

Robotics & Cybernetics

Challenges in human-centered applications

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1. Main Objectives and Trends
2. Abilities for performing non-prehensile manipulations
3. Concluding remarks

Main Objectives and Trends

Main Objectives

- Developing sensing technologies and robotic components;
- Developing new principles for designing machines and mechanisms;
- Developing control architectures and methods for enabling autonomy of systems;
- Creating robots with
 - new abilities
 - new functionality
 - learning and knowledge extraction skills

Research Focus: example of open call in H2020

ICT-47-2020: Research and Innovation boosting promising robotics applications

Specific Challenge: Robotics enables a significant part of the economic impact of **AI by delivering physical intelligence**. Logistics, **Healthcare**, Agri-Food, Inspection and Maintenance, Mobility, Construction, Decommissioning; **all require physical intelligence, for example in object manipulation**. Physical intelligence is derived from combinations of underlying **functional capabilities and developing these capabilities beyond the state of the art** depends on fundamental R&D&I which crosses between technical domains, for example into materials research or human interaction. It is therefore **important to enhance the capability of robots by exploring and developing the opportunities offered by novel technical developments related to physical intelligence**.

Scope: Innovative approaches to hard research problems in relation to applications of robotics in promising new areas are particularly encouraged. Proposals are expected to enable substantially improved solutions to challenging technical issues, with a view of take-up in

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- resulted in a high-level sequence (or a policy) of abstracted actions

Approach \Rightarrow Grasp \Rightarrow Re-orient $\Rightarrow \Rightarrow \dots \Rightarrow$ Action/Ability N $\Rightarrow \dots$

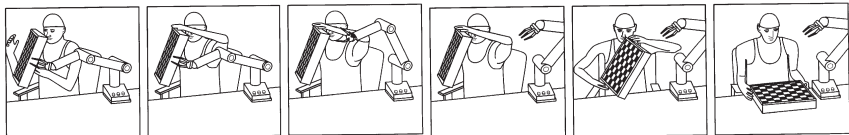


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- Learning processes for humans are embodied, **what do AI tools suggest for a given robot?**

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PROSPECTS

Biological
Cybernetics

Dynamic primitives of motor behavior

Neville Hogan · Dagmar Sternad

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Abstract We present in outline a theory of sensorimotor control based on dynamic primitives, which we define as attractors. To account for the broad class of human interactive behaviors—especially tool use—we propose three distinct primitives: submovements, oscillations, and mechanical impedances, the latter necessary for interaction with objects.

briefly review three types of interactive behaviors: constrained motion, impact tasks, and manipulation of dynamic objects.

Keywords Discrete · Submovement · Rhythmic · Oscillation · Impedance · Primitive



Dynamic primitives in the control of locomotion

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Humans achieve locomotor dexterity that far exceeds the capability of modern robots, yet this is achieved despite slower actuators, imprecise sensors, and vastly slower communication. We propose that this spectacular performance arises from **encoding motor commands in terms of dynamic primitives**. We propose three primitives as a foundation for a comprehensive theoretical framework that can **embrace a wide range of upper- and lower-limb behaviors**. Building on previous work that suggested discrete and rhythmic movements as elementary dynamic behaviors, we define submovements

Concepts: motion primitives, impedance, passive DoF

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(19) **United States**

(12) **Patent Application Publication**
Wang et al.

(10) **Pub. No.: US 2005/0234433 A1**

(43) **Pub. Date: Oct. 20, 2005**

(54) **APPARATUS FOR PERFORMING SURGICAL PROCEDURES WITH A PASSIVELY FLEXING ROBOTIC ASSEMBLY**

(75) Inventors: **Yulun Wang**, Goleta, CA (US); **Darrin R. Uecker**, Santa Barbara, CA (US); **Keith Phillip Laby**, Santa Barbara, CA (US); **Jeff Wilson**, Santa Barbara, CA (US); **Steve Jordan**, Santa Barbara, CA (US); **James Wright**, Santa Barbara, CA (US)

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PATENT DEPT.

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(73) Assignee: **Intuitive Surgical, Inc.**, Sunnyvale, CA

(21) Appl. No.: **11/080,198**

(22) Filed: **Mar. 14, 2005**

Related U.S. Application Data

(63) Continuation of application No. 09/000,934, filed on

filed on Jul. 31, 1997, now Pat. No. 5,815,640, which is a continuation of application No. 08/613,866, filed on Mar. 11, 1996, now Pat. No. 5,907,664, which is a continuation of application No. 08/603,543, filed on Feb. 20, 1996, now Pat. No. 5,762,458, which is a continuation of application No. 08/072,982, filed on Jun. 3, 1993, now Pat. No. 5,524,180, which is a continuation-in-part of application No. 08/005,604, filed on Jan. 19, 1993, now abandoned, which is a continuation-in-part of application No. 07/927,801, filed on Aug. 10, 1992, now abandoned.

Publication Classification

(51) **Int. Cl.⁷** **A61B 17/00**

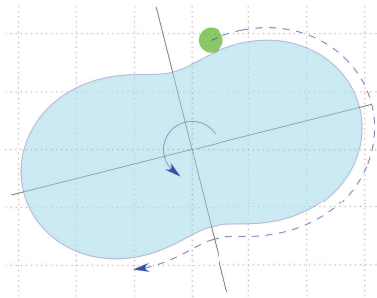
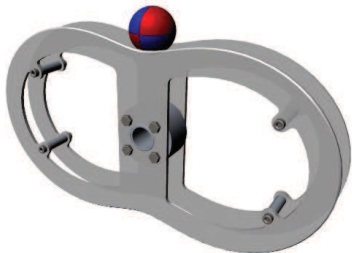
(52) **U.S. Cl.** **606/1**

(57) **ABSTRACT**

A robotic system that moves a surgical instrument in response to the actuation of a foot pedal that can be operated by the foot of a surgeon. The robotic system has an end effector that is adapted to hold a surgical instrument such as an endoscope. The end effector is coupled to a robotic arm assembly which can move the endoscope relative to the patient. The system includes a computer which controls the

Abilities for performing non-prehensile manipulations

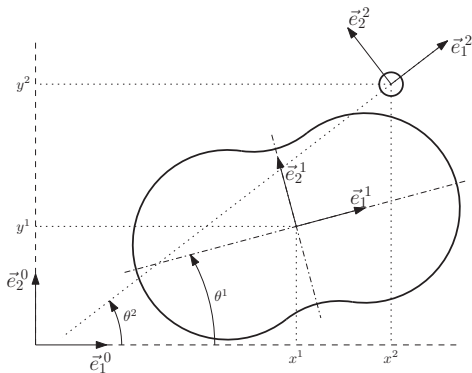
Example: the Butterfly robot



The tasks are

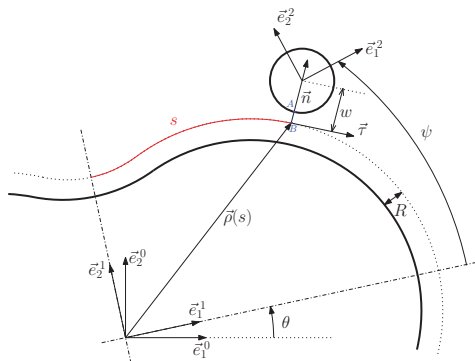
- to plan a rolling of a sphere on a frame
- to design a feedback controller to stabilize a motion

Choices of coordinates



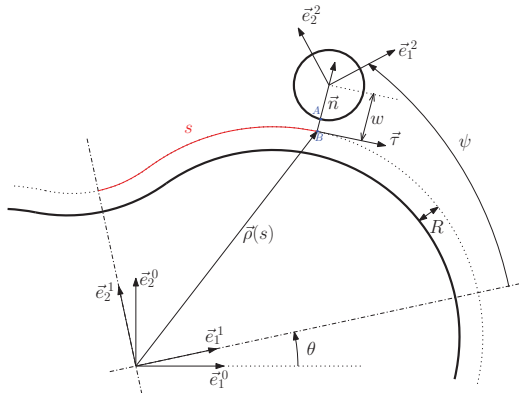
- Each body in plane requires 3 coordinates (x, y, θ) for describing its configuration.
- The hand has a fixed point, therefore 4 quantities will be enough for reconstruction of the status of the hand and the disc

Choices of coordinates



- θ is the angle of rotation of the hand
- s is the distance to go to the shortest to the center of the disc point along the virtual curve γ_c
- w is the distance to that point along the normal direction
- ψ is the angle of rotation of the disc in the hand frame

Constraints valid on a motion



Properties valid for rolling without slipping

- w is zero, i.e. the hand and the disc has a point contact
- $\frac{d}{dt}s \approx -R \frac{d}{dt}\psi$, i.e. the disc does not slip when rolls

Ability description

The dynamics of the system in excessive coordinates $q = (\theta, \psi, s, w)$ are

$$M_e(q)\ddot{q} + C_e(q, \dot{q})\dot{q} + G_e(q) = [u, 0, 0, 0]^T + F_1 + F_2$$

with u being a control variable; F_1, F_2 being the corresponding reaction forces.

The dynamics admit the reduction of the model for two variables (θ, ψ)

$$\begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \begin{bmatrix} \ddot{\theta} \\ \ddot{\psi} \end{bmatrix} + \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} \begin{bmatrix} \dot{\theta} \\ \dot{\psi} \end{bmatrix} + \begin{bmatrix} g_1 \\ g_2 \end{bmatrix} = \begin{bmatrix} u \\ 0 \end{bmatrix}$$

We have to search for a forced periodic solution

$$\theta^*(t), \quad \psi^*(t), \quad u^*(t)$$

of this system, for which the constraints hold.

Motion generator for one-directional rolling

If the motion $[\theta^*(t), \psi^*(t)]$ is found then the disc will roll in one direction



the angle $\psi^*(t)$ can be used for representation instead of time: $\theta^*(t) = \Phi(\psi^*(t))$



$$\frac{d}{dt}\theta^* = \frac{d}{d\psi}\Phi \frac{d}{dt}\psi^*, \quad \frac{d^2}{dt^2}\theta^* = \frac{d}{d\psi}\Phi \frac{d^2}{dt^2}\psi^* + \frac{d^2}{d\psi^2}\Phi \left[\frac{d}{dt}\psi^*\right]^2$$



The passive dynamics for that motion

$$m_{21}\ddot{\theta} + m_{22}\ddot{\psi} + c_{21}\dot{\theta} + c_{22}\dot{\psi} + g_2 = 0$$

can be re-written as an ODE for ψ -variable –

$$m_{21} \left[\Phi' \ddot{\psi} + \Phi'' \dot{\psi}^2 \right] + m_{22} \ddot{\psi} + c_{21} \Phi' \dot{\psi} + c_{22} \dot{\psi} + g_2 = 0$$

$$\left[\alpha(\psi, \{k_i\}) \ddot{\psi} + \beta(\psi, \{k_i\}) \dot{\psi}^2 + \gamma(\psi, \{k_i\}) = 0 \right]$$

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Ability reconstruction: a motion planner for rolling

- Choose a set of synchronization functions: $\theta = \Phi(\psi, k_1, \dots, k_n)$

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- Search for constants k_1^*, \dots, k_n^* and one of solutions $\psi^*(t)$ such that the pair

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meets the listed constraints (unilateral, max velocity etc.)



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- If so, compute control variable $u^*(t)$ from the system dynamics

$$m_{11}\ddot{\theta}^* + m_{12}\ddot{\psi}^* + c_{11}\dot{\theta}^* + c_{12}\dot{\psi}^* + g_1 = u$$

Otherwise, modify the parameters and re-do the search.

Concluding remarks

Important points

- Learning (extreme) abilities of robots is challenging
- Learning under constraints (a continuum set of equalities) requires preliminary steps in
 - representation of behaviors
 - alternative choices (movement dependent) of generalized or excessive coordinates
 - searching convenient sets of transverse coordinates (movement dependent)
- Most of arguments are scalable:
 - Cascaded representation for motion planning/control

$$\theta(t) \rightarrow [q_1(t), \dots, q_n(t)] = [\Phi_1(\theta(t)), \dots, \Phi_n(\theta(t))]$$

- Model based representations for analysis and control:

$$M(q)\ddot{q} + C(q, \dot{q})\dot{q} + G(q) = B(q)u + \sum_i F_i \rightarrow q(t)$$