Make it flexible, redundant, and safe: how ADL's work inspired our research

Paolo Rocco

ADL Surprise Festschrift – Roma, January 9, 2018

Rome and Milan, the two capitals of Italy…

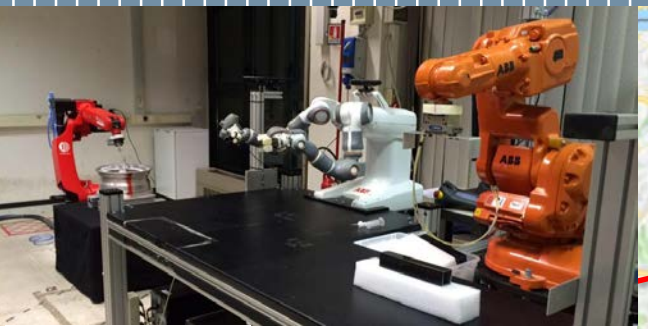
(well, Roma is the only capital…)

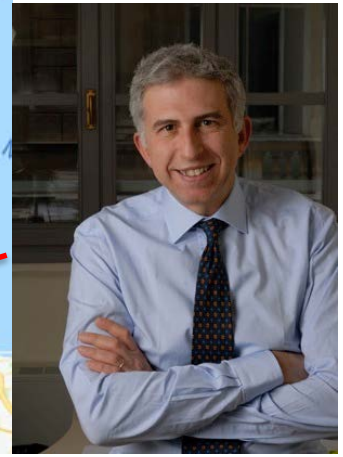
… and hosts of two BIG universities

POLITECNICO
MILANO 1863

SAPIENZA
UNIVERSITÀ DI ROMA

ADL has always been a master and a source of inspiration to us…



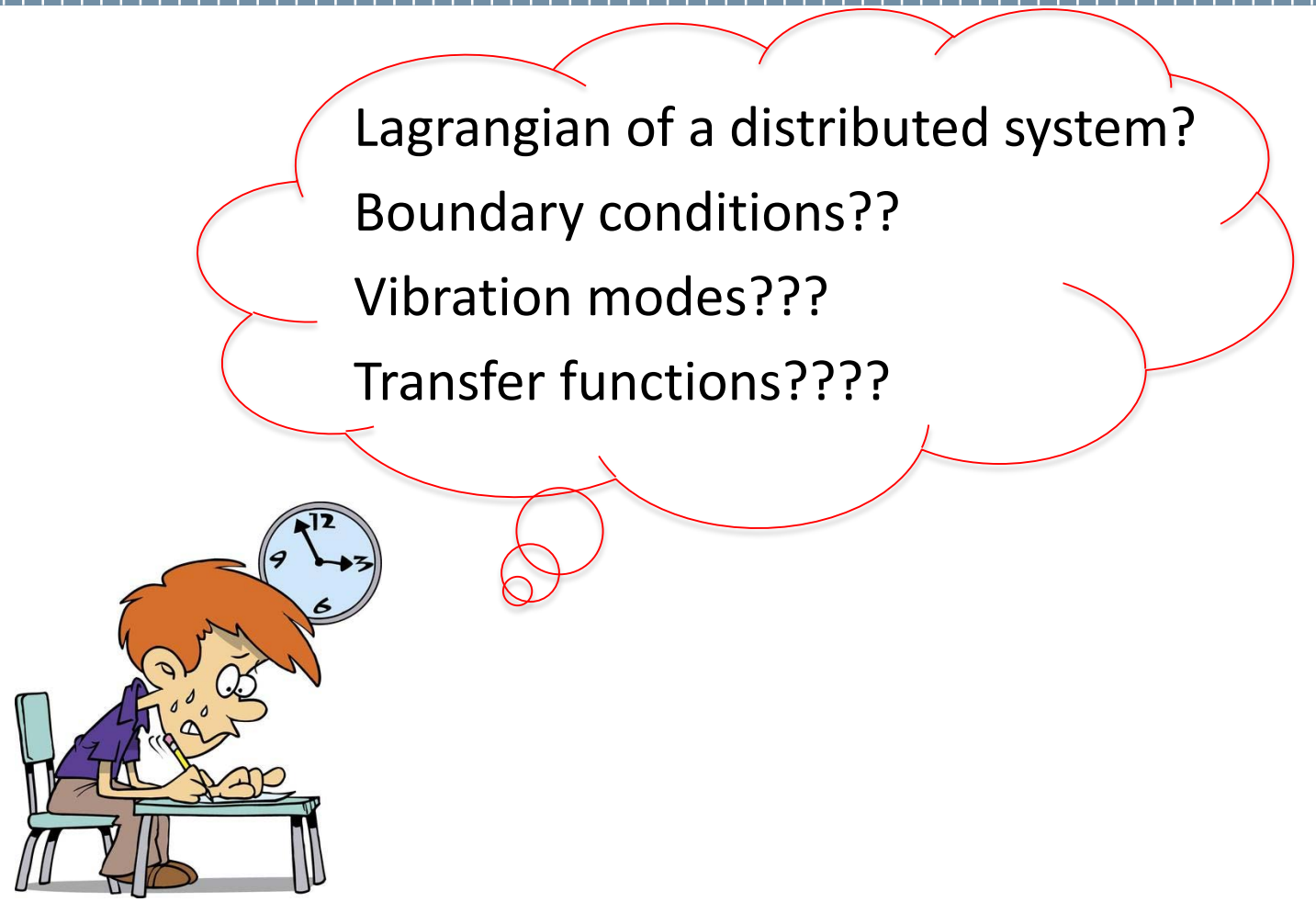


Taking inspiration from ADL

Make it flexible!

1995: a young guy travelling from Milano to Atlanta…

… and struggling to understand dynamics of flexible beams



Until he finds this…

Chapter 6

Flexible links

This chapter is devoted to modelling and control of robot manipulators with *flexible links*. This class of robots includes lightweight manipulators and/or large articulated structures that are encountered in a variety of conventional and nonconventional settings. From the point of view of applications, we can think about very long arms needed for accessing hostile environments (nuclear sites, underground waste deposits, deep sea, space, etc.) or automated crane devices for building construction. The ultimate challenge is the design of mechanical arms made of light materials that are suitable for typical industrial manipulation tasks, such as pick-and-place, assembly, or surface finishing. Lightweight structures are expected to improve performance of robots with typically low payload-to-arm weight ratio. As opposed to slow and bulky motion of conventional industrial manipulators, such robotic designs are expected to achieve fast and dexterous motion.

In order to fully exploit the potential offered by flexible robot manipulators, we must explicitly consider the effects of structural link flexibility and properly deal with active and/or passive control of vibrational behaviour. In this context, it is highly desirable to have an explicit, complete, and accurate *dynamic model* at disposal. The model should be explicit to provide a clear understanding of dynamic interaction and couplings, to be useful for control design, and to guide reduction or simplification of terms. The model should be complete in that, even if it is simple, it inherits the most relevant properties of the system. The model should be accurate as required for simulation purposes, design of advanced model-based nonlinear controllers, and off-line optimal trajectory planning. These general guidelines are even more important in the modelling of flexible robotic structures, where schemata or approximations of the modes of link deformation are unavoidably introduced. Symbolic manipulation packages may prove useful

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… and everything becomes crystal clear!

A. De Luca, B. Siciliano, "**Flexible links**," in C. Canudas de Wit, B. Siciliano, G. Bastin (Eds.) *Theory of Robot Control*, pp. 219-261, Springer Verlag, Berlin, 1996

Later we used know how in flexible link manipulator in our research

Proceedings of the 1996 IEEE
International Conference on Robotics and Automation
Minneapolis, Minnesota - April 1996

MODELLING FOR TWO-TIME SCALE FORCE/POSITION CONTROL OF FLEXIBLE ROBOTS

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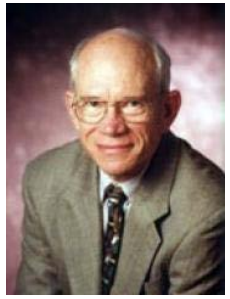
Abstract - **Distributed flexibility of the links is a severe obstacle for the endpoint position control of lightweight manipulators. In order to accomplish with satisfactory performance certain tasks involving a controlled interaction of the tip of the robot with the worksurfaces, a combined control of the motion and the contact forces can provide some advantages. This paper presents a general and systematic model of a flexible robot interacting with a rigid** which shows some interesting differences from previous results on the same subject [10], [11]. A control scheme for the force/position control of flexible robots has also been designed in this research [14]. However, since the focus of this paper is the development of the model, the control is here only briefly introduced to show the utility of the model.

Two-Time Scale Visual Servoing of Eye-in-Hand Flexible Manipulators

Luca Bascetta and Paolo Rocco, *Member, IEEE*

***Abstract*—Visual servoing of eye-in-hand flexible manipulators is addressed in this paper. Dynamic effects of both the rigid and the flexible motion of the manipulator are fully taken into account in a control solution where the two-time scale nature of the problem is exploited. The visual information is used in the "slow" subsystem for a task-space-oriented control law, where computationally expensive operations, such as inverse and time derivative of the Jacobian, are avoided. A constructive proof of stability of this control scheme, based on Lyapunov theory, is also presented. The effectiveness of the proposed controller is shown** the camera is fixed and observes both the target and the robot tip, and eye-in-hand systems, when the camera is mounted on the robot end effector.

IBVS approaches have experienced increasing popularity mainly due to the shortcomings inherent in the pose estimation problem. PBVS in fact needs a calibrated camera, and any calibration error leads to errors in the pose evaluation, with a consequent loss of precision in task execution. Moreover, with this approach, the position of the features of interest on



Taking inspiration from ADL

Make it redundant!

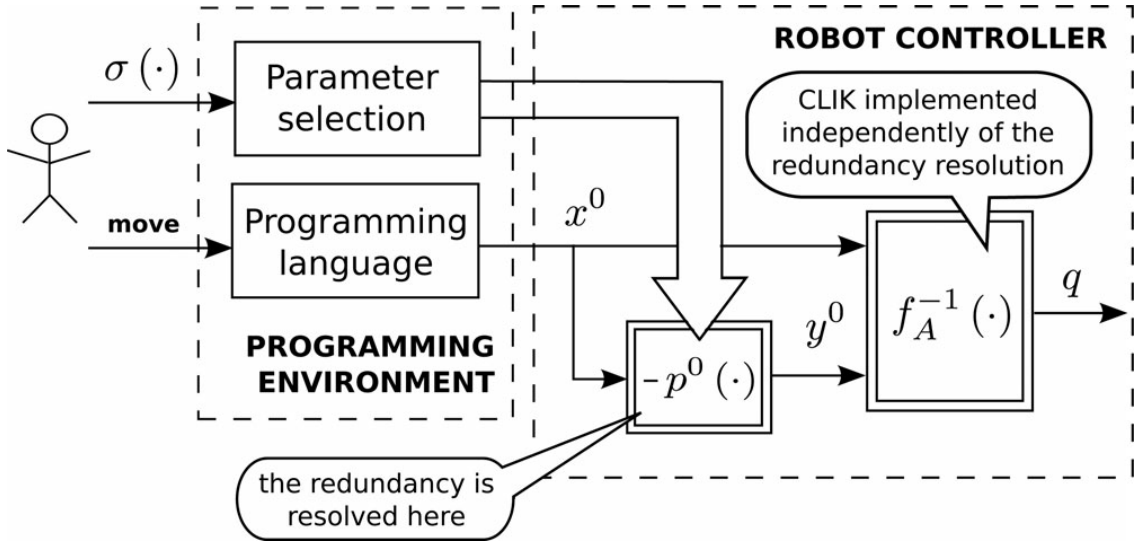
ADL's works on redundancy resolution have been a source of inspiration for us

IEEE TRANSACTIONS ON ROBOTICS, VOL. 28, NO. 2, APRIL 2012

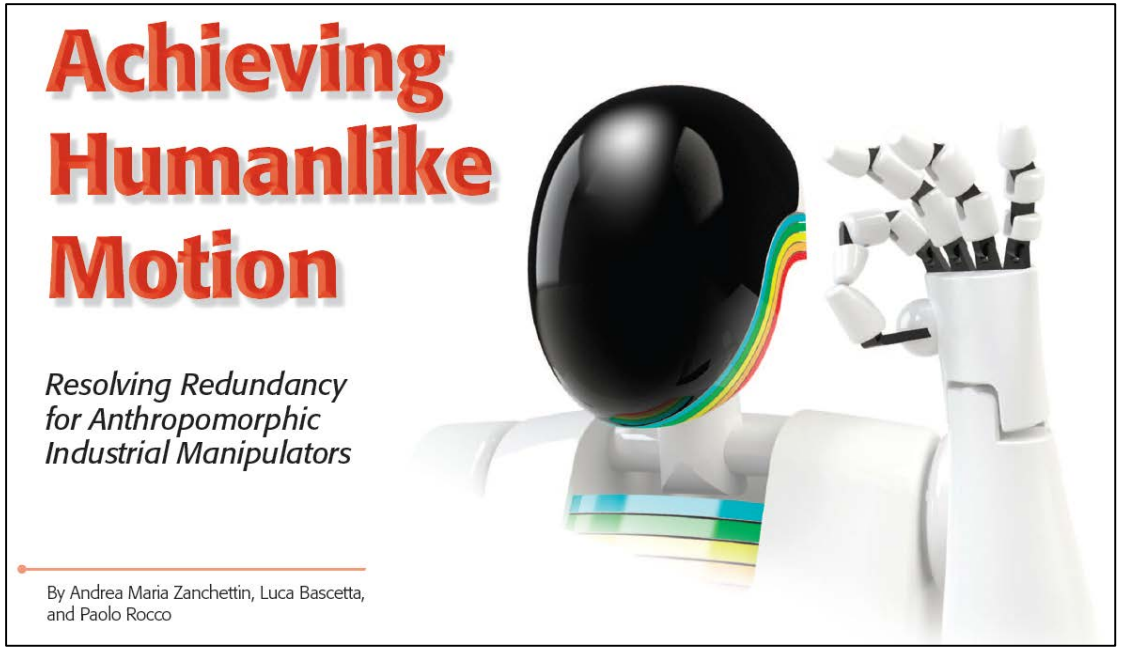
A General User-Oriented Framework for Holonomic Redundancy Resolution in Robotic Manipulators Using Task Augmentation

Andrea Maria Zanchettin and Paolo Rocco

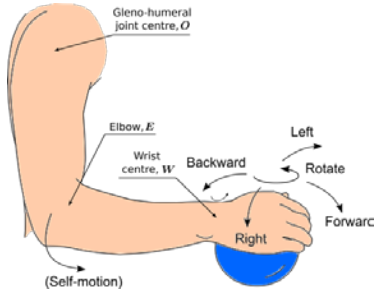
Abstract—Redundant robotic manipulators under kinematic control may exhibit unpredictable behaviors at the joint level. When the end effector describes a closed trajectory, the joint angles may not return to their initial values. Likewise, final configuration in the joint space may depend on the trajectory that is followed by the end effector. In this paper, a complete parameterization of holonomic redundancy resolution techniques that avoid these problems is proposed. The flexibility of the proposed approach is discussed. In particular, it is shown that the selection of the redundancy resolution criterion is totally decoupled from the implementation of a closed-loop inverse kinematics (CLIK) algorithm. Any user-defined redundancy resolution criterion can, thus, be enforced. Potentialities of this new methodology are experimentally verified on an industrial robot in a case study where functional redundancy occurs and is applied in simulation on a 7-degree-of-freedom (7-DOF) anthropomorphic manipulator.

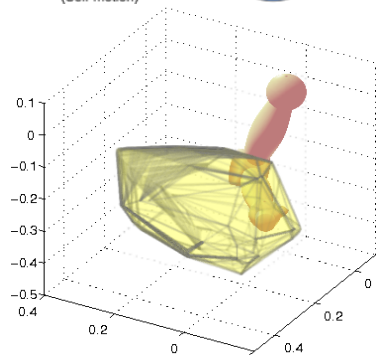


ADL's works on redundancy resolution have been a source of inspiration for us



- Generation of a «human-like» robot motion
- Bio inspiration of the arm trajectories
- Test of acceptability on volunteers
- Clear correlation between motion naturalness and psychological comfort





ADL's works on redundancy resolution have been a source of inspiration for us

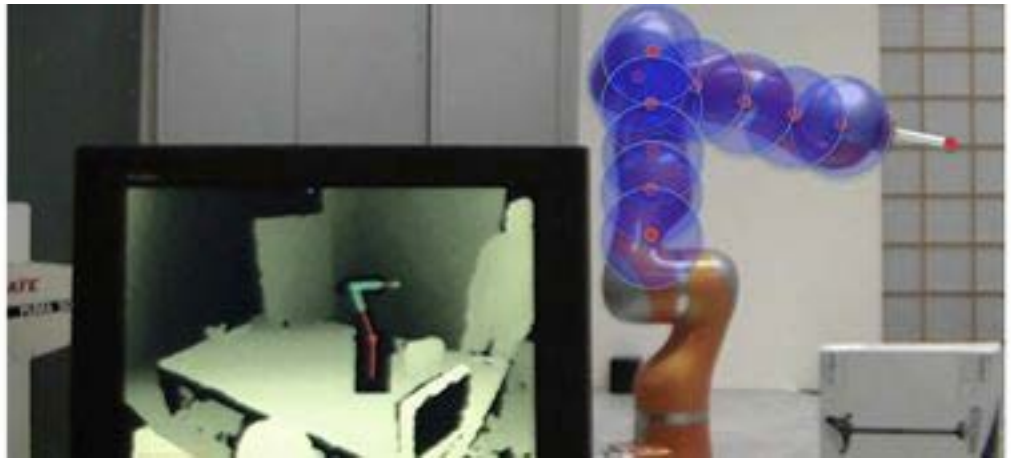
https://www.youtube.com/watch?v=aMMFA-zkbUQ

Taking inspiration from ADL

Make it safe!

Taking inspiration from ADL

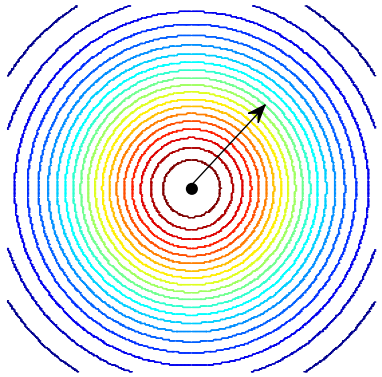
SAPHARI
Safe and Autonomous Physical Human-Aware Robot Interaction

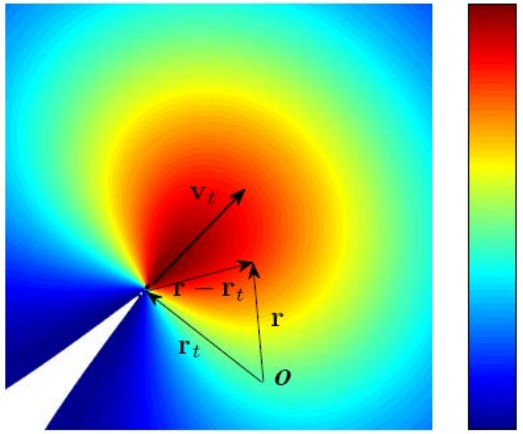


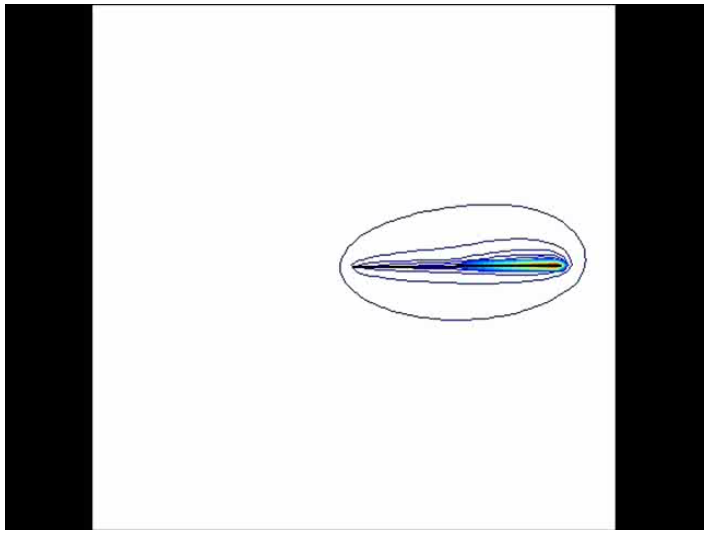
ADL's work on safe human-robot interaction was a source of inspiration as well for us.

In particular with the SAPHARI project.

The danger field







A decreasing function w.r.t. the distance from the “source of danger”

Takes into account a velocity vector of the source of danger as well

IEEE TRANSACTIONS ON ROBOTICS, VOL. 29, NO. 5, OCTOBER 2013 1257

Safety Assessment and Control of Robotic Manipulators Using Danger Field

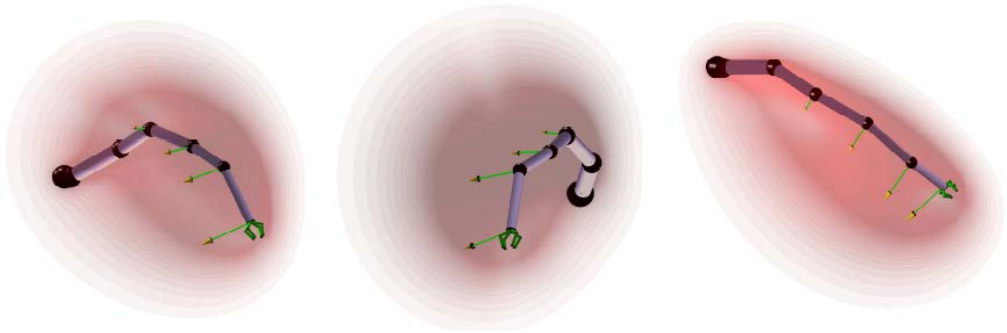
Bakir Lacevic, *Member, IEEE*, Paolo Rocco, *Member, IEEE*, and Andrea Maria Zanchettin, *Member, IEEE*

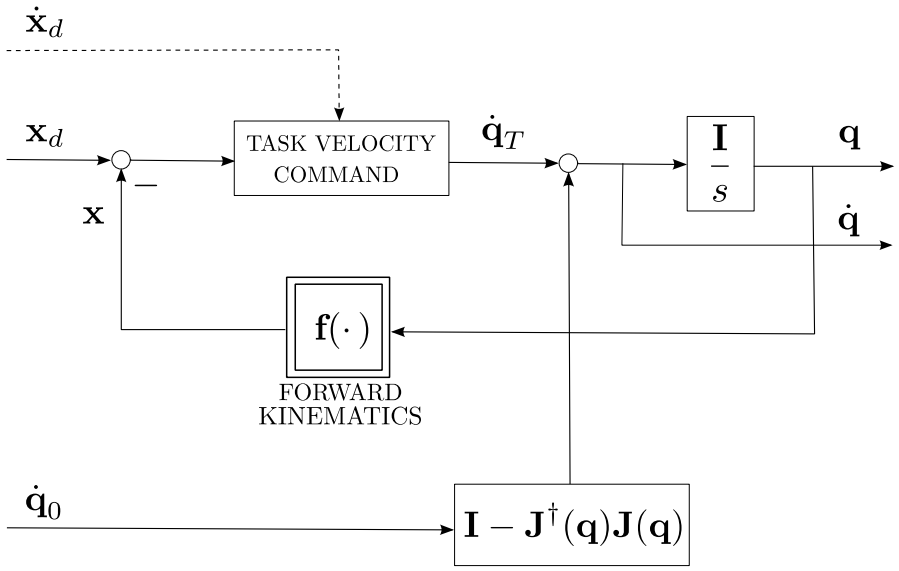
***Abstract*—This paper presents a synergistic approach to danger assessment and safety-oriented control of articulated robots that are based on a quantity called *danger field*. This quantity captures the state of the robot as a whole and indicates how dangerous the current posture and velocity of the robot are to the objects in the environment. The field itself is invariant with respect to objects around the robot and can be computed in any given point of the robot's workspace using measurements from the proprioceptive sensors. Furthermore, the danger field can be expressed in the closed form, which enables its fast computation. Apart from being a pure safety assessment, the danger field provides a natural prelude to safety-oriented control strategy. Namely, the information about the danger field can easily be fed back to shape standard control schemes in order to make the motion of the robot safer to the environment. The proposed method is validated through simulations and experiments.**

Conservative safety guidelines (e.g., ANSI/RIA R15.06-1999 [1]) prescribe the physical separation of the robots and operators. A relaxation toward more collaborative requirements was introduced in ISO 10218-1:2006 [2]. This standard states that one of the following requirements always has to be fulfilled to allow HRI: the Tool Center Point (TCP)/flange velocity must be at most 0.25 m/s, the maximum dynamic power at most 80 W, or the maximum static force at most 150 N. However, in [3], it is shown that these conditions are still conservative and can substantially mitigate the performance of the robot.

Although there are very few specifications for the coexistence or cooperation between humans and robots, large attention has been given to this matter in the scientific community.

Reactive control based on the danger field

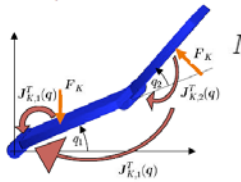




https://www.youtube.com/watch?v=CYUNSksIXZU

ADL's residual method for force identification widely used in our lab!

- dynamic model of robots with elastic joints and environment interaction



$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + g(q) = \tau_J + \tau_K$$

joint torque due to link collision

$$\tau_K = J_K^T(q) F_K$$

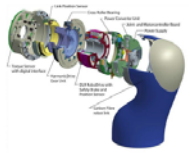
$$B\ddot{\theta} + \tau_J = \tau$$

motor torques commands

elastic torques at the joints

$$\tau_J = K(\theta - q)$$

- DLR LWR-III robot with multiple joint sensors
  - **encoders** for motor (θ) and link (q) positions
  - joint **torque sensor** for τ_J



monitoring signal: (link) momentum-based residual vector

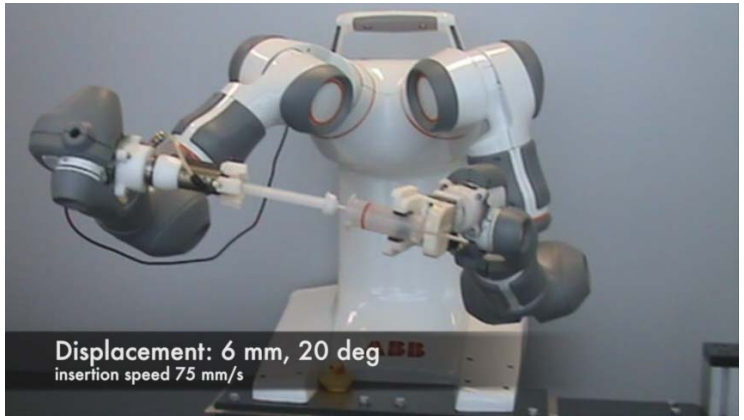
$$r = K_I \left(M(q)\dot{q} - \int_0^t \left(\tau_J + C^T(q,\dot{q})\dot{q} - g(q) + r \right) ds \right)$$

$K_I > 0$ (diagonal and large) $\Rightarrow$ $\dot{r} = -K_I r + K_I \tau_K$

$r \approx \tau_K$ **detection** (over a threshold)

$r = [* \ \dots \ * \ * \ \underbrace{0}_{i+1} \ \dots \ \underbrace{0}_{N}]^T$ **isolation** (collision at link i)

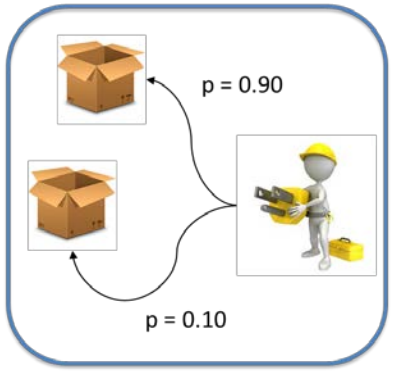
https://www.youtube.com/watch?v=FyWhN2gJi9c



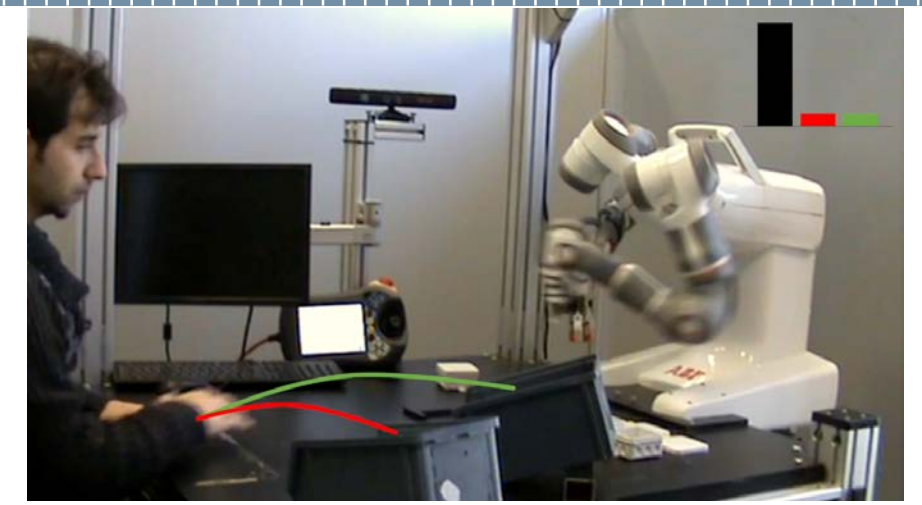
https://www.youtube.com/watch?v=K0MuAYSNcos

https://www.youtube.com/watch?v=hxdBxtpHsX4

A glimpse of our recent results



Prediction of operator intention (labelling)



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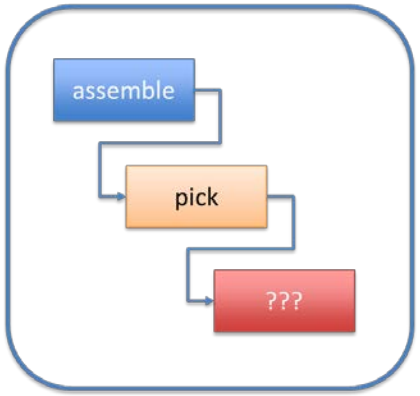
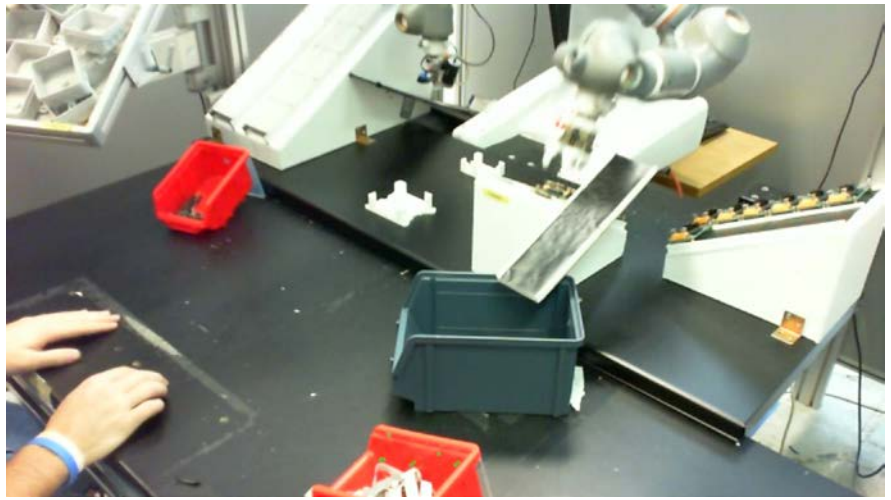


Prediction of patterns of activities



https://www.youtube.com/watch?v=KG7WLNdi8Uw

Personal memories: the Editorial Board of the T-RO

A typical e-mail to the EB: 1685 words, 5 colors, not a single typo

IEEE TRANSACTIONS ON ROBOTICS
A PUBLICATION OF THE IEEE ROBOTICS AND AUTOMATION SOCIETY

Dear Members of the Editorial Board

****NEWS****

1) Starting from August 15, **all initial submissions should be already in Transactions format.**
The standard length (i.e., without extra page charges) in Transactions format is, as before, **10 pages** for Regular papers, **5 pages** for Short papers, and **3 pages** for Communication items (for Regular papers, this length includes also authors' bio-sketch and pictures).
Accordingly, I will set up T-RO Papercept so as not to accept a submission (at any stage) whose pdf is longer than **17 pages** for a Regular paper, **9 pages** for a Short paper, and **4 pages** for a Communication item (all intended for Transactions format). Until now, we had much longer allowance (e.g., 35 pages for regular papers) intended for allowing a free format of initial submission, say single column-double space.

2) The instructions on the T-RO web site will be soon updated accordingly.

****MONTHLY REPORT****

Attached please find the T-RO Monthly Load Report for **July 2008** (updated at **July 31, 2008, 2:00 PM CEST**) in Excel and pdf form.

This report is intended for sharing information on the review process status across all members of the Board, and it includes both:
- papers in review in the **old** system (**only a few remaining**, with paper ID in PURPLE)
- papers in review with the **new T-RO PaperCept** system (paper ID in BLACK).

The pdf version **highlights:**
- **in yellow** (orange for former AEs), **papers that need immediate intervention by the assigned AE**
- **in green, conditionally accepted papers in delay**
- in violet, papers for Special Issues that need prompt intervention

Notes for papers in review in the new T-RO PaperCept (paper IDs 08-(0)YYY):

- If a paper (with a new ID) is a resubmission of a former paper previously handled in the old system (with RR/RS/R/RE decisions), Editors and AEs will find under the link "Files" of the paper also a zipped file (code PAST) with ALL the previous review material (txt) and the pdf of the former paper. This material is routinely uploaded by the EiC office. These papers include a Reply to previous reviewers comments (code RPT).

- "Conditionally accepted" papers that are resubmitted have the same paper ID, but an increased Version. Among the "Files", you can find also the Author Response (code RP) and have direct access also to the material related to the previous version.

- Resubmissions of papers with "Revise and Resubmit" decision have a new paper ID, and a bidirectional link (in the paper "Details") to the previous submission. They include an Author Response (code RP).

- Resubmissions of papers with "Reject" (of any type) decision have a new paper ID, and the paper ID of the previous submission (08-XXXX) in the "Details". They typically include a Response to previous reviewers comments (code RPT). The previous paper and review material (which is already in PaperCept) is also automatically accessible to the new Editor and is made accessible by the EiC in case of a change of AE.

- The AE Report is NOT automatically attached to the final decision of the Editor handling the paper and therefore it does not go "as such" to the authors. This is consistent with our previous policy and allows the maximum freedom of expression by an AE. The AE Report is always saved in the "Archive" of a paper for later editorial uses, but never accessible to the authors.

- There are two sections in the AE Report: "Confidential comments to the Editorial staff" and "Draft formal report for transmittal to the author". You can use them freely at this stage. Still, AEs can help Editors by filling the "Draft formal report" section with what they would like to be transferred to the authors. In fact, for very good AE Reports, Editors typically "cut and paste" this part in their decisions. I have seen that an explicit mention to "AE comments" is used sometimes in the Editor decisions, where this is deemed appropriate.

- It is not needed to list the names of the reviewers in your AE Report. These are already in the system. However, while summarizing their comments, please refer to each of them by using the reviewer code assigned by the system.

- If you feel that some important document or file, or external mail, is worth to be kept inside the system, use the "archive items" feature (and make it available to the paper handlers--the pertinent Editor and the EiC).

- Please refer any technical difficulty or doubt to me (and/or to Pradeep Misra, pradeep.misra@wright.edu).

Notes for papers in review in the OLD system (paper IDs X07-YYY):

Only **31** papers are still concerned with the old system.

There is **1** contributed paper left in (late) review, without AE recommendation... **X07-480**

There are also **20** conditionally accepted papers currently in re-review in the old system (7 of which for V-SLAM urgently due).

10 papers submitted up to Dec 31, 2007 are in the conditionally accepted status, and we are waiting for their resubmission by the authors. These papers will be the last ones to remain in the old system.

When we will be done with all these papers, we shall close the OLD T-RO web site, review forms, and procedures. My previous estimate is confirmed: this will happen by the mid of September.

Special Issues in process:

- **Special Issue on Visual SLAM (V-SLAM)** -handled in the old system: Out of the 49 submissions (45 regular papers and 4 short papers, 16 with multimedia) the status is:

Decisions: 11 accepted (1 final at IEEE, 5 finals to arrive at EiC office, 5 accepted by GE with decision by Editor being sent out ---3 of which completed right after the preparation of this report), 2 conditionally accepted in final review (**X07-581 with GE xxxx, and X07-567 with GE xxxx**), 36 reviewed and not accepted (3 editorially rejected). The acceptance rate is thus **26,5 %** (12 regular + 1 short paper).

We need to close the final review of the two pending papers by Monday, August 4 at the latest, in order to make it for the October issue as planned. Because of the very tight schedule, we are asking the authors of these late accepted papers to submit the final material directly to IEEE **by August 10** (with copy of the pdf to the EiC office). We are also waiting for the **Guest Editorial by the GEs.**

- **Special Issue on Rehabilitation Robotics** -handled in T-RO PAperCept: No submissions were received up to now. We are expecting about 30 to 50 papers by the submission deadline of **September 15, 2008.** I will assign all papers to the supervising Editor xxxx (relieving him in part of the normal contributions), who should arrange with the three Guest Editors the way these will be distributed/handled among them.

Situation of papers:

- At **two months from its 5 years** of life (i.e., since October 1, 2003, when submissions to T-RO were first open), T-RO received **2418** submissions: 87 in the last three months of 2003, 425 in 2004, 449 in 2005, 555 in 2006 (out of which, 467 contributed submissions), 600 in 2007 (out of which, 498 contributed submissions), and **302 in the first seven months of 2008 (all in T-RO PaperCept).** Submissions in July were **47**, while we had in the past years: 58 in 2007, 33 in 2006, 36 in 2005, and 47 in 2004.

- Out of the total number of 2418 submissions (Oct 1, 2003 to July 31, 2008), 2275 have already been reviewed/processed (at least once):

57 returned by the EiC
2 discarded (error submissions)
36 withdrawn
1669 reject or revise and resubmit
47 conditionally accepted --37 of which currently in re-review
464 accepted papers -- 428 of which published in 25 T-RO issues (including the forthcoming August 2008 issue)

- The overall **acceptance rate is 23.44%**, as computed by the formula:

acceptance rate =
(papers accepted + papers conditionally accepted) / (papers reviewed - papers returned by EiC, discarded, or withdrawn)

- Out of the **143** papers in review, **22 papers have past their deadline without AE recommendation, and**

13 of them since more than three weeks. I am expecting recommendations/decisions to be taken on all these within the next two weeks.

- Out of the **37** conditionally accepted papers in review, **12 papers are in delay without AE recommendation (2 for VSLAM)**

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Thank you very much for your improved efforts in obtaining quality reviews in a timely fashion.

Best
Alessandro and Daniela

P.S.: Two more monthly reports for us to go...

NOTES FOR READING THE ATTACHED FILES

a) The report is updated with data collected until **July 31, 2008, 2:00 PM CEST**, and includes:

- T-RO papers in review (in the old system, as well as in the new T-RO PaperCept system)
- T-RO conditionally accepted papers in review

b) The Load Report is sent to all members of the Editorial Board, including Guest Editors. It is also sent to previous members that still have assigned papers in review. The Load Report only contains papers **under review** (without Editor decision) at the report date.

c) On top of the report, the list of papers in "nominal" charge to the Editors refer to papers co-authored by an Editor or an Associate Editor and handled by another AE (masked). This is in accordance with our privacy policy. For the conditionally accepted papers at the end of the report, a blue dash (---) indicates a similar situation.

d) The format for dates is month-day-year, time intervals are expressed in days. The names of the fields should be self-explanatory. In particular:

* AssignToE = date of paper assignment from EiC to Editor
* AssignToAE = date of paper assignment from Editor to AE
* EdTime = date of this report - AssignToE
* If AE Recommendation has been sent, then AETime = AERecommToE - AssignToAE,
  else AETime = date of this report - AssignToAE

e) The last column contains the **total** number of papers handled by an AE in the last **12 months** (MOB=AE No longer On Board).

Personal memories: the review committee of the SAPHARI project

A typical e-mail to the reviewers: 967 words, 3 colors, and, of course, not a single typo

Dear SAPHARI Reviewers and PO

Thank you for waiting so patiently for us... here is a long email for you!

We have uploaded to the SAPHARI web site http://www.saphari.eu the materials due for Y1 review.

You have been registered to the web site (and should have received a confirmation mail). You can login and access now also selected reserved areas using the following:

username: your surname (all lowercase)
password: your first name (all lowercase, with accents if present!)

Below is a list of what you will find (I have added a few useful notes).

LAST MINUTE: We are currently having a problem with the Aruba server for some large files that appear to be corrupted.
In the meantime, please use the following dropbox link to download the three documents mentioned at items 1) ad 2) below.

http://dl.dropbox.com/xxxxxxxxxxx.zip (135MB, 3 minutes download with an office-like fast connection)

All the rest is working from the SAPHARI web site. Sorry for the inconvenience.

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1) The main Deliverable D10.1.2 "Yearly periodic activity and management report - Year 1" as a zipped/PDF file In **Documents-->Periodic Reports-->Y1**

SAPHARI_periodic_report_y1_Final.zip (the pdf file is about 60MB)

This is a 200+ page document. About 3/4 is devoted to the progress on RTD activities (WP1-WP8) during Y1: pp. 11-160.
The part on WP9 Dissemination includes also the lists of events, papers, media/news, etc. (pp. 161-184).
The last sections of the report (from Section 3 to the end, pp. 185-212) concern Management (WP10).

Please note that we have an on-going administrative amendment to the project.
This concerns the inclusion of a new beneficiary (University of Bremen), starting from November 1, 2012 (i.e., from Y2 on), as a result of the move of Prof. xxxxx group from TUM to UNI-HB.
The only change to the original SAPHARI workplan is that tasks, costs etc of TUM will be distributed between TUM and UNI-HB.

Being such amendment (actually, this is Amendment 2) currently active/pending in the EC NEF site, the official Forms C for Y1 could not be filled yet on the EC web site.

However, the equivalent and complete information has been already included in the Tables of the last part of the Y1 Report, as per our agreement with our PO.
(see: 5. Explanation of the use of the resources, pp. 188-207; 6. Cost budget follow-up table, pp. 208-209; 7. Person-Month status table, p. 210)

Therefore, Section 8 (Financial statements, Forms C, and Summary Financial report) of the Y1 Report is currently empty ---will include forms/tables downloaded from the EC web site, once ready.

2) Zipped archives of all Y1 Milestones and all Y1 Deliverables in **Documents-->Periodic Reports-->Y1**

Milestones_y1.zip (7 pf files)
Deliverables_y1.zip (5 pdf files)

In order to reduce downloads, you will find these two zipped archives in the same area (the single files are also separately available, as described below at items 4 and 5).

3) The list of all SAPHARI publications of Year 1 (with PDFs for download) in **Documents-->Periodic Reports-->Y1 Publications**

Few PDFs are still missing, but will be uploaded asap (we are actively working on this).

Note that the same list of Y1 publications (Nov 2011-Oct 2012) is also publicly accessible at **Download-->Publications,**
but without PDFs (we will try later on to resolve copyright issues appropriately).

4) The seven Milestones due in Year 1 as PDF files in **Documents-->Reference Library-->Official-->Milestones**

MS1 Community building and support tool - Alpha version
MS2 Preliminary prototypes of new actuators
MS3 Optimal control of modular VSA manipulators
MS4 Selection of safety-relevant sensors for human-robot interaction
MS5 Implementation of a voxel-based scene representation
MS6 Conceptual design of interface framework
MS7 Use case requirements communicated to other WPs (for T8.2-T8.4)

5) The other Deliverables due in Year 1 as PDF files in **Documents-->Reference Library-->Official-->Deliverables**

- two deliverables are from RTD work packages (respectively, WP4 and WP8):

D4.4.1 Detection and isolation of sensors/actuators faults
D8.4.1 Alternative scenario(s) fully exploiting the pMRI in a hospital setting

- one is from the Dissemination WP9, and is divided in two parts: D9.1.2_Poster and D9.1.2_Leaflet

- one is from the Management WP10: D10.1.1 Project presentation

This deliverable refers mainly to a slide presentation of the project, which is publicly accessible (on-line view or PDF download) under the top menu **PROJECT-->PRESENTATION**

- note that D9.1.1 is the web site itself (so, there is a total of 6 deliverables in Y1, including the Periodic Report)

6) A collection of videos related to SAPHARI research activities in Y1 in **Download-->Video Gallery**

This is a publicly accessible collection of videos which can be viewed on line, or downloaded individually. More videos may be soon uploaded.

7) The official documentation of the project in **Documents-->Reference Library--> Official-->DoW and Agreements**

I suggest to refer to the two main documents, which are:

- DOW SAPHARI 287513 2012-02-29.pdf [Description of Work - Annex I: Part A, Workplan Tables, and Part B]
- GPF SAPHARI 287513 2012-02-29.pdf [Grant Preparation Forms]

The date is the one of the Amendment 1 (February 2012), where we changed a few administrative data and included the Appendix 5 in Part B (the list of Milestones, with means of verification), which was erroneously left out in the pdf of the first DOW.

Please let me know if you encounter any problem in accessing/downloading/reading the materials.

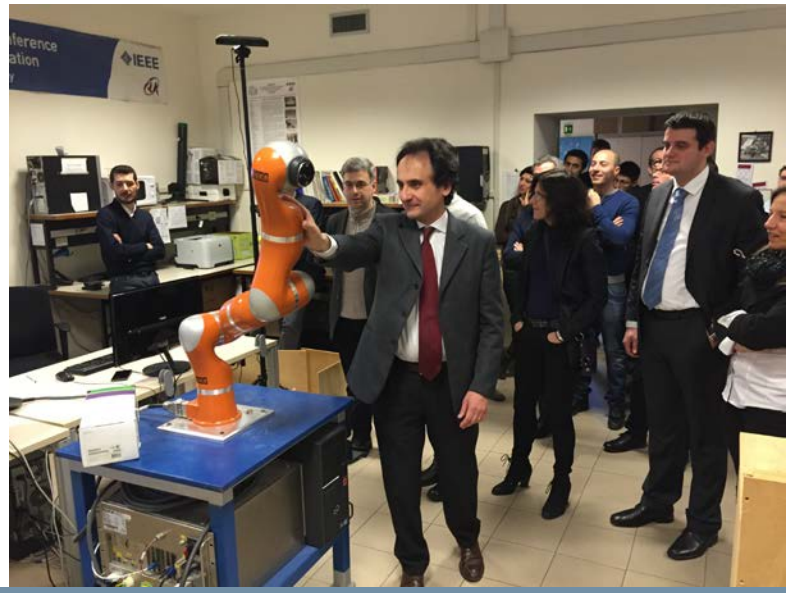
Also, let Laura Maley know if you wish to receive at your place the hard copy of the whole material (or of selected parts). She will send it to you by express courier.

Finally, the organization of the Y1 review meeting (DLR, Oberpfaffenhofen, February 6-7, 2013) is in progress. I will be back to you with a more detailed agenda by the end of this week.

Best regards

Alessandro De Luca
Coordinator of SAPHARI

SAPHARI
SAFE AND AUTONOMOUS PHYSICAL HUMAN-AWARE ROBOT INTERACTION



Happy 60s Alessandro!