clearance had to be increased to 400mm to minimize the dispersion of sediments while driving. The resulting platform is illustrated in Fig. 16. It has six actuated wheels of 400mm diameter, a total size of 1200x700x650mm, a maximum speed of 1m/s and it weighs 30kg. The construction followed the design principles of the VolksBot RT series using the UDU with chain transmission. Only a few drive unit parts like the bearing blocks and bearings had to be replaced by plastic parts to avoid corrosion.

A Nano ITX barebone PC is used for the control of the robot. It can communicate to a base station via WLAN and UDP connection in shallow water allowing remote control and monitoring of the sensor data.

In software, both, a cockpit for the operator and the robot control software has been implemented in ICONNECT by use of the existing module library. Future development will include autonomous operation by use of multiple sensors like GPS, IMU, compass and vision allowing the robot to go from shallow water into depths of up to 30m.

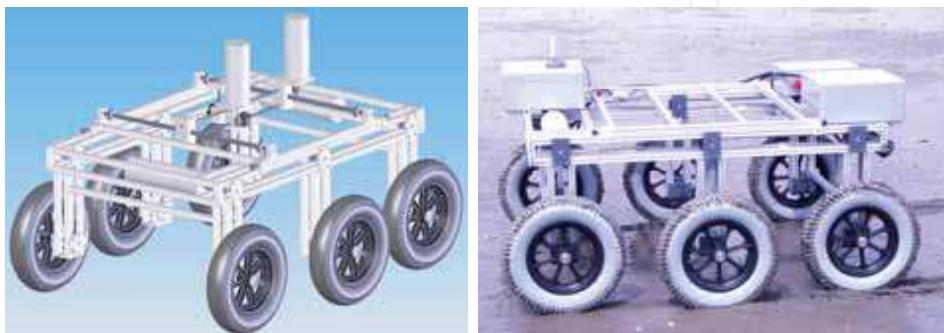


Fig. 16. CAD assembly (left) and image of MarBot (right), an underwater VolksBot variant

4.3.3 FuelBot

In cooperation with the Fraunhofer Institute ISE (Fraunhofer ISE) we developed a VolksBot variant which uses a fuel cell as central power supply. The fuel cell provides up to 400W power at 24 VDC. Depending on the mode of operation and the size of the metal hydride tanks filled with hydrogen it allows up to 24h of continuous operation. In this case, applying our prototyping concept allowed us to design the robot around the existing fuel cell, which is another good indicator for the flexibility of the concept. A VolksBot RT3 variant was used as the basis for this development. The robot then was equipped with a SICK Laserscanner, an industrial PC and a TFT display and was presented at the Hannover fair 2007 in Germany.

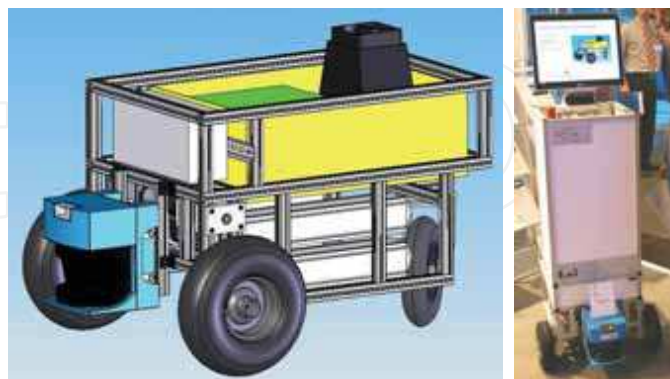


Fig. 17. CAD assembly (left) and image of FuelBot (right), a fuel cell powered VolksBot

6. Conclusion

In this chapter we have presented the a concept for application oriented prototyping of mobile robots. After defining design goals and deriving design criteria, we presented the mechanical, hardware and software components which followed these criteria and form the VolksBot construction kit. Then, variants of robot platforms for diverse applications were presented, including general platforms for indoor (VolksBot Indoor) and outdoor (VolksBot RT) use, a platform for high mobility applications (VolksBot XT), robots for participation in the Robocup Middle Size, Rescue and @Home league, a demonstrator for autonomous transportation (PeopleMover), an underwater variant (MarBot) and finally a fuel cell powered VolksBot (FuelBot).

Having successfully designed and constructed this number of robots indicates the feasibility and effectiveness of our design approach. Future work will include a constant enhancement of the construction kit allowing for even more applications. This includes the development of a modular, steerable drive unit, the use of tracks instead of wheels and a redesign of the XT variant for even higher mobility and payload. In software the FAIRlib will be further developed, including reusable modules for indoor and outdoor localization and navigation and various functionality in the @Home domain.

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Microsoft, Microsoft Robotics Studio. <http://msdn.microsoft.com/robotics>

ODE. <http://www.ode.org>

OMG, Robotics DTF. <http://robotics.omg.org>

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ProfiBot. <http://www.profibot.de>

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Many papers in the book concern advanced research on (multi-)robot subsystems, naturally motivated by the challenges posed by robot soccer, but certainly applicable to other domains: reasoning, multi-criteria decision-making, behavior and team coordination, cooperative perception, localization, mobility systems (namely omnidirectional wheeled motion, as well as quadruped and biped locomotion, all strongly developed within RoboCup), and even a couple of papers on a topic apparently solved before Soccer Robotics - color segmentation - but for which several new algorithms were introduced since the mid-nineties by researchers on the field, to solve dynamic illumination and fast color segmentation problems, among others. This book is certainly a small sample of the research activity on Soccer Robotics going on around the globe as you read it, but it surely covers a good deal of what has been done in the field recently, and as such it works as a valuable source for researchers interested in the involved subjects, whether they are currently "soccer roboticists" or not.

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