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Dynamics and Actuation of the Acroboter Platform

A. Zelei[*], **L. Bencsik**[†], **G. Stépán**[†], **L. L. Kovács**[*]

[*] HAS-BUTE Research Group on
Dynamics of Machines and Vehicles
Muegyetem rkp. 3., H-1111, Budapest, Hungary
[zelei, kovacs]@mm.bme.hu

[†]Department of Applied Mechanics
Budapest University of Technology and Economics
Muegyetem rkp. 3., H-1111, Budapest, Hungary
[bencsik, stepan]@mm.bme.hu

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Abstract
Obstacle avoidance is an important problem in service and mobile robotics. Obstacles on the floor of a room include various objects such as stairs, doorsteps, chairs, tables and even the edge of carpets. Hence, floor based domestic robots need to have strategies to overcome randomly placed objects. A new direction in the development of indoor service robots is the use of robotic structures that can move on the almost obstacle free ceiling of a room.

This paper presents the dynamical modeling and the actuation concept of a pendulum like underactuated service robot platform Acroboter (see Figure 1) developed within the ACROBOTER IST-2006-045530 project [1]. This ceiling suspended robot is designed to be applied in indoor environments, where it can perform pick and place task autonomously with close cooperation with humans. It can also serve as platform that carries other service robots with lower mobility. The crane-like structure of the robot platform makes it possible to control and utilize the pendulum-like motion of the system, and provide large workspace and efficient maneuverability.

The Acroboter system consists of anchor plates (AP) placed on the suspended ceiling, a climber unit (CU) that can swap between these APs and a swinging unit (SU) which has a mechanical interface for connecting the payload. The CU including the rotation arm (RA) is an RRT robot that moves parallel to the ceiling and provides the horizontal motion of the system. The length of the main cable (MC) is varied by the main cable winch (MW) and it connects the CU and the SU through the cable connector (CC) to which the secondary orienting cables (SC) are also attached. Power supply and communication is realized via the MC. By using the mechanical interface the SU can be equipped with grippers and various tools. In this concept the three secondary cables orientate the SU, while the three pairs of ducted fans arranged in 120° directions are used for performing and stabilizing the motion of the SU along its desired trajectory. The thrust forces provided by the ducted fans (DF) make it also possible to move the payload even if the CU does not move at all. Nevertheless the CU is moving during normal operation of the system.

The above detailed cable suspended robot has a complex mechanical structure which may hardly be modeled using conventional robotic approaches. Conversely, complex multibody systems can be modeled by non-minimum set of descriptor coordinates, to be more precise the so-called natural coordinates are used for the geometric description of the Acroboter system. In such case the dynamical model can be written in the form of a differential algebraic equation, which has the following general form [2]:

$$\mathbf{M}\ddot{\mathbf{q}} + \boldsymbol{\Phi}_{\mathbf{q}}^{\mathrm{T}}(\mathbf{q})\boldsymbol{\lambda} = \mathbf{Q}(\mathbf{q}) + \mathbf{H}(\mathbf{q})\mathbf{u}, \tag{1}$$

$$\boldsymbol{\phi}(\mathbf{q}) = \mathbf{0}, \tag{2}$$

where $\mathbf{M} \in \mathbb{R}^{n\times n}$ is the constant massmatrix and $\boldsymbol{\Phi}_{\mathbf{q}}(\mathbf{q}) = \partial\boldsymbol{\phi}(\mathbf{q})/\partial\mathbf{q} \in \mathbb{R}^{m\times n}$ is the constraint Jacobian associated with the geometric constraints $\boldsymbol{\phi}(\mathbf{q}) \in \mathbb{R}^m$. $\mathbf{Q}(\mathbf{q}) \in \mathbb{R}^n$ is the vector of gravitational forces. $\mathbf{H}(\mathbf{q}) \in \mathbb{R}^{n\times l}$ is the control input matrix and $\mathbf{u} \in \mathbb{R}^l$ is the control input vector.

The number of DoFs, descriptor coordinates and actuators are summarized in Table 1. The CU is a fully actuated RRT robot modeled by minimum-set generalized coordinates. The CC is modeled as a particle, thus it is described by the 3 Cartesian coordinates. The actuation of the MW defines the

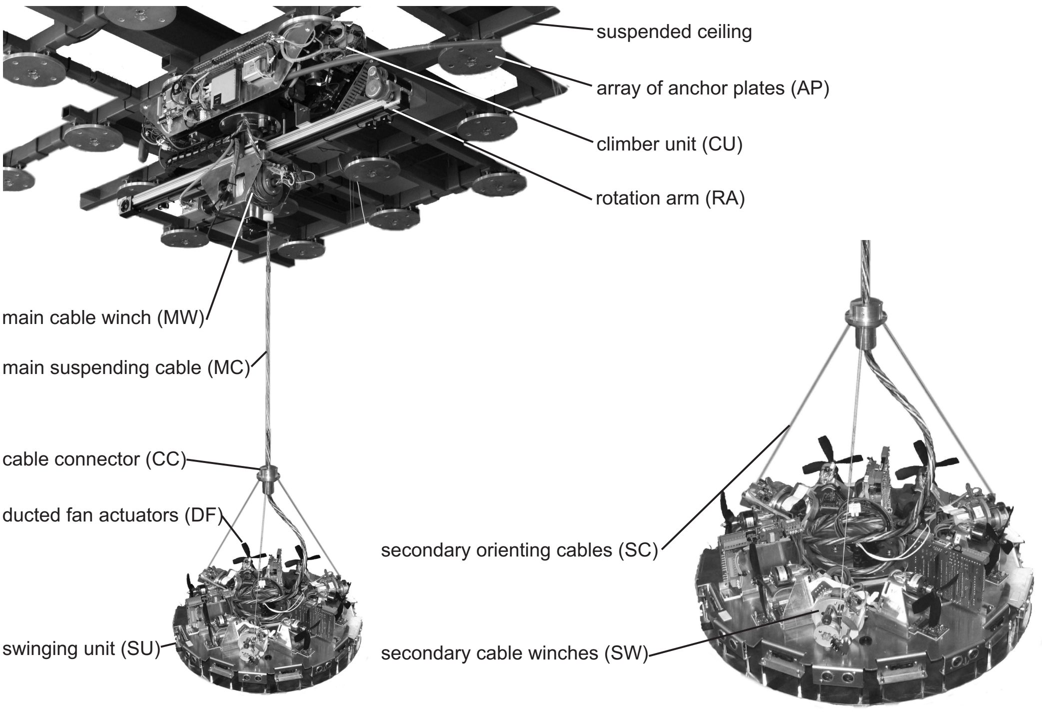

Figure 1: Acroboter prototype.

distance of the CC from the cable outlet point on the MW. The swinging unit is modeled as a rigid body, consequently is has 6 DoFs, but the number of descriptor coordinates is 12: 9 Cartesian coordinates for the 3 base points and the 3 coordinates of a unit vector perpendicular to the plane defined by the base points. The motion of the SU is controlled by 3 pairs of DF which are capable to generate an arbitrary direction resultant force in the plane parallel to the baseplate of the SU and a resultant torque which is perpendicular to it. The orientation of the SU is also controlled by the 3 SWs.

Table 1: DoFs, descriptor coordinates and actuators of the main units of the Acroboter.

unit	**DoFs**	**coordinates**	**actuators**
climber unit	3	3	3
cable connector	3	3	1
swinging unit	6	12	6

Despite of the large number of actuators, the ACROBOTER robot is still underactuated [3], thus we can say that the dimension of the control input l is less than the degrees of freedom $n-m$. The application of the method of computed torque control for this system leads to a set of differential algebraic equations adjoining to the geometric constraints which also appear as algebraic equations. The motion control of the present underactuated multibody system is a challenging task.

References

[1] G. Stépán et al, "A ceiling based crawling, hoisting and swinging service robot platform," in *Proceedings of Beyond Gray Droids: Domestic Robot Design for the 21st Century Workshop at HCI 2009,* 2009.

[2] J.G. de Jalón and E. Bayo, *Kinematic and dynamic simulation of multibody systems: the real-time challenge,* Springer-Verlag, 1994.

[3] M. W. Spong, "The control of underactuated mechanical systems," in *First International Conference on Mecatronics*, Mexico City, 1994.