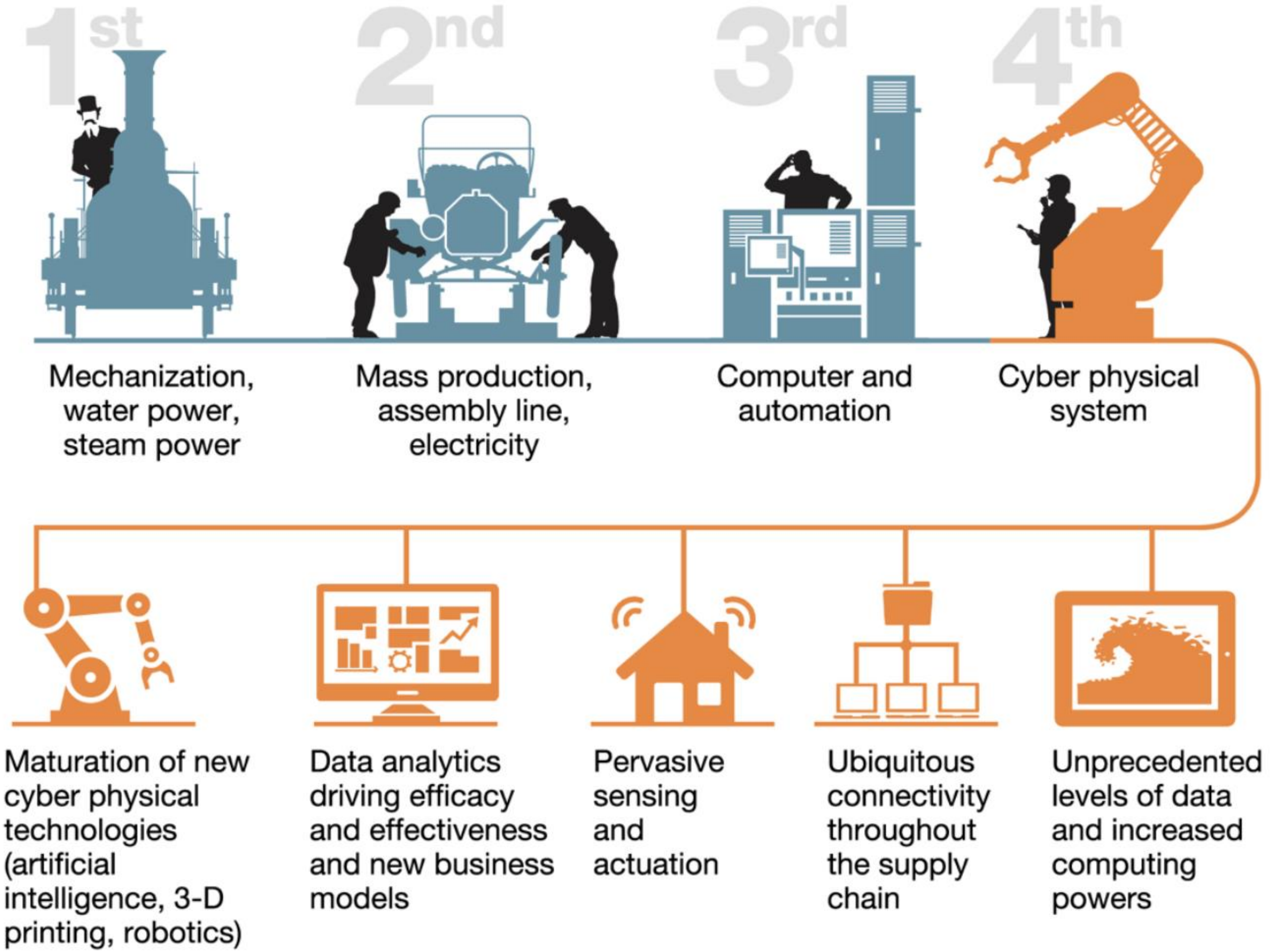
Going Soft with ADL

antonio bicchi
manuel catalano
giorgio grioli
manolo garabini
matteo bianchi
giovanni tonietti
lucia pallottino
et al.

CENTRO "E. PIAGGIO"
UNIVERSITA' DI PISA

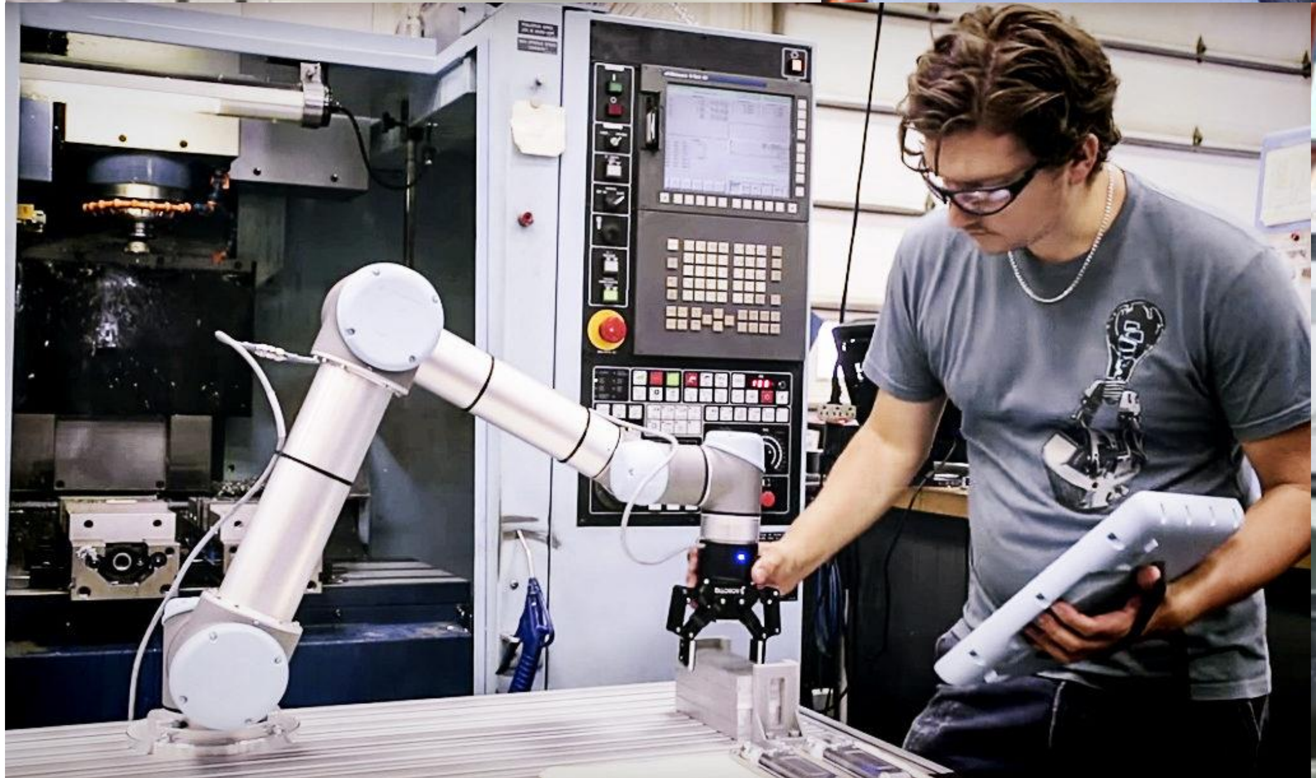
iit SoftBots
ISTITUTO ITALIANO
DI TECNOLOGIA



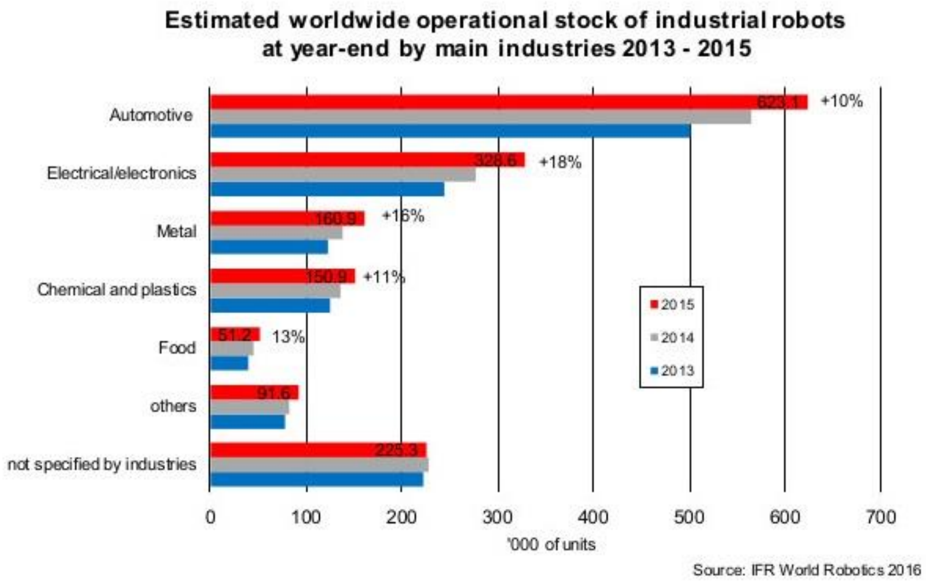
McKinsey&Company | Source: *Forbes*; World Economic Forum

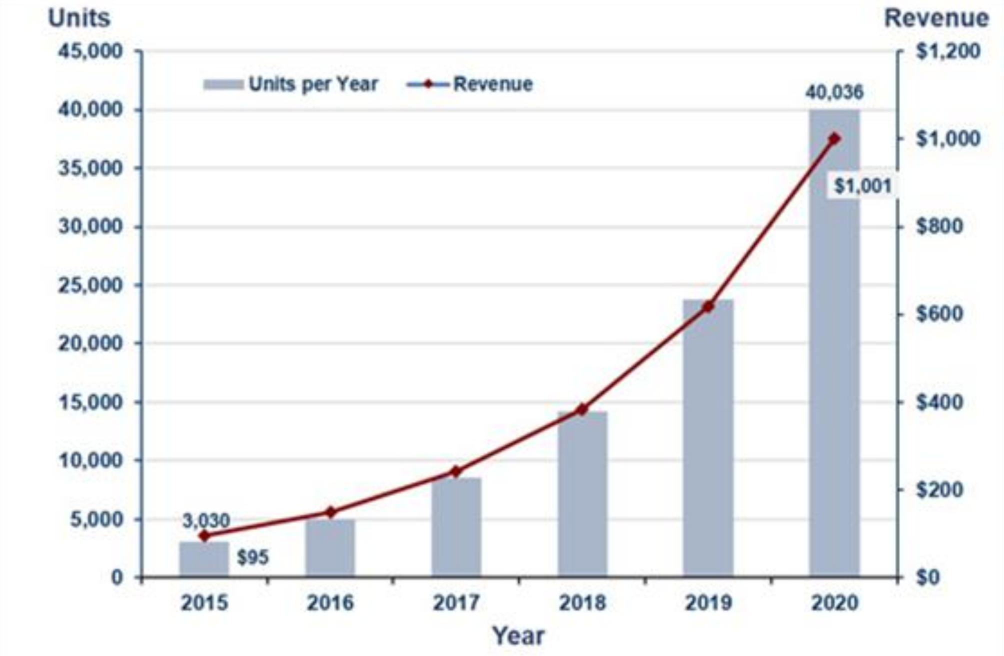





KUKA
KUKA



Collaborative Industrial robotics





Collaborative robot sales projected to exceed $1 billion by 2020.
(Courtesy of ABI Research)

We (Barclays Research) believe the co-bot high growth phase will last until at least 2025

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Germany	100	220	450	700	1 100	3 000	5 000	9 000	15 000	25 000	35 000	47 000	59 000	68 000
United States	100	220	450	1 000	1 300	6 000	11 000	16 000	28 000	46 000	67 000	89 000	111 000	128 000
China	100	220	450	800	2 500	12 000	20 000	30 000	49 000	83 000	123 000	161 000	201 000	232 000
Japan	100	220	450	700	2 000	6 000	10 000	16 000	27 000	46 000	67 000	87 000	109 000	126 000
South Korea	100	220	450	700	2 200	2 000	6 000	10 000	16 000	28 000	39 000	52 000	66 000	76 000
Other Countries	200	200	250	400	1 000	3 000	6 000	9 000	15 000	25 000	37 000	48 000	61 000	70 000
Total Co-Bot units	**700**	**1 300**	**2 500**	**4 300**	**10 100**	**32 000**	**58 000**	**90 000**	**150 000**	**253 000**	**368 000**	**484 000**	**607 000**	**700 000**
Average Selling Price	22,700	22 700	24 000	28 177	27 860	24 812	23 386	21 951	20 955	20 273	19 470	18 732	18 079	17 448
Market Size Estimate US$ Mn	16	30	60	116	282	808	1 348	1 978	3 146	5 123	7 157	9 074	10 970	12 228

Source Barclays Equity Research

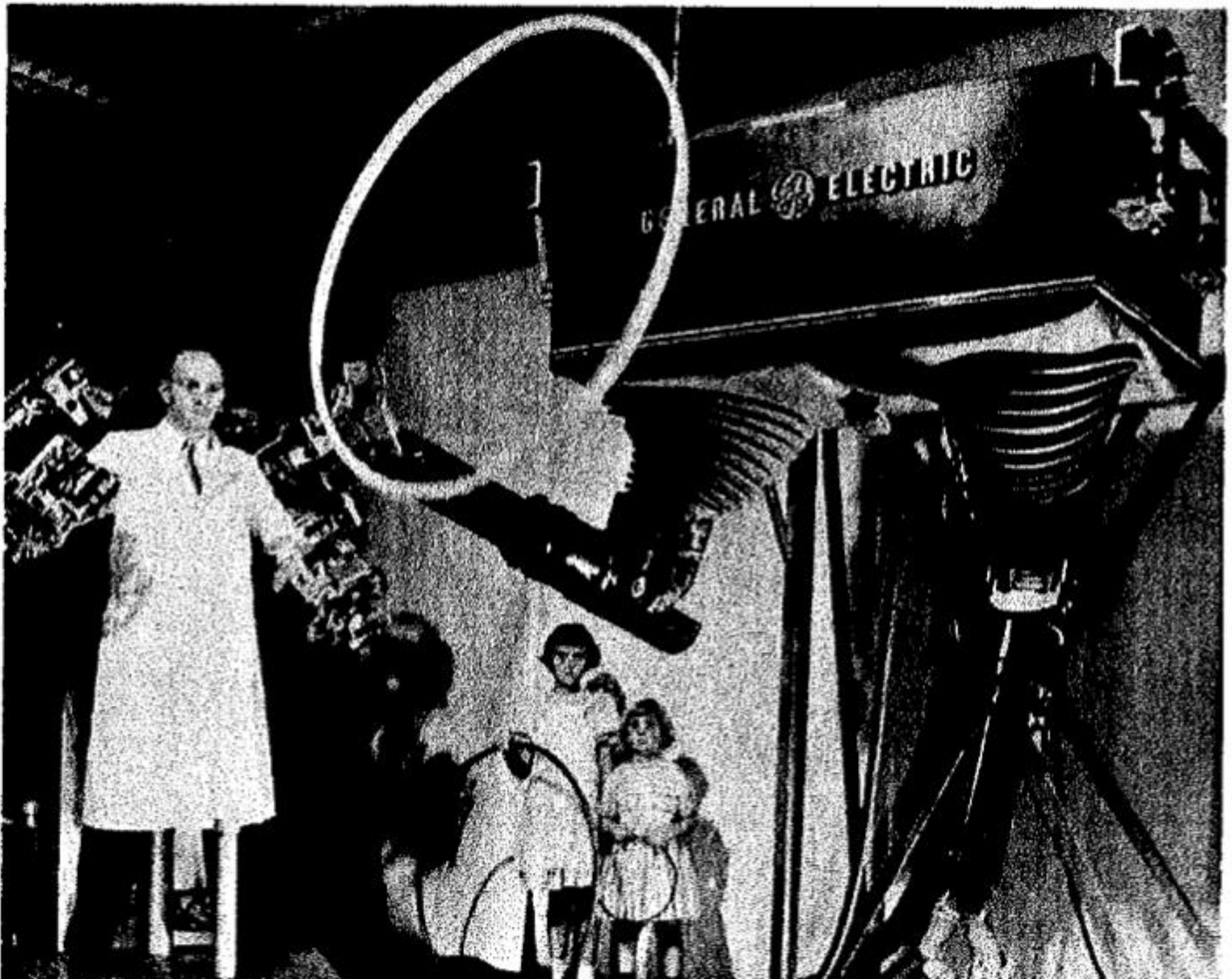
Collaborative Robotics

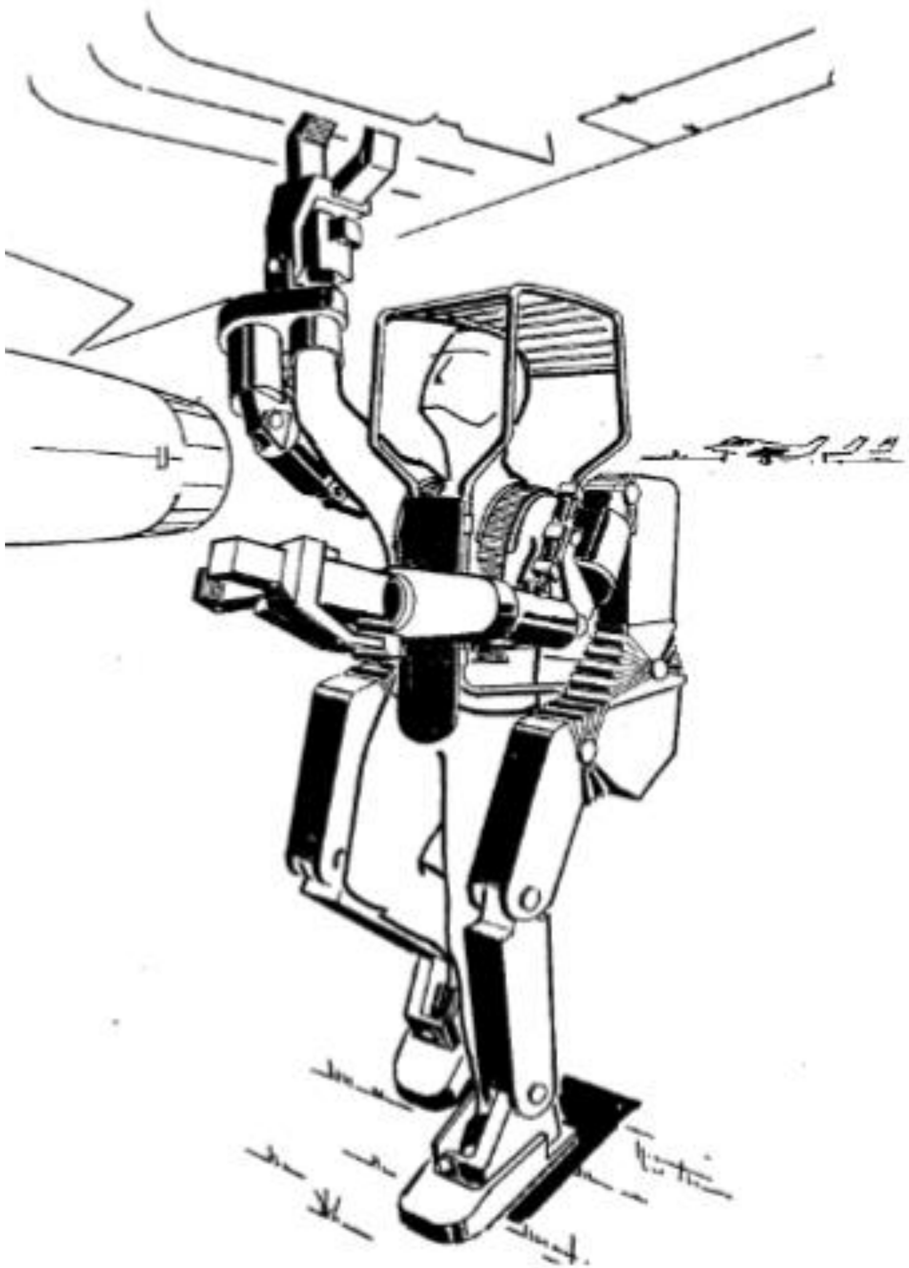
- Motivations
- A historical perspective
  - The sixties
  - The nineties
  - Today
- Soft Robotics
- Manipulation

Collaborative Robotics

First Wave: the Sixties

1967 General Electric





Handyman to Hardiman

Ralph S. Mosher
Research and Development Center
General Electric Company

670088

Figure 4a. Lacking Human Sensing, Robot Snaps Door.

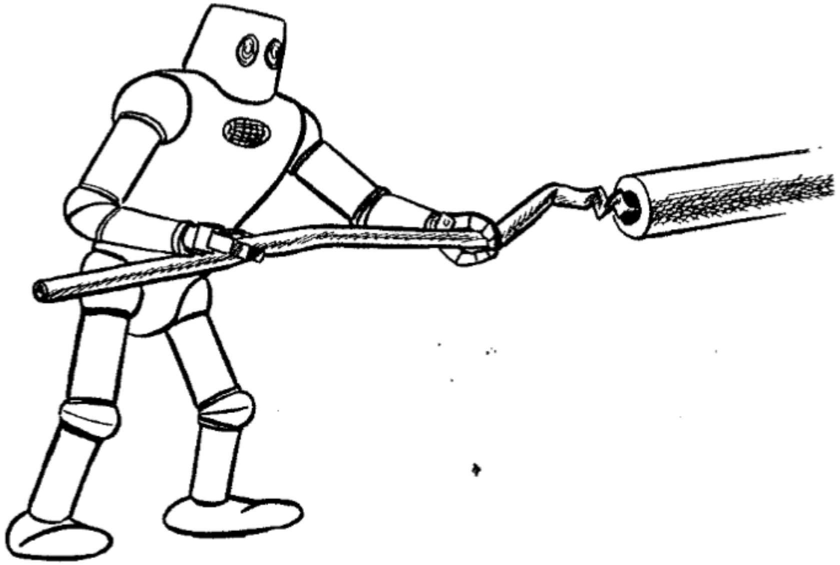


Figure 4c. Lacking Human Sensing, Robot Jams and Bends Pipe.

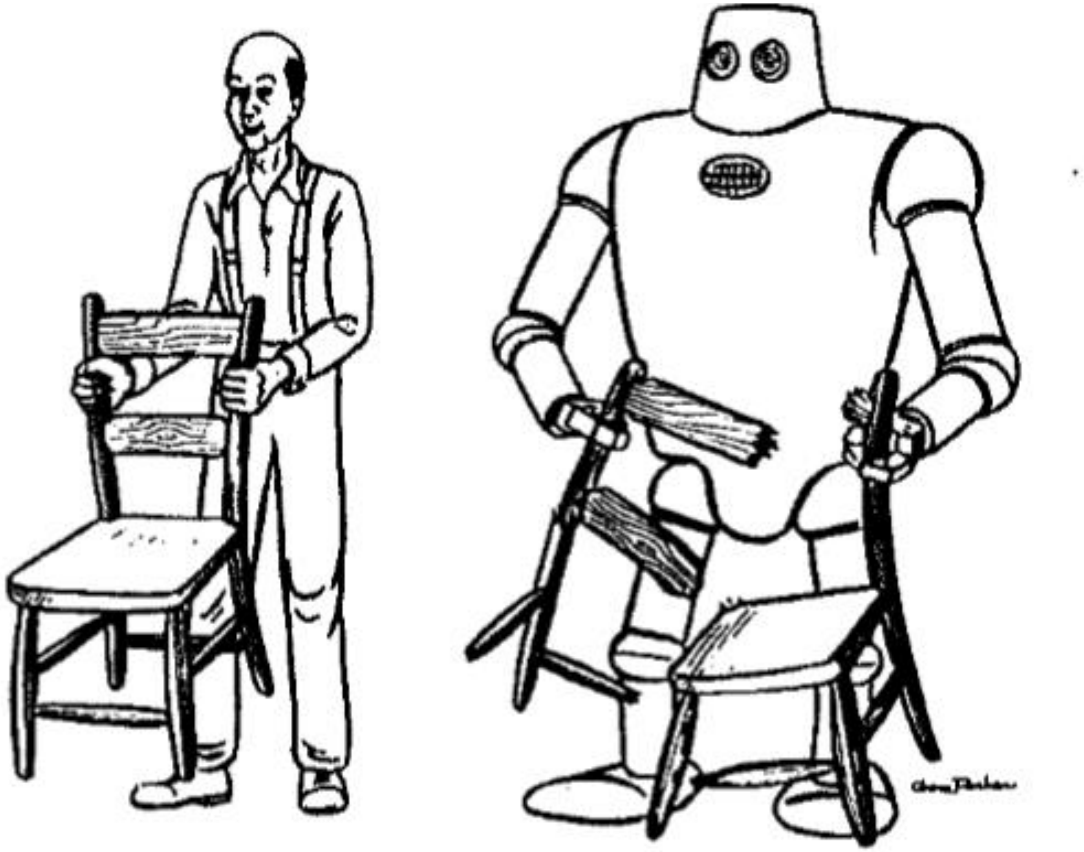


Figure 4b. Lacking Human Sensing, Robot Shatters Chair.

Collaborative Robotics

Second Wave:
the Nineties

H. Kazerooni

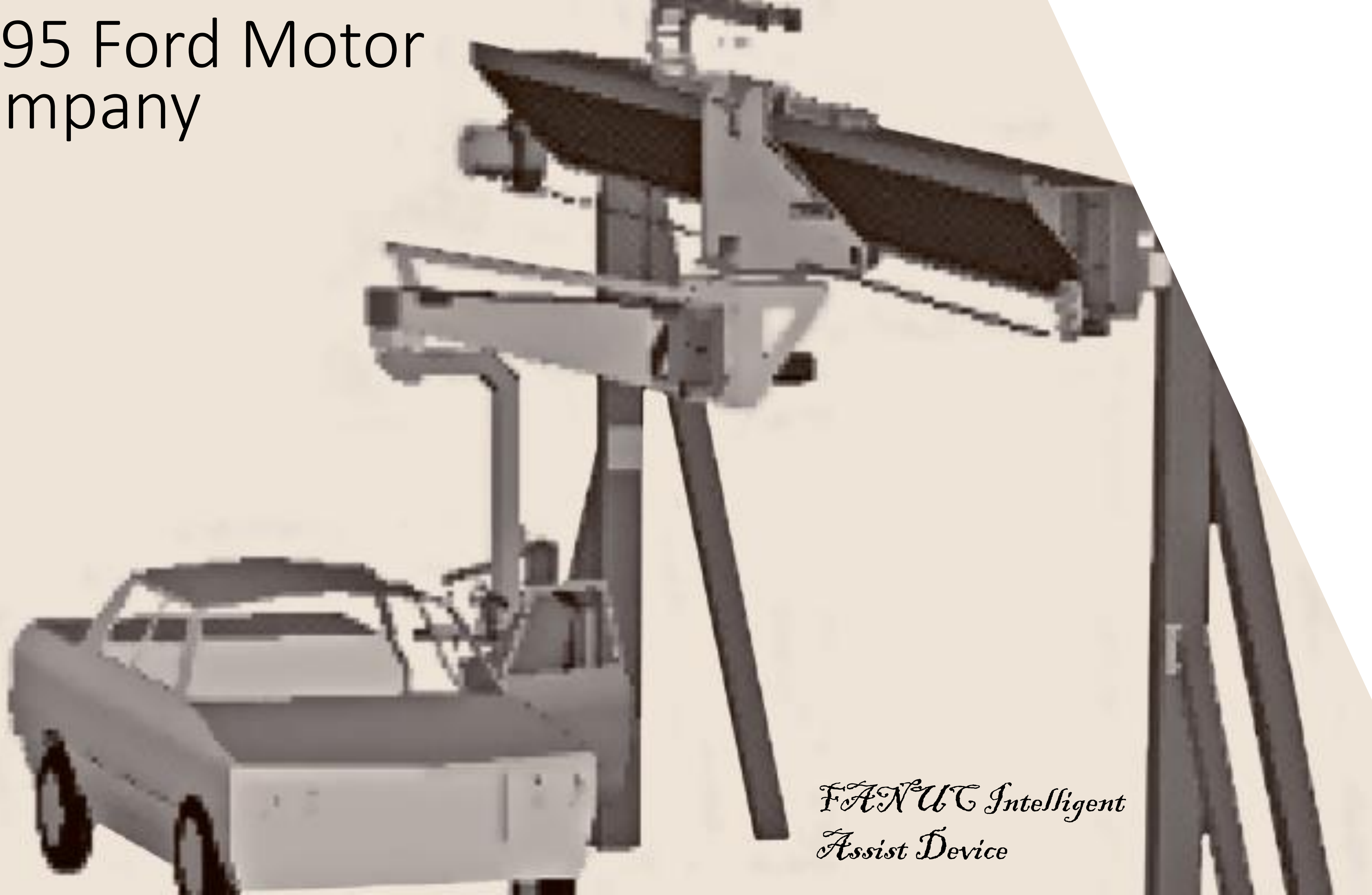
U.C.Berkeley

1995 General Motors

M. A. Peshkin, J. E. Colgate
Northwestern Univ.

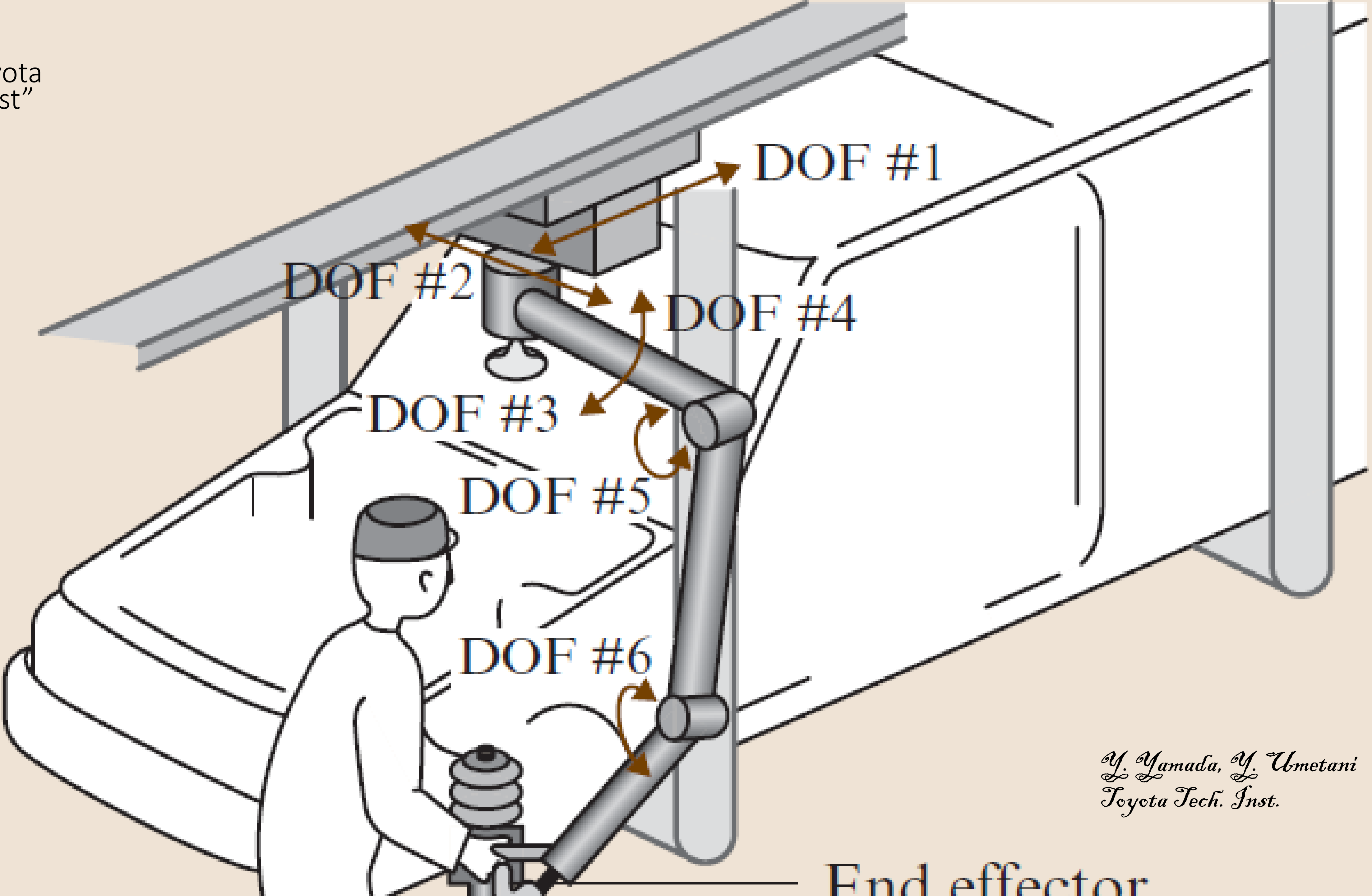
1995 General Motors

1995 Ford Motor Company



FANUC Intelligent Assist Device

1999: Toyota
"Skill Assist"

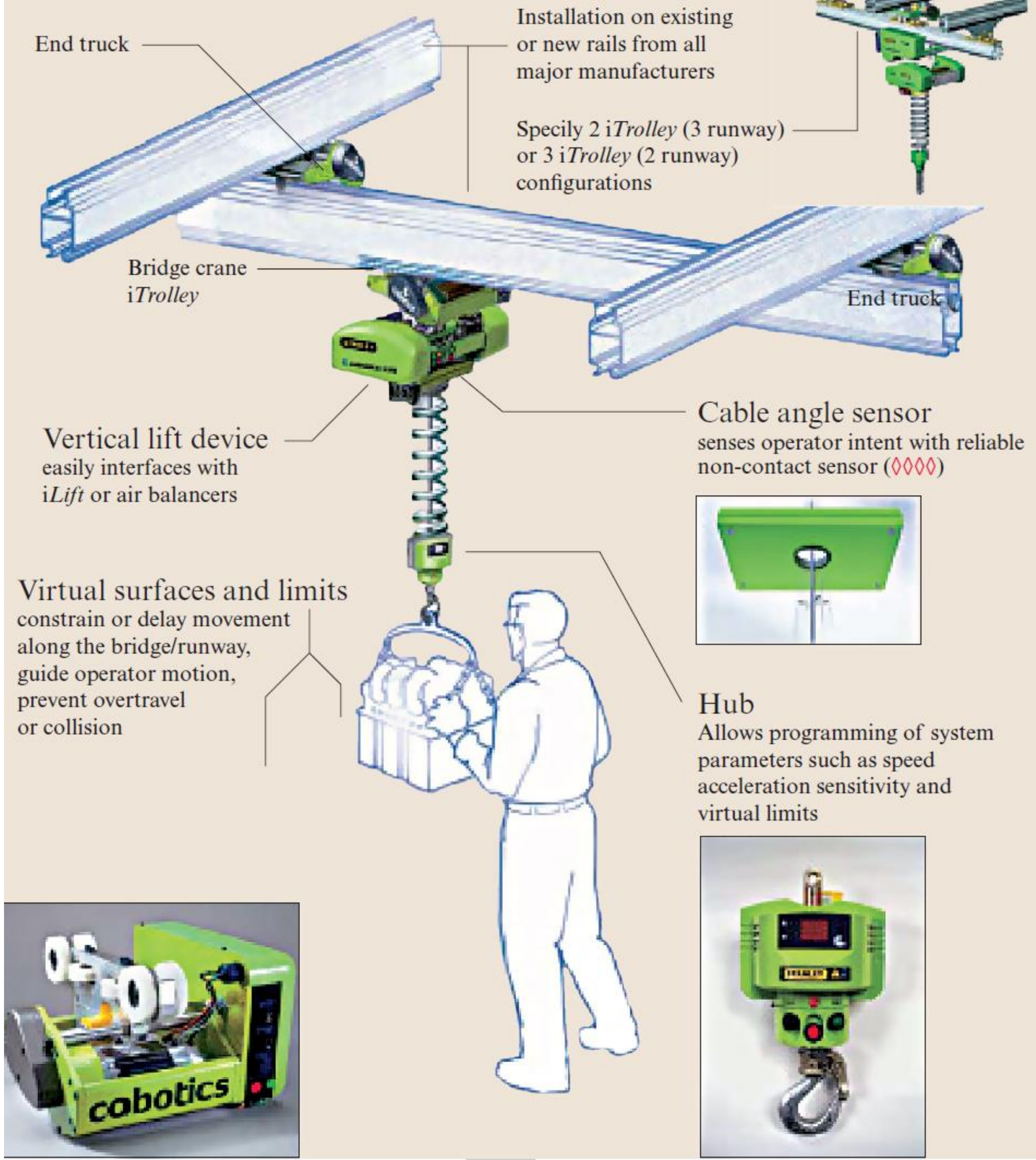


Y. Yamada, Y. Umetani
Toyota Tech. Inst.

1995

M. A. Peshkin and J. E. Colgate launch a spinoff for producing IADs

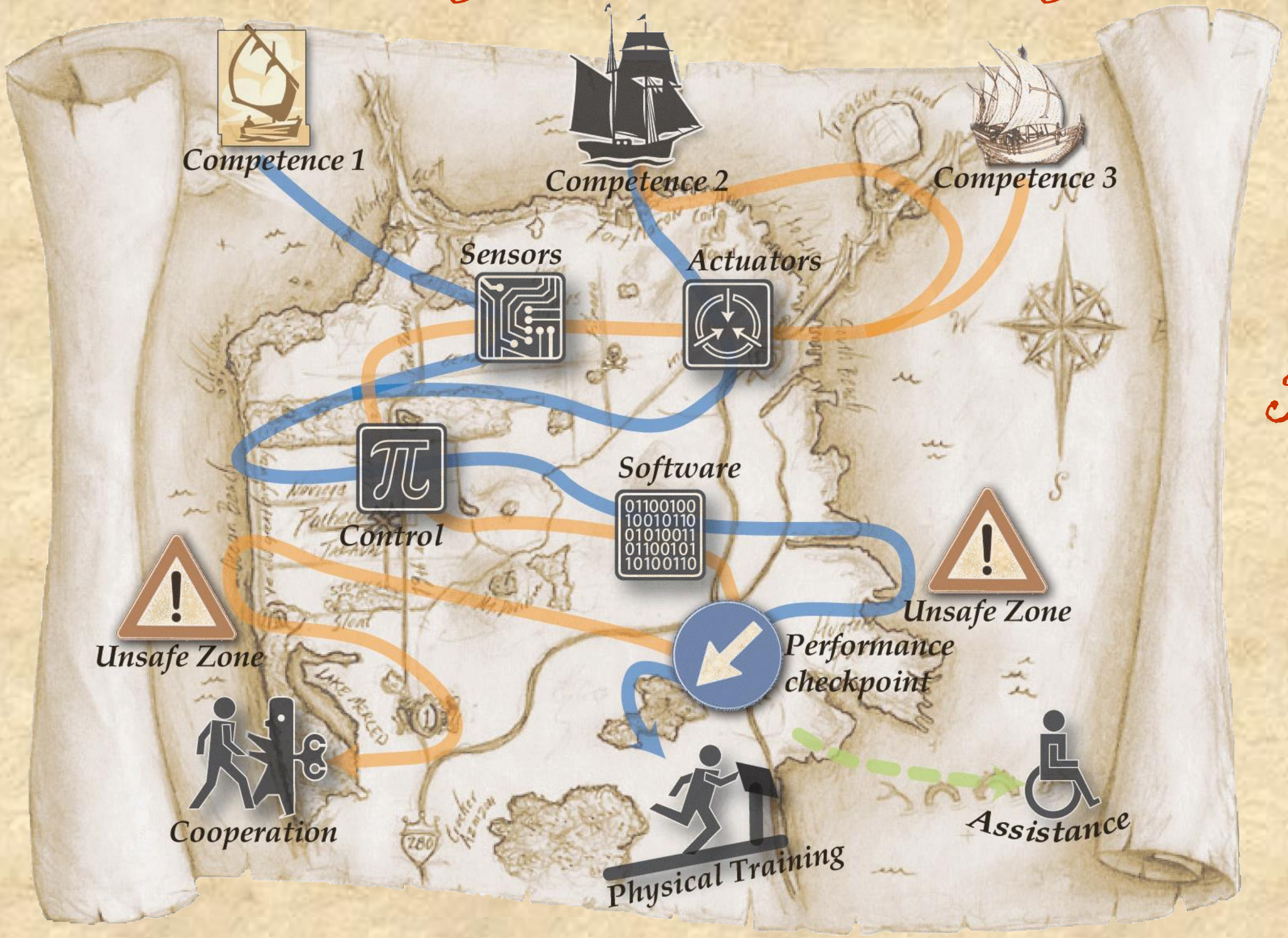
Cobotics
is born



Collaborative Robotics

The New Wave
2004-Today

Physical Human-Robot Interaction in Anthropic Domains: Safety and Dependability

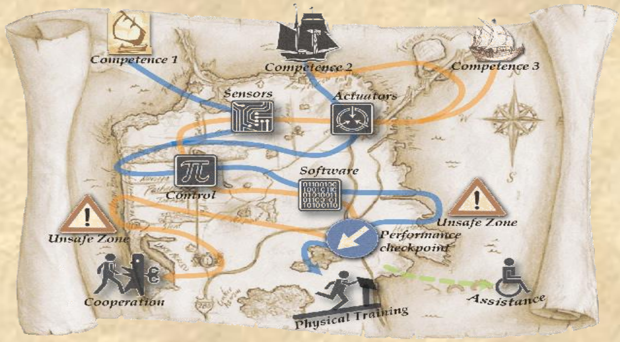


PHRIDOM

EURON 2005
Prospective Research Project

PHRIDOM

PHYSICAL HUMAN-ROBOT INTERACTION IN ANTHROPIC DOMAINS: SAFETY AND DEPENDABILITY



This project is about charting a new territory, whose exploration has been only recently undertaken.

The "*territory*" is that of physical Human-Robot Interaction (pHRI).

Its "*geographical features*" mainly consist of:

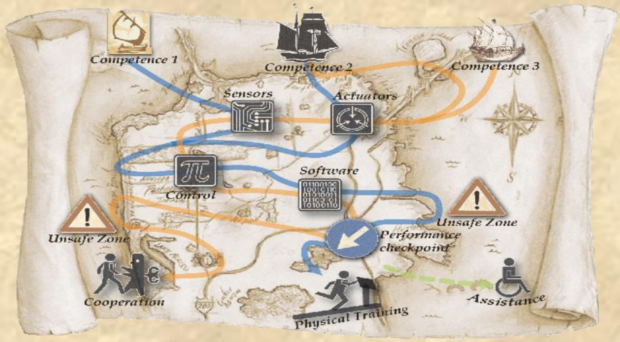
- ***Applications* (“Destinations”):** tens of examples of intelligent machines embedded in anthropic domains – i.e. environments shared by machines and humans, working together elbow-to-elbow, or even more closely;

- ***Requirements* (“Viability conditions”):** safety, dependability, reliability, failure recovery, performance;1

…

PHRIDOM

PHYSICAL HUMAN-ROBOT INTERACTION IN ANTHROPIC DOMAINS: SAFETY AND DEPENDABILITY



…

- ***<u>Technologies</u> ("Strongholds"):*** sensors, actuators, mechanics, control, SW architectures;

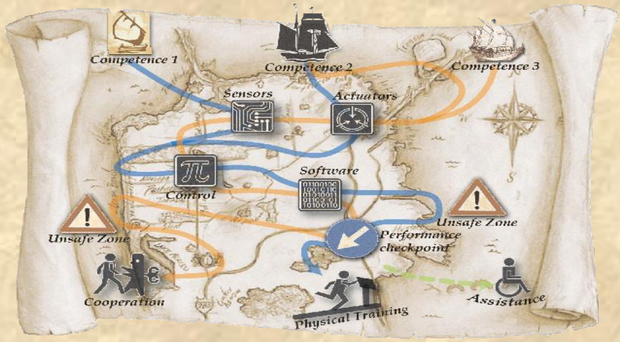
- ***<u>Systems</u> ("Routes"):*** connecting crucial components and leading to technological solutions to applications, while fulfilling the requirements;

- ***<u>Competences</u> ("Crews"):*** the centres of excellence among academic and industrial groups from which a successful research crew can be recruited.

PHRIDOM CREW

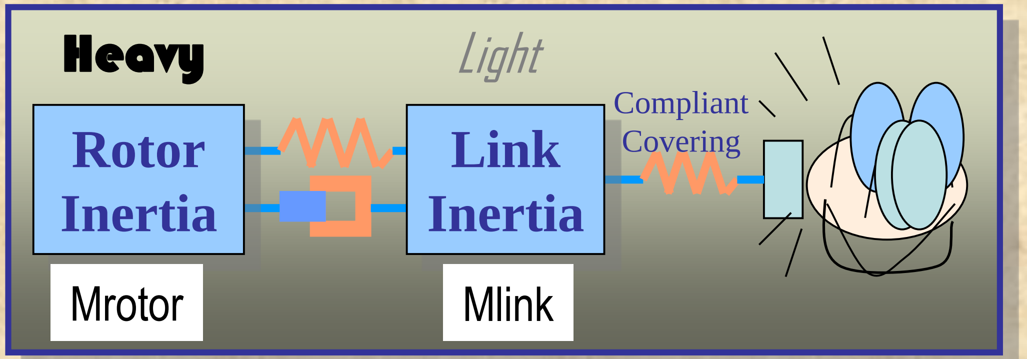
- *UNIPI* – The Interdepartmental Research Center "E. Piaggio" *[A. Bicchi]*
- *LAAS* – Laboratoire d'Automatique et de Systèmes *[G. Giralt]*
- *UNINA* – DIS PRISMA Lab *[B. Siciliano]*
- *DLR* – Deutsches Zentrum für Luft- und Raumfahrt *[G. Hirzinger]*
- *UNIROMA1* – DIS LabRob *[A. De Luca]*

CONTRIBUTIONS TO PHRIDOM

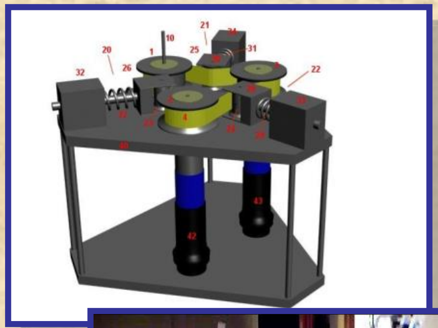


UNIPI:

1. Co-design of mechanics and control for intrinsic safety



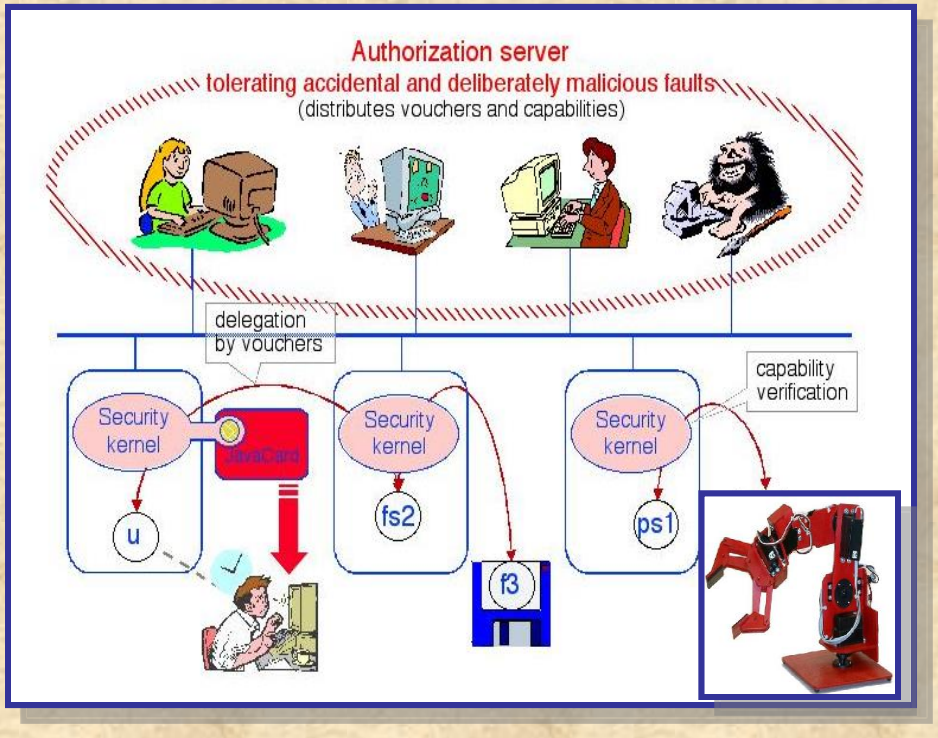
2. Variable Impedance Actuators



CONTRIBUTIONS TO PHRIDOM

LAAS:

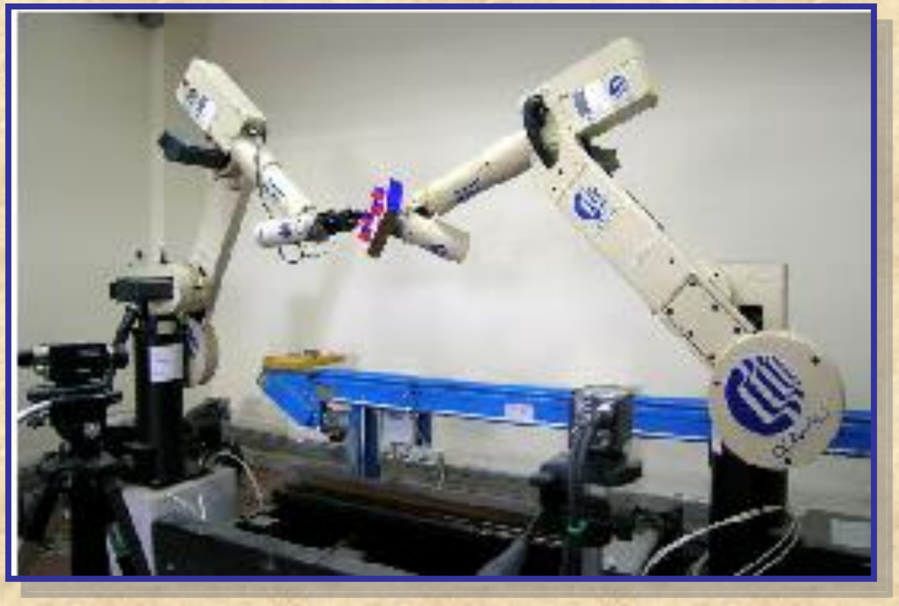
1. Dependable decision-making for autonomous robots and systems
2. Dependable computing, fault tolerance in distributed systems
3. Tools

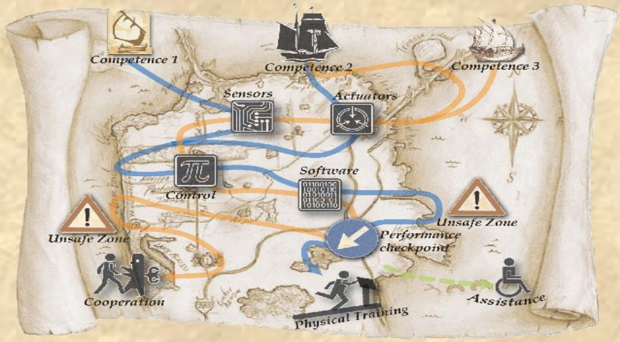


CONTRIBUTIONS TO PHRIDOM

UNINA:

1. Visual servoing and Cooperation
2. Task-space and Force-Impedance Control of Compliant Arms
3. Adaptive and fault-tolerant control

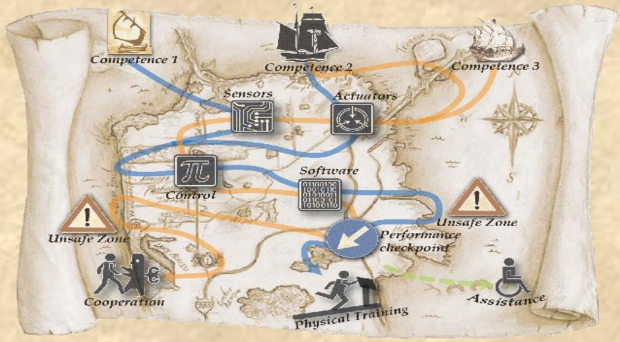




CONTRIBUTIONS TO PHRIDOM

DLR:

1. Light-weight design
2. Redundant sensors
3. Control strategies



CONTRIBUTIONS TO PHRIDOM

UNIROMA1:

1. Control of robots with flexible elements (links/joints)
2. Sensorless collision detection
3. Force-motion control of robots in contact with the environment

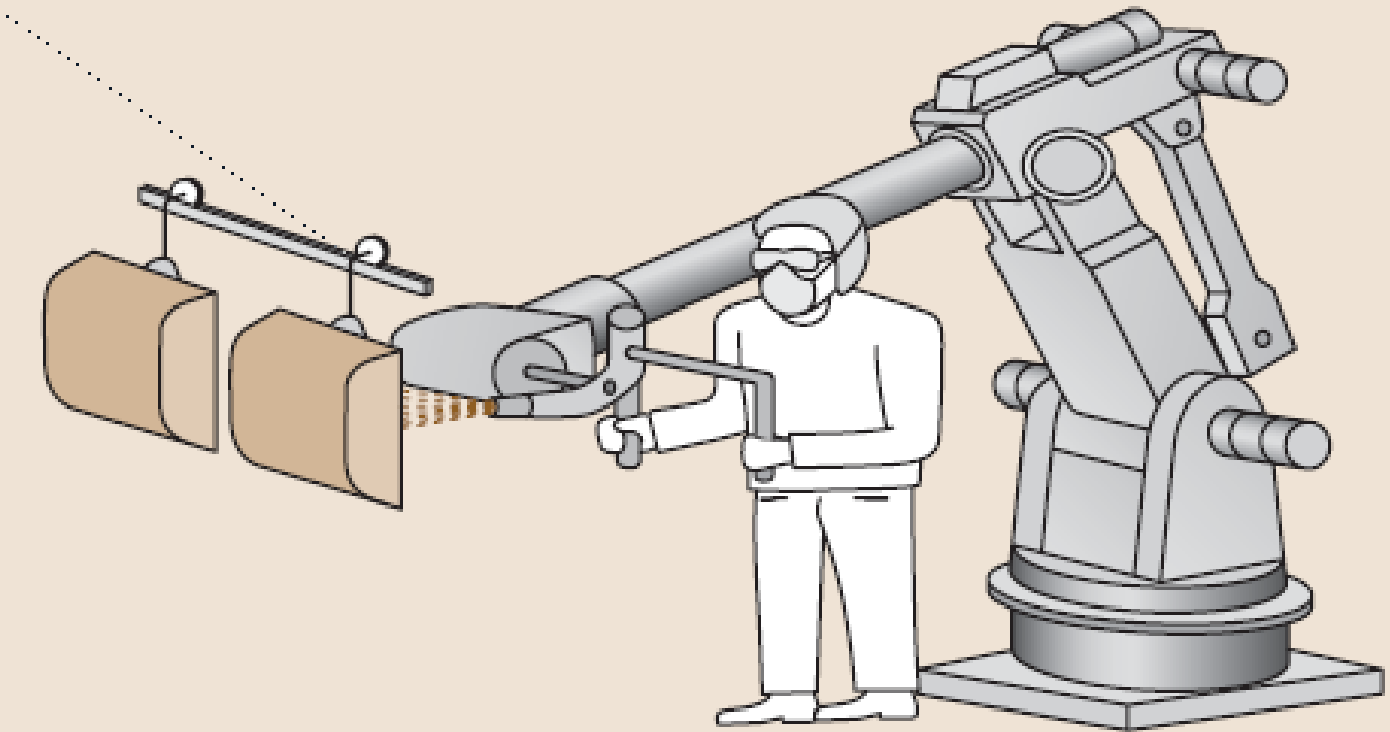
Physical Human-Robot Interaction in Anthropic Domains: Safety and Dependability

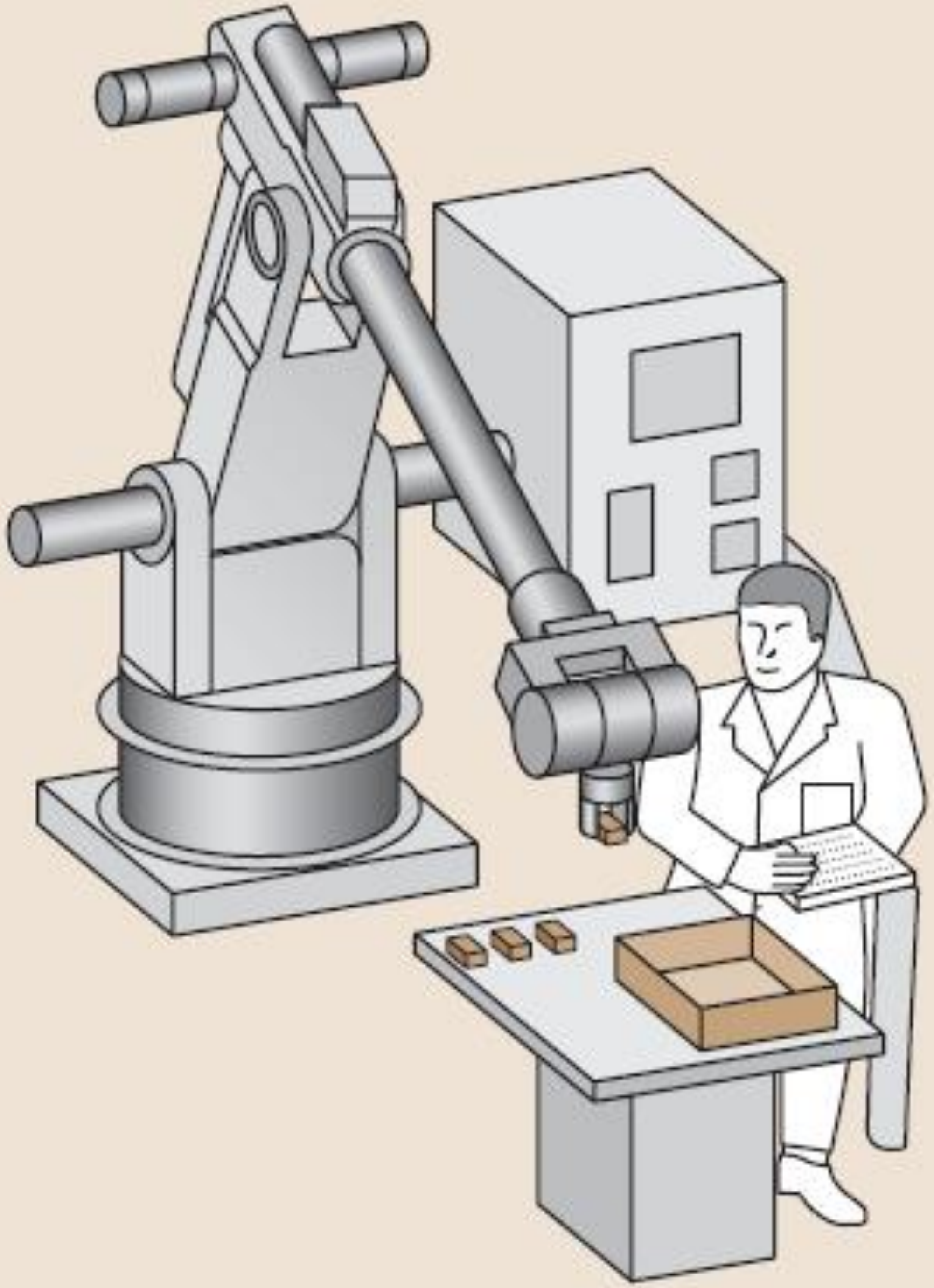
PHRIDOM

EURON 2005
Prospective Research Project

“many robot accidents do not occur under normal operating conditions, but instead during programming, program touch-up or refinement, maintenance, repair, testing, setup, or adjustment. During many of these operations the operator,
programmer, or corrective maintenance worker may temporarily be within the robot's working envelope where unintended operation could result in injuries”

[OSHA’06]



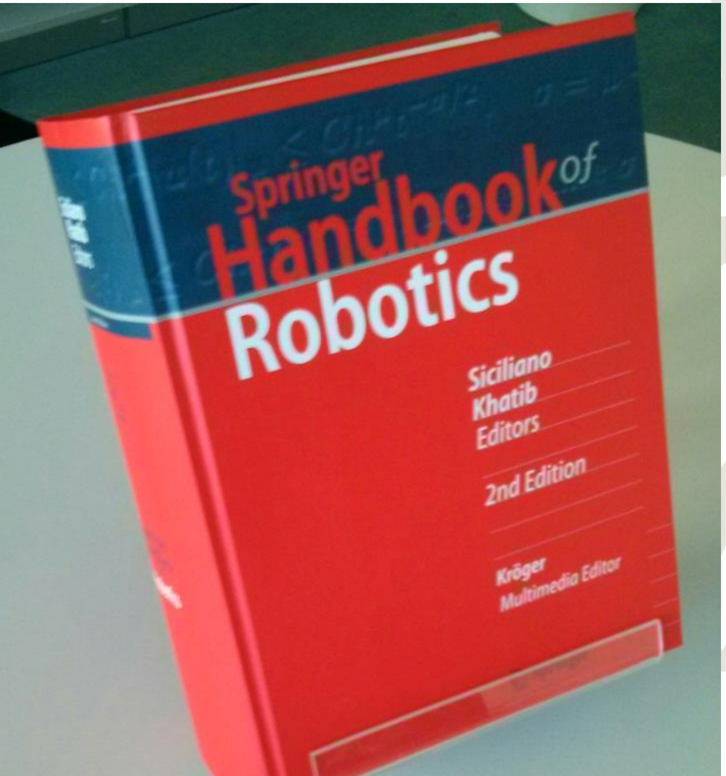


CoBots Milestones: 2006

Springer Handbook of Robotics

Bruno Siciliano, Oussama Khatib (Eds.)

With DVD-ROM, 953 Figures, 422 in four color and 84 Tables



57. Safety for Physical Human–Robot Interaction

Part A | 57

A. Bicchi, M.A. Peshkin, J. E. Colgate

In this chapter, we report on different approaches to dealing with the problem of achieving the best performance under the condition that safety is provided throughout task execution. We also report on intelligent assist devices that go beyond conventional notions of robot safety to protect human operators from possible harm, such as cumulative trauma disorders. However, intelligent assists and other physical human–robot interaction (pHRI) devices are themselves generally powerful enough to cause harm. We argue that the differences between pHRI applications and conventional industrial manipulation entail that safety and reliability standards be rethought, and offer a preview of the direction currently being undertaken by international standard committees.

This chapter discusses the new frontiers of robotic physical interaction with humans, describing first motivations and applications of safe pHRI. The state of the art, and the technical challenges to develop new robotic systems for safe and effective collaboration with people, are hence discussed, subdividing the exposition into hands-off and hands-on pHRI systems. We finally present an overview of the applicable safety standards and their ongoing development.

MINISTERO DELL'ISTRUZIONE, DELL'UNIVERSITÀ E DELLA RICERCA
DIPARTIMENTO PER L'UNIVERSITÀ, L'ALTA FORMAZIONE ARTISTICA, MUSICALE E COREUTICA E PER LA RICERCA SCIENTIFICA E TECNOLOGICA
PROGRAMMI DI RICERCA SCIENTIFICA DI RILEVANTE INTERESSE NAZIONALE
RICHIESTA DI COFINANZIAMENTO (DM n.582/2006 del 24 marzo 2006)

PROGRAMMA DI RICERCA - MODELLO A
Anno 2006 - prot. 2006091443

PARTE I

1.1 Programma di Ricerca afferente a

Area Scientifico Disciplinare *09: Ingegneria industriale e dell'informazione 100%*

1.2 Titolo del Programma di Ricerca

Testo italiano
Metodi orientati alla sicurezza per l'interazione fisica tra robot e utenti (ESPHRI - Enhanced Safety in Physical Human-Robot Interaction)

Testo inglese
ESPHRI - Enhanced Safety in Physical Human-Robot Interaction

1.7 Coordinatore Scientifico del Programma di Ricerca

DE LUCA *(Cognome)* *ALESSANDRO* *(Nome)*

Submission = Deadline + 1 Minute

MINISTERO DELL'UNIVERSITÀ E DELLA RICERCA
DIREZIONE GENERALE PER IL COORDINAMENTO E LO SVILUPPO DELLA RICERCA
PROGRAMMI DI RICERCA SCIENTIFICA DI RILEVANTE INTERESSE NAZIONALE
RICHIESTA DI COFINANZIAMENTO (DM n. 1175 del 18 settembre 2007)

PROGETTO DI RICERCA - MODELLO A
Anno 2007 - prot. 2007CCRNFA

---

1 - Titolo del Progetto di Ricerca

Testo italiano
Sicurezza per l'Interazione nel Contatto tra Umani, Robot e Ambiente (SICURA)

Testo inglese
Safe Physical Interaction between Robots and Humans (SICURA)

---

5 - Coordinatore Scientifico

DE LUCA	*ALESSANDRO*	
Professore Ordinario	*11/10/1957*	*DLCLSN57R11H501E*

The PHRIENDS Project 2006-2009

Physical Human-Robot Interaction: DepENDability and Safety





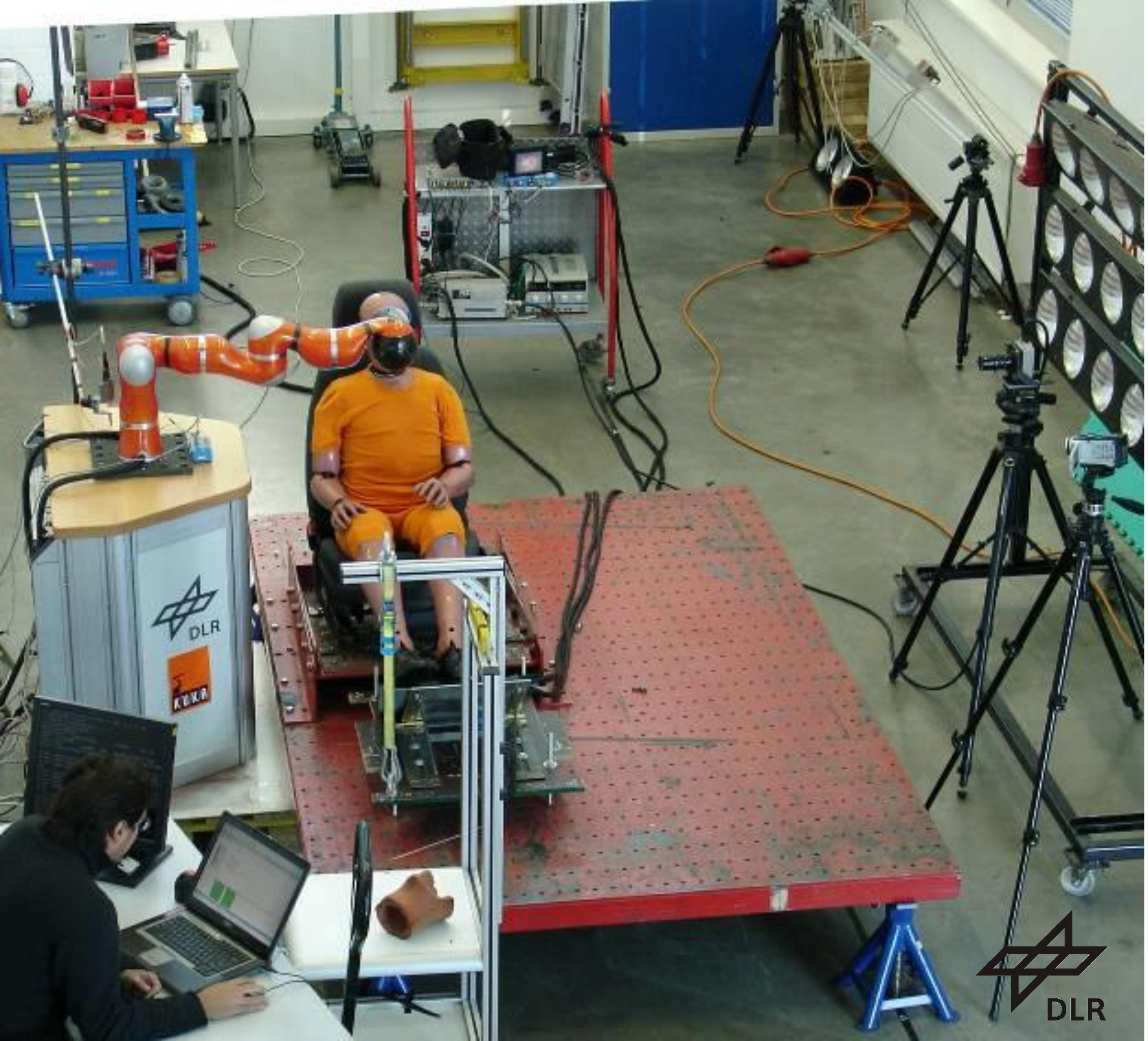

Safety and Dependability in pHRI

- The “holy grail” of pHRI design is *intrinsic safety*:

to design a robot that will be safe for humans no matter what failure, malfunctioning, or even misuse might happen.

- Naturally, perfect safety against all odds is not feasible for machines which have to deliver performance in terms of weight lifting, swift motion, etc.:

- the **trade-off between safety and performance** is the **name of the pHRI game**.



2006

First Robotic Crash Tests Worldwide

(No-Nonsense about Safety)

Explaining the Residuals

Phriends' Most Famous Video

Take home message:
You can trust ADL!

The PHRIENDS legacy:

new projects
new standards
new approaches

new products

SAPHARI

SAFE AND AUTONOMOUS PHYSICAL HUMAN-AWARE ROBOT INTERACTION

SEVENTH FRAMEWORK PROGRAMME

COGNITIVE SYSTEMS & ROBOTICS

Project funded by the European Community's 7th Framework Programme (FP7-ICT-2011-7)
Grant Agreement ICT–287513

From the lab to
new ISO/DIN standards

ISO 10218-1:2011

Preview

Robots and robotic devices -- Safety requirements for industrial robots -

ISO 10218-1:2011 specifies requirements and guidelines for the inherent safe design, protective measures and information for use of industrial robots. It describes basic hazards associated with robots and provides requirements to eliminate, or adequately reduce, the risks associated with these hazards.

ISO 10218-1:2011 does not address the robot as a complete machine. Noise emission is generally not considered a significant hazard of the robot alone, and consequently noise is excluded from the scope of ISO 10218-1:2011.

ISO 10218-1:2011 does not apply to non-industrial robots, although the safety principles established in ISO 10218 can be utilized for these other robots.

General information

Current status : Published

Publication date : 2011-07

Edition : 2

Number of pages : 43

Technical Committee : ISO/TC 299 Robotics

ICS : 25.040.30 Industrial robots. Manipulators

ISO 10218-2:2011

Preview

Robots and robotic devices -- Safety requirements for industrial robots

ISO 10218-2:2011 specifies safety requirements for the integration of industrial robots and industrial robot systems as defined in ISO 10218-1, and industrial robot cell(s). The integration includes the following:

- the design, manufacturing, installation, operation, maintenance and decommissioning of the industrial robot system or cell;
- necessary information for the design, manufacturing, installation, operation, maintenance and decommissioning of the industrial robot system or cell;
- component devices of the industrial robot system or cell.

ISO 10218-2:2011 describes the basic hazards and hazardous situations identified with these systems, and provides requirements to eliminate or adequately reduce the risks associated with these hazards. ISO 10218-2:2011 also specifies requirements for the industrial robot system as part of an integrated manufacturing system. ISO 10218-2:2011 does not deal specifically with hazards associated with processes (e.g. laser radiation, ejected chips, welding smoke). Other standards can be applicable to these process hazards.

General information

Current status : Published

Publication date : 2011-07

Edition : 1

Number of pages : 72

Technical Committee : ISO/TC 299 Robotics

ICS : 25.040.30 Industrial robots. Manipulators

ISO/TS 15066:2016

Preview

Robots and robotic devices -- Collaborative robots

ISO/TS 15066:2016 specifies safety requirements for collaborative industrial robot systems and the work environment, and supplements the requirements and guidance on collaborative industrial robot operation given in ISO 10218-1 and ISO 10218-2.

ISO/TS 15066:2016 applies to industrial robot systems as described in ISO 10218-1 and ISO 10218-2. It does not apply to non-industrial robots, although the safety principles presented can be useful to other areas of robotics.

NOTE This Technical Specification does not apply to collaborative applications designed prior to its publication.

General information

Current status : Published	**Publication date :** 2016-02
Edition : 1	**Number of pages :** 33

Technical Committee : ISO/TC 299 Robotics

ICS : 25.040.30 Industrial robots. Manipulators

Design

Traditional approach:

→ *add covers*

→ *add sensors (force, contact, proximity,…)*
→ *modify controllers for rigid robot manipulators* (stiffness, impedance control)

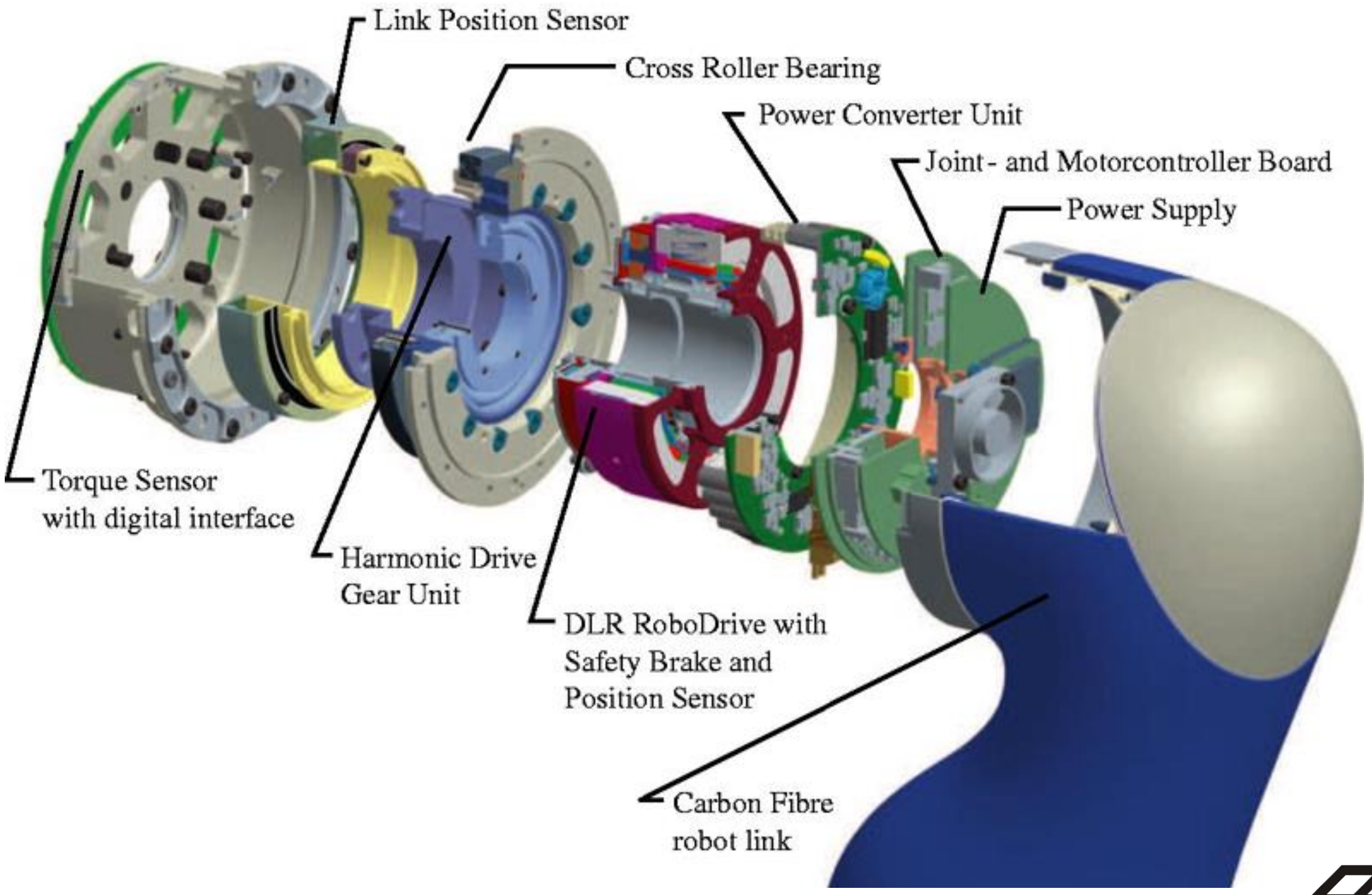
Well known intrinsic limitations to alter by control the behavior of the arm if the mechanical bandwidth is not matched to the task

In other words, **making a rigid, heavy robot to behave gently and safely is an almost hopeless task, if realistic conditions are taken into account**

→ Co-design of Mechanisms and Control

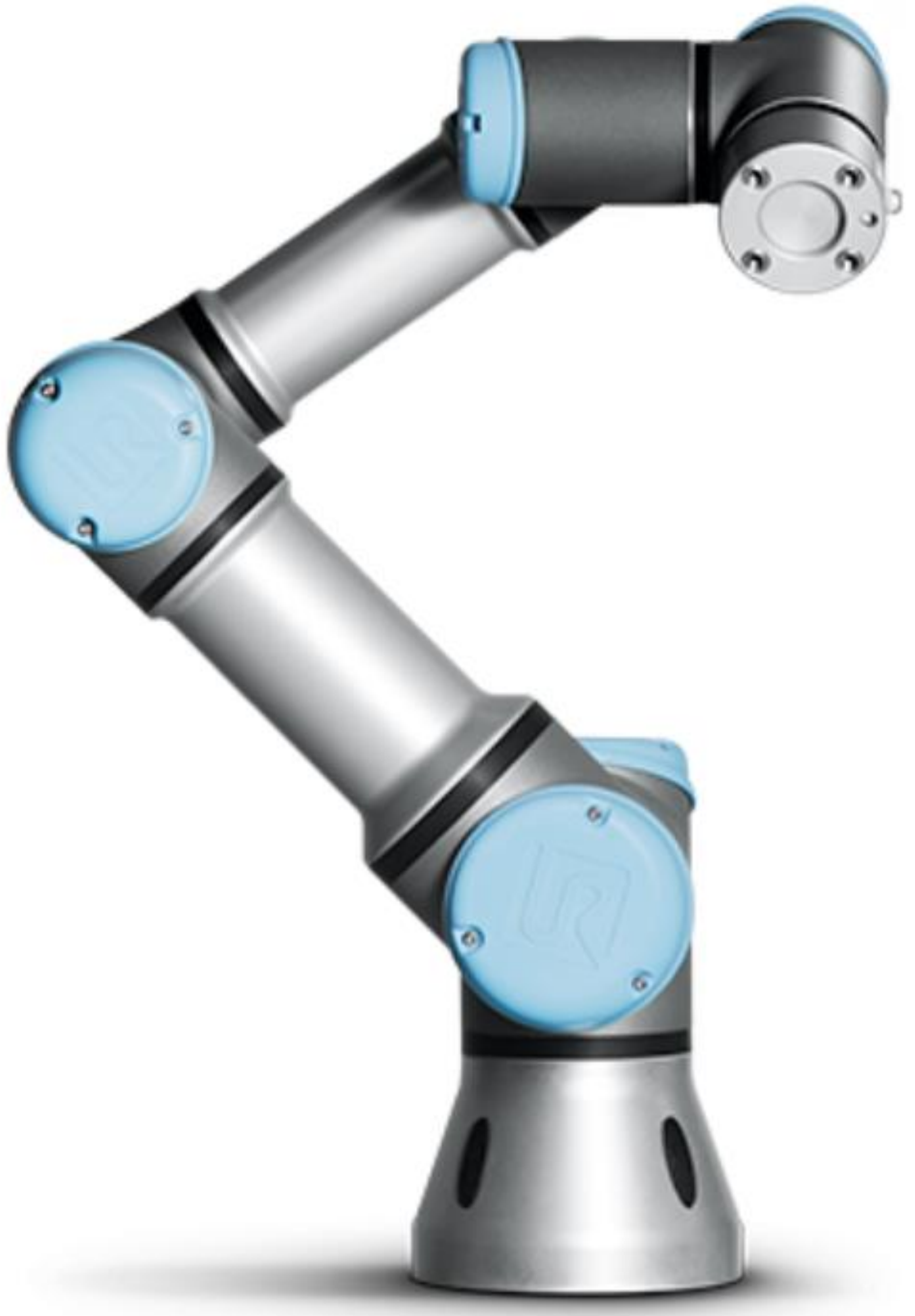
The WAM robot
by Barrett Technology Inc.

The LWR III - G. Hirzinger, A. Albu-Schaeffer
DLR → KUKA


Link Position Sensor
Cross Roller Bearing
Power Converter Unit
Joint- and Motorcontroller Board
Power Supply
Torque Sensor
with digital interface
Harmonic Drive
Gear Unit
DLR RoboDrive with
Safety Brake and
Position Sensor
Carbon Fibre
robot link

KUKA A.G.
LBR IIWA

2008
Universal Robot

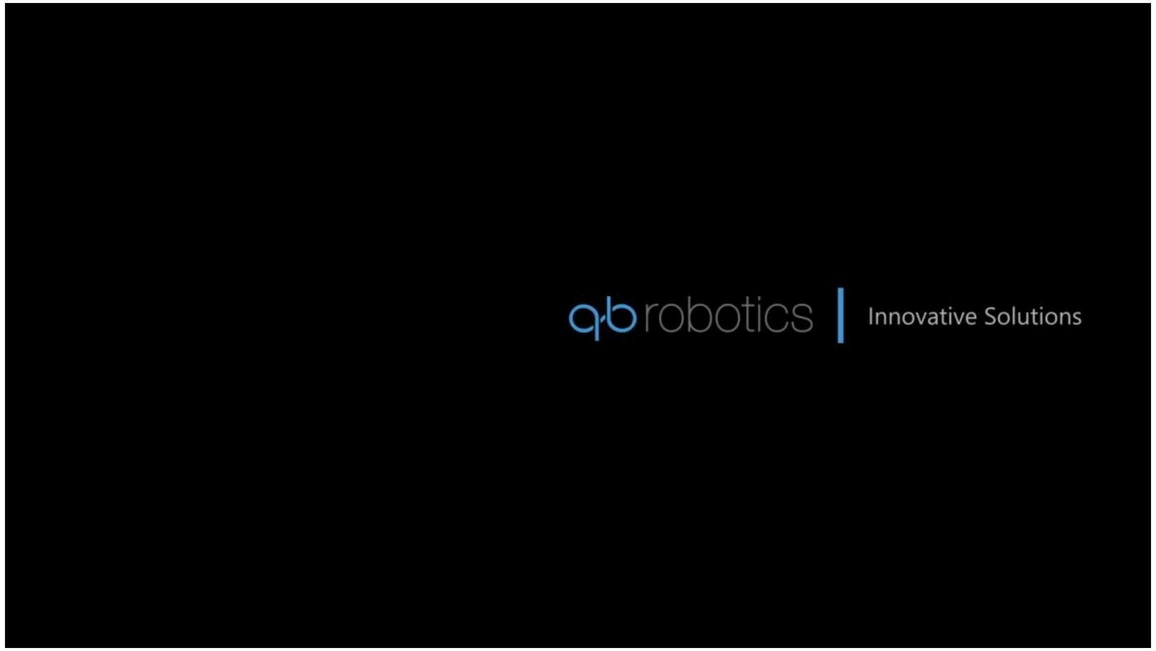


FRANKA
EMIKA

The interconnected, sensitive and safe robot for everybody!

qb robotics®

Fast Flexible Technology




10 Kg


Technical points

- Nonholonomic Motion Planning and Control

- Physical Human-Robot Interaction (with our beloved Fabrizio)
- The *third way* of robotics
- *Impedance observers*
- Variable Impedance Actuator control
- Feedback vs Feedforward


Seattle
KUKA
KUKA


χαρούμενα γενέθλια Alessandro
Auguri Prof!!!
Handbook of Robotics