ACROBOTER: a ceiling based crawling, hoisting and swinging service robot platform

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ABSTRACT
Concept and design of a new indoor service robot locomotion technology are described in the paper. The proposed solution extends the workspace of existing indoor ground based service robots in the vertical direction, while ensuring higher payload capability than aerial robots and less environment invasive than industrial gantry robots. The concept under development is highly innovative in the sense that it will combine the planar stepping motion of an arm on the ceiling in 2D, and the thrusted-hoisted pendulum like motion of the working unit in 3D relative to the arm. This is a novel approach to cover the whole volume of a room. In addition, the ACROBOTER is designed to work autonomously or in close cooperation with humans and to be capable of collaborating with other robotic devices.

Categories and Subject Descriptors
Primary Classification: I.2.9 [**Computing Methodologies**]: Artificial Intelligence – *Robotics.*

Additional Classification: I.2.10 [**Computing Methodologies**]: Artificial Intelligence – *Vision and Scene Understanding*

I.2.8 [**Computing Methodologies**]: Artificial Intelligence – *Problem Solving, Control Methods, and Search* - Subjects: Plan execution, formation, and generation, Subjects: Signal processing

General Terms
Algorithms, Design, Security, Human Factors.

Keywords
Service robots, Conceptual design, Control architecture, Autonomous positioning, Mobile robot navigation, Localization, System integration

1. INTRODUCTION
A major challenge in development of a robot for movements inside a building is to make it able to move freely and quickly in any direction. In addition, the obstacles found in buildings, specifically in a domestic environment where objects may not be static over time, is a problem. Examples include stairs, doorsteps, chairs, tables and various surface conditions including carpets. Past developments which address the general need for a robot to climb walls and ceiling inside a building are the MATS robot [1], biped walking robots like the Honda Asimo robot [2] and mobile robot devices like the Care-o-Bot from IPA [3]. The task to move freely inside a building includes many issues which are not easily solved. Comparing the listed service robots as well as the proposed ACROBOTER concept to cconventional gantry crane, the key advantages in mounting complexity and the use of multiple units in one workspace appear. The closest solution to the ACROBOTER concept found in the literature so far is the Flora ceiling based service [4] robot. Flora is suspended onto the ceiling and uses electromagnetic force to keep the mobile cart on the ceiling and telescopic arms to navigate the working unit into the 3D workspace. The permanent magnet traction method and the rigid telescopic structure make this service robot concept less affordable for multipurpose domestic use.

The Acroboter concept stands out by its innovative locomotion technology that allows covering the whole volume of a room; additionally it is being designed to be able to work autonomously or in close cooperation with humans, and to be capable of collaborating with other robotic devices. In particular, there are two main issues to work with which are in favor for the ACROBOTER system: autonomous operation / navigation and power. The working principles of biped robots mean that they walk on the floor and thus the navigation in a domestic environment is crucial for successful operation. The power of the system is a limitation compared with the ACROBOTER which can be fed with power in a practically unlimited way.

2. REQUIREMENTS ANALYSIS
The research started with the definition of the application scenarios that will be considered for the system design. 11 service robot application scenarios were selected and analyzed: 1. cleaning systems, 2. museum tourist guides, 3. assistive technologies to elderly and handicapped people, 4. general pick and place applications, 5. physical and mental recreation, 6.

robots in Cooperative Working Environments, 7. tidying a children's room, 8. moving cameras into auditoriums, 9. greenhouse service, 10. haptic interfaces, 11. movement rehabilitation systems. The literature and market survey considered the technical development of these systems, as well as collected the relevant user requirements and general safety requirements. Initial considerations suggest that only the application of ACROBOTER as haptic interface needs to be excluded from the list of potential application scenarios. In the next step the user requirements were defined based on the method of New Product and Process Development.

3. CONCEPTUAL DESIGN

In parallel with the literature review and the user requirements the structural, actuation and control properties of the existing service robots were assessed. In the framework of a standard function analysis the collected solutions were supplemented with more generic solutions. A template was prepared and used to define the system requirements of the respective subsystems in a coherent way. Being a service robot the safety requirements within the system requirements attracted special attention. A state of the art risk analysis method was used to support the identification of additional system requirements.

3.1 System architecture

In order to fulfill the above set system requirements, the ACROBOTER platform consists of mechanical-, navigational- and control subsystems. The mechanical subsystems include the grid of anchor points on the ceiling of constructed environments, the climber unit that moves on the grid of anchor points, and the swinging unit which is connected onto the climber unit (see Figure 1.). For vertical positioning of the robot, the climber unit is

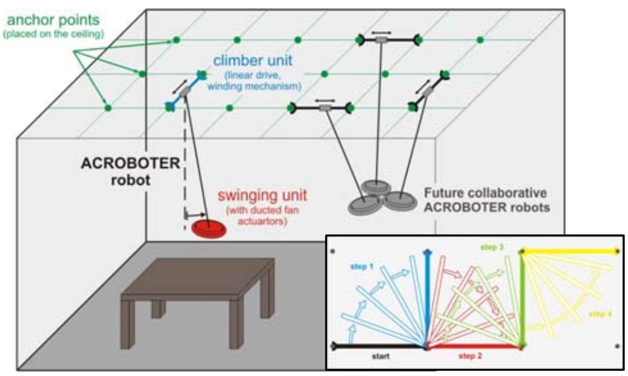

Figure 1. Concept of the ACROBOTER platform (framed part shows the movement of the climber unit between the anchor points). The concept opens ways of collaboration of more platforms in a physically coupled configuration.

equipped with a winding mechanism. In addition, the swinging unit is equipped with ducted fan actuators that provide a free motion inside a conic volume. In other words, the robot can fly around the suspension point, while the ducted fan system is also used for fine positioning and for the stabilization of the robot's motion (see Figure 2.). The ACROBOTER robot itself is a mobile platform that carries other service robot or a tool and performs the desired tasks (Figure 3.).

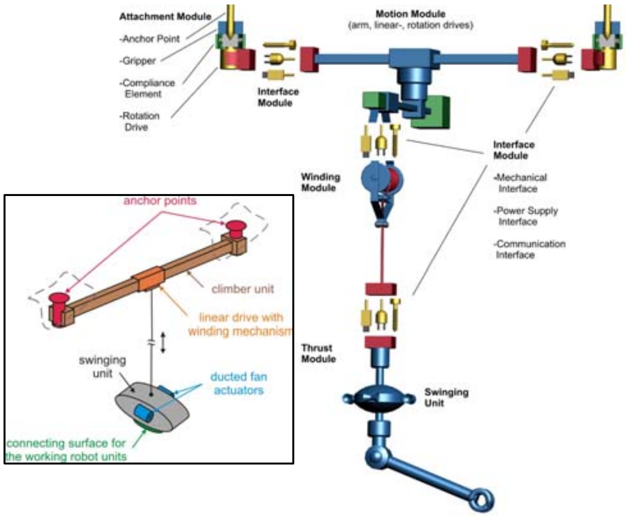

Figure 2. Embodiment design evolution of the ACROBOTER system.

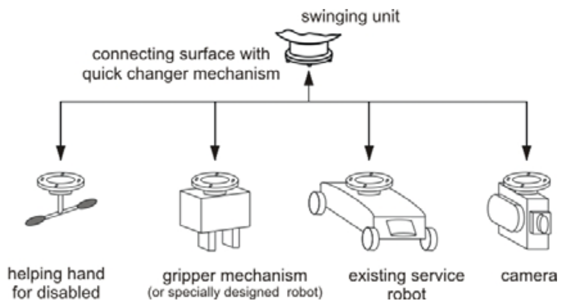

Figure 3. ACROBOTER is a mobile service robot platform.

3.2 Modelling and simulation

Autonomous manipulation of a payload by an overhead crane is difficult due to the pendulum motion swinging effects and the requirement to do so in three dimensions simultaneously. It is important that the payload is transported in a trajectory and that the load oscillations are suppressed as quickly as possible [5]. This non-linear behaviour raises issues of performance and safety such as, damage to payload (objects that it carries), damage to surrounding environment and in the case of the ACROBOTER framework, injury that can be caused to humans interacting with the robot(s). Several studies reported in the literature [6], [7], [8] show different control strategies for real-time non-linear control of cranes. Often these strategies involve an off-line path planning that takes into account some optimisation criterion, followed by an online controller loop. Although these types of control methodologies are appropriate for the ACROBOTER robot, the degree of robot complexity and the interaction issues between humans and the robot, and consequently between robots require the adoption of a distributed system, not only at the hardware level but also at its control methodologies.

In parallel with the concept generation the detailed design of the subsystems was carried out. Depending on the nature of the subsystem the work included embodiment design, CAD modelling, FEA analysis, mathematical modelling and simulation of multibody kinematics and dynamics, reduction of noise and

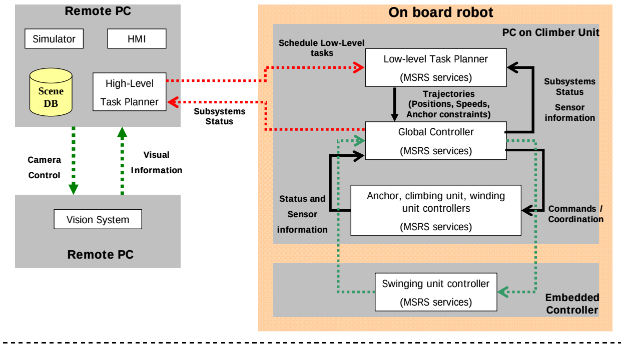

Figure 4. Proposed control architecture: systems and services

airflow emission, and control strategies. The work has lead to creating two unified simulation environments: 1) for more theoretical analysis in Matlab/Simulink, and 2) in MSRS adopting the HIL strategy that can easily allow testing the physical systems together with a simulation system.

3.3 Control

A Microsoft Robotics Studio (MSRS) based distributed control approach is considered for Acroboter. The global control architecture, the Human Machine Interface of the robotic platform, the Microsoft Windows CE control approach for the time critical servo actuators (adopting MSRS wrapper technique) and the accuracy, the range, the update frequency, and the latency of the proposed global pose measuring system, have been specified (see Figure 4.). A 4 CC camera based vision system for environment reconstruction supplemented with optical and RF beacon technologies for object recognition and identification is developed.

The work on control development can be grouped into three classes of contributions: innovations, cutting edge implementations and classical approaches (see Table 1).

4. PROTOTYPE DEVELOPMENT

The first step towards detailed design was to refine and update the

Table 1. Classification of contributions to control development

Innovations	Cutting edge implementations	Classical approaches
Distributed software architecture allowing complex control of multiple DOF hybrid (serial-parallel) redundant and underactuated Acroboter robot	HMI implemented using the best UI technology available	Path planner uses Octree search algorithms and A* path planning algorithms
	Low-level control methodologies	Scene DB uses SQL designs
	RFID tagging technologies (Ubisense system)	Global Controller uses finite state transition machine design
Plugging behaviour and presentation of tasks	Fusion of sensor information and filtering	Pose estimation uses well known sensor and processing algorithms
Vision recognition and reconstruction system		Visual beacon is implemented using well developed APIs
Simulation of multiple Machine-Machine Interactions		Standard sensor and actuation systems

set of mathematical models and simulation tools to support all phases of the prototype design: preliminary design, selection of components, redesign and optimization, and verification. The design phase was efficiently supported by modern CAD and simulation tools. The goal of the implementation work was to realize modular and robust subsystems with sophisticated interfaces to support their integration in the full-scale prototype. Currently the standalone prototype units and subsystems are tested (see Figure 5.) as a precondition for further integration and subsystem control development and testing

5. SYSTEM INTEGRATION AND VALIDATION

For final system integration and validation a seminar room at the Budapest University of Technology and Economics will provide a full scale test environment. Figure 6 illustrates a scenario when the ACROBOTER platform picks up an electrical two-finger gripper from the accessory storage mounted on the wall and places bottles on the table before a meeting. The seminar room validation will include other scenarios like placing glasses, notebooks and pens to the desks, scanning surfaces and finding objects, clearing by a vacuum cleaner and collecting garbage to

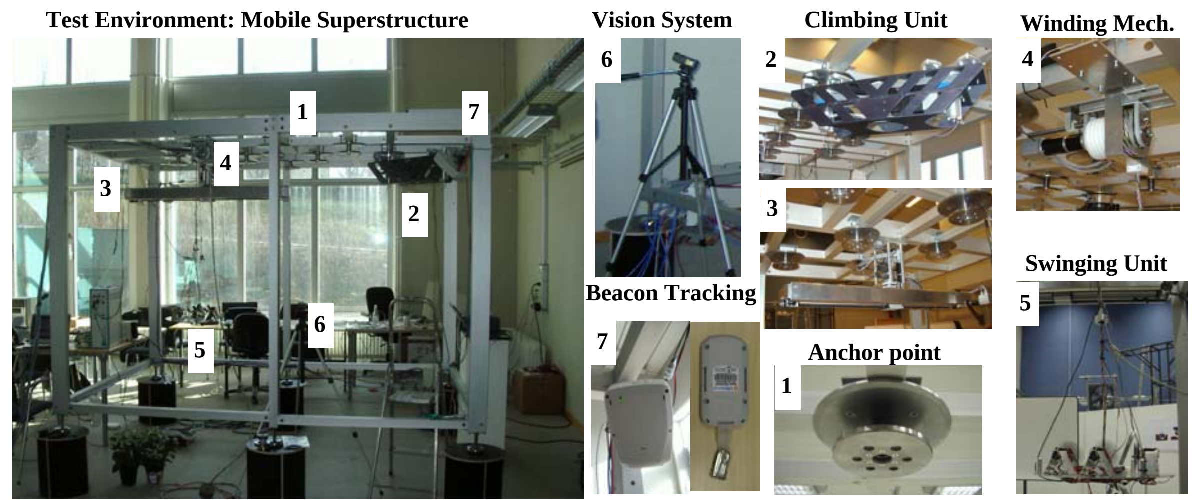

Figure 5. Subsystems test in the mobile superstructure before system integration.

Figure 6. ACROBOTER places bottles for a meeting in a full scale seminar room validation (building in progress)

garbage-can. The principal objective of this research is not to test the platform in various human-robot collaboration scenarios but to prove the viability of the indoor service robot locomotion concept. Collaboration of single ACROBOTER platforms with humans like in leisure and assistive scenarios (see Figure 7) as well as of multiple platforms like in care/rehabilitation and haptics scenarios will be implemented in simulation environment.

Figure 7. ACROBOTER plays billiard (left) and ACROBOTER serves a cup of tea to the disabled (right).

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7. PATENTS PENDING

Application No.: HU-P0900466. Application date: July 28, 2009. Title: "Payload suspension system"

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9. REFERENCES

[1] Carlos Balaguer, Antonio Gimenez, Alberto Jardón Huete, Angelo M. Sabatini, Mike Topping and Gunnar Bolmsjö, "The MATS Robot" IEEE Robotics & Automation Magazine, 13(1):51-58), 2006.

[2] http://www.honda.co.jp/ASIMO/

[3] http://www.care-o-bot.de/english/

[4] Sato, T.; Fukui, R.; Morishita, H. and Mori, T.: Construction of Ceiling Adsorbed Mobile Robots Plaform Utilizing Permanent Magnet Inductive Traction Method, Proc 2004 IEEE/RSJ International Conference on Robots and Systems, September 28 – October 2, 2004, Sendai, Japan, pp.552-558.

[5] Yu J., Lewis F.L., and Huang T. "Nonlinear feedback control of a gantry crane" Proceedings of the American Control Conference, Seattle, Washington, pp. 4310-4315, 2005.

[6] Fang Y., Dixon W.E., Dawson D.M., and Zergeroglu E. "Nonlinear coupling control laws for a 3-dof overhead crane system" Proceedings of the 40th IEEE Conference on Decision and Control, Orlando, Florida, USA, pp. 3766-3771 , 2001

[7] Deng J., and Becerra V.M. "Real-time constrained predictive control of a 3D crane system" Proceedings of the IEEE Conference on Robotics, Automation and Mechatronics, Singapore, pp. 583-587, 2004.

[8] Bartolini G., Pisano A., and Usai E. "Robust control of container cranes: theory and experimental validation" Proceedings of the IEEE Conference on Robotics, Automation and Mechatronics, Orlando, Florida, USA, pp. 1409-1414, 2001.