ISTITUTO DI TECNOLOGIE DELLA COMUNICAZIONE, DELL'INFORMAZIONE E DELLA PERCEZIONE

PERCRO Perceptual Robotics Laboratory

Scuola Superiore Sant'Anna

Introduzione alla robotica
Lesson #1

Antonio Frisoli

PERCRO, Scuola Superiore Sant'Anna

Programma del corso

- Introduzione alla robotica; primi elementi di bioingegneria: vantaggi della riabilitazione robotica
- Il segnale EMG ed il suo utilizzo per la robotica riabilitativa
- La riabilitazione robotica e l'apprendimento motorio: aspetti clinici
- Sistemi esoscheletrici per la riabilitazione
- Il segnale EEG, sistemi di Brain Computer Interfaces
- Elementi di biomeccanica per la bioingegneria
- Elementi di biomeccanica, controllo motorio e sistema muscoloscheletrico (con OpenSim)
- Esercitazione di biomeccanica
- Tecnologie di ambienti virtuali per la riabilitazione

The PERCRO Lab

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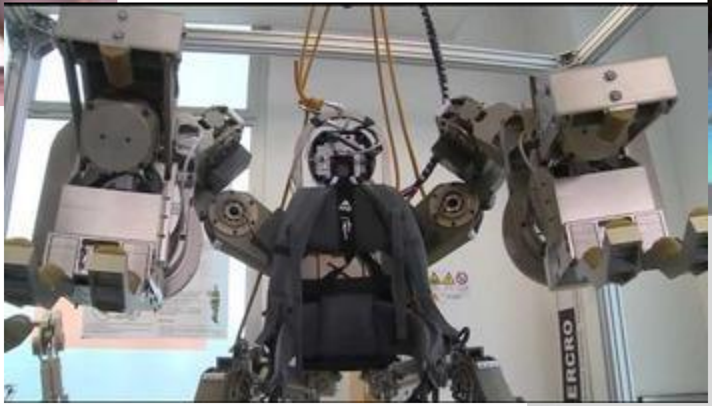
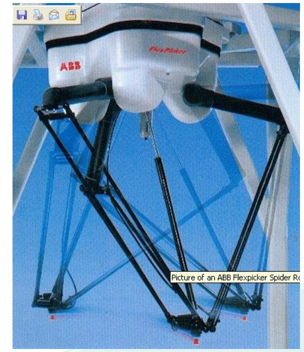
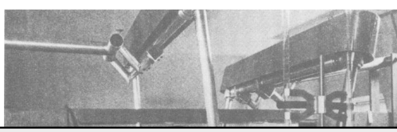


PERCRO Perceptua
Robotics Laborator

The evolution of robotics up to nowadays





2000- New generations of robots

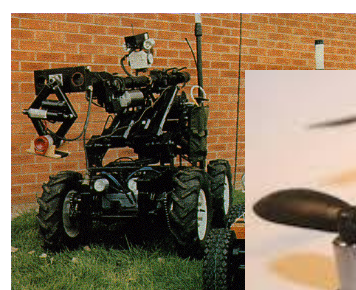
’90 New architectures of robots

’80 Robots used in

Don’t even call it robot, if you want to make a commercial product

Unimation and first production of PUMA robot

1951 First teleoperation experiments



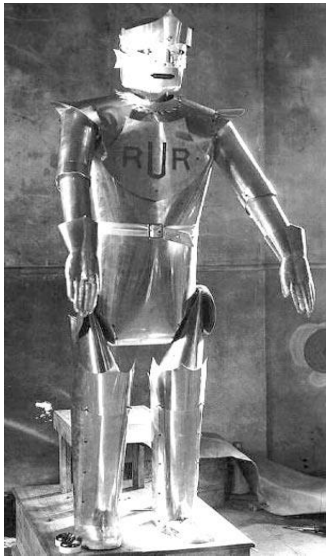
The challenge

"This technology provides hope that individuals with paralysis and lower extremity weakness can walk. Through our collaboration, we bring innovative technology directly to patient care when conducting clinical trials."

Steven Kirshblum, MD,

Medical Director and Director of Spinal Cord Injury Rehabilitation at Kessler Institute for Rehabilitation

L’evoluzione delle tecnologie robotiche



- La parola ROBOT ha origine da una parola ceca “robota” che significa lavoro forzato. Per la prima volta fu introdotta nel 1921 dallo scrittore ceco lo scrittore ceco Karel Capeck in R.U.R., commedia, nella quale le macchine sono capaci di passioni, e prese da impeto vendicativo, le macchine, liberate, perseguono i loro carcerieri punendoli per le umiliazioni subite.

The RUR robot così come appare in un film tratto dall’opera di Karel Capek's Rossum. Circa 1930's.

- Ma i robots, sono sempre più presenti negli ambienti di vita quotidiana ed a contatto con l’uomo, richiedendo quindi l’evoluzione verso tecnologie robotiche in grado di percepire e di interagire con l’uomo in modo sicuro.

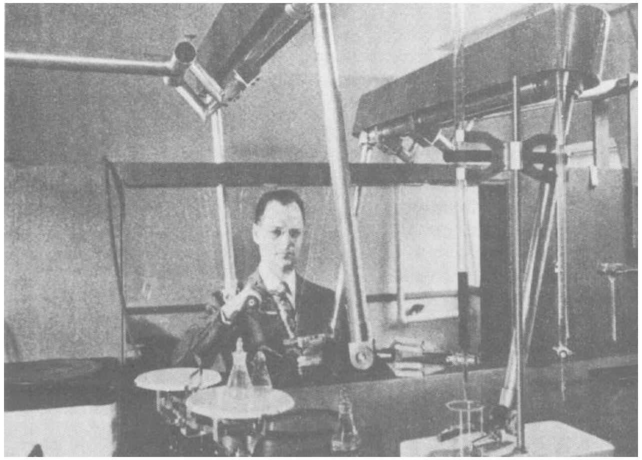
- Il progresso delle tecnologie di interazione uomo-computer (HCI) ha fatto sì che anche i paradigmi di interazione innovativi siano sempre di più alla portata di un grande numero di persone (Nintendo 3DS, Kinect)

JUSTIN
DLR (Germany)

EMIEW2
Hitachi (Japan)

L’inizio della robotica

I primi esperimenti di teleoperazione iniziarono ai tempi della II guerra mondiale, presso i laboratori americani di Argonne ed Oak Ridge National Laboratories.
Nel 1951, in Francia presso il CEA (Centre Energie Atomique) Raymond Goertz progetta il primo braccio teleoperato. Il disegno è completamento basato su una trasmissione meccanica fra bracci meccanici master e slave, a mezzo di cavi metallici e puleggie. Questi sistemi sono ancora i più utilizzati nella manipolazione di sostanze all’interno di centrali nucleari.

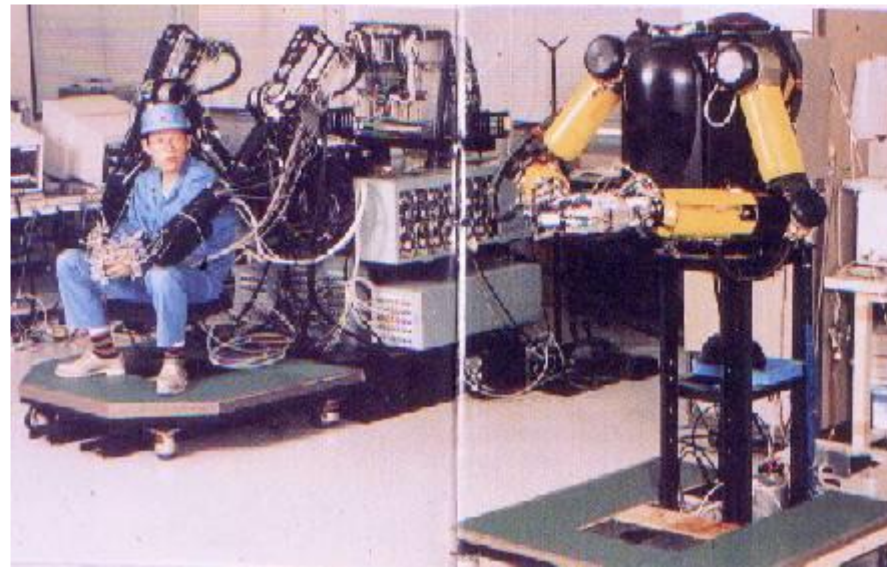


L'inizio della robotica

- Nel 1801, Jacquard introduce il concetto di macchina riprogrammabile, realizzando un telaio riprogrammabile con schede perforate per tessere filati

L’inizio della robotica

Nel 1954 George Devol and Joe Engleberger ebbero l’idea di sostituire la trasmissione meccanica a cavo con una trasmissione elettrica, usando dall’altra parte una macchina riprogrammabile, il primo “braccio” robotico programmaibile ed usarono il termine Universal Automation per la prima volta.
In questo modo piantarono il seme per la compagnia futura che si chiamerà Unimation (fondata nel 1961).



Nel 1961 il primo robot viene installato in uno stabilimento della General Motors.

Storia robotica

- Alcuni robots famosi
  - PUMA (Programmable Universal Machine for Assembly) ’78
  - SCARA (Selective Compliant Articulated Robot Assembly) ’79
- Anni’80: miglioramento della performance: feedback control and design; I bracci robotici diventano più flessibili. Robot a cinematica parallela
- Anni’90: Robot autonomi mobili, robot controllati da sistemi di visione, walking robots, surgical robotics
- Anni 2000: new generation of robots

Robot definizione

Definizione IFToMM(1983):
"Macchina ripogrammabile per svolgere funzioni di manipolazione, movimentazione, ...lavorazione, in grado di interagire con il suo ambiente circostante e dotata di un certo grado di autonomia"

Versatilità
Autonomia
Riprogrammabilità

On wearability and wearable computing

- Sony introdusse nella seconda metà del XX secolo le prime cuffie con il Walkma
- Google nel 2012 ha svelato il progetto Glass, per lo sviluppo di occhiali per realtà aumentata e virtuale
- Sebbene I primi HMDs risalgano al 1968, questi primi occhiali ideati da Google dovranno essere estremamente wearable
- Oculus Rift è stato finanziato attraverso una campagna di crowd funding che in soli 45 giorni ha raccolto **6,238,563 dollari**

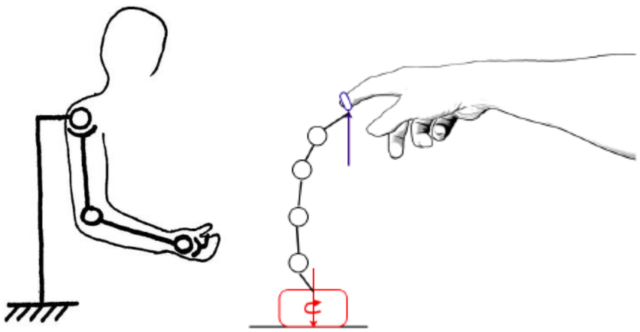
Sony Walkman (1980)
[courtesy of Sony Corporation]

Google Glasses (2012)
[courtesy of Google Inc.]

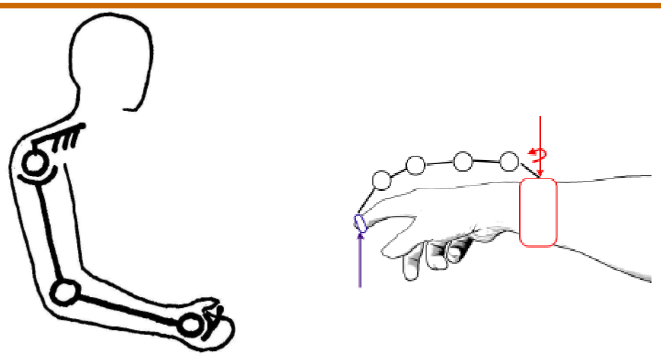
Oculus rift (2013)

Human-Robot Interaction and Haptics

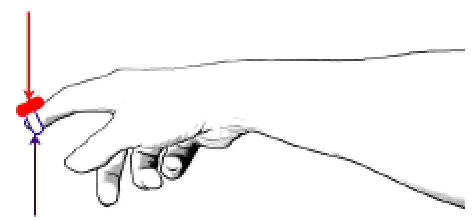
- **Robot systems for Physical <u>Human-Robot Interaction</u> and <u>Cooperation</u>**
  - **Robots that can interact safely with human for the purpose of**
    - **Skills transfer**
    - **Support and force augmentation**
    - **Tele-operation**
    - **Cooperation**
    - **Rehabilitation and power augmentation**
    - **Interaction with digital contents**
  - **Requirements of**
    - **Safety**
    - **Better compliance**



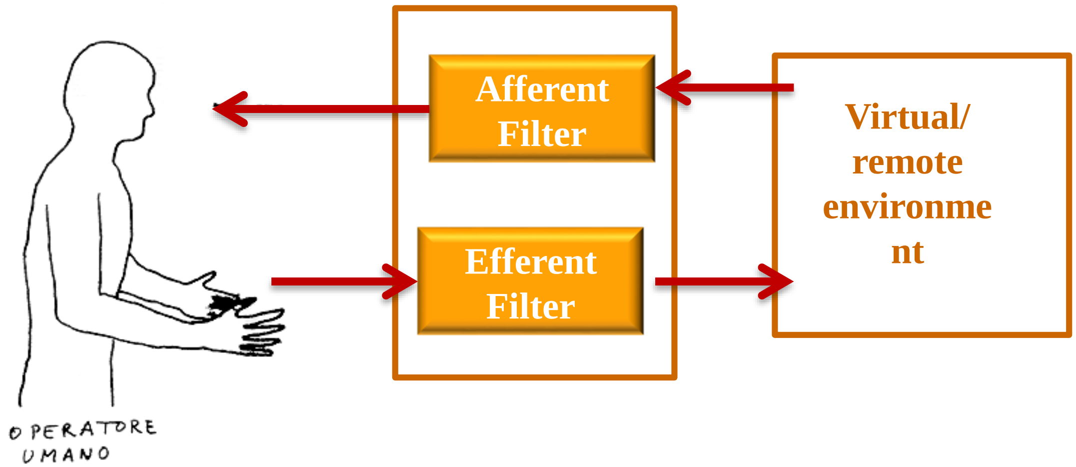
Grounded haptics



Portable exoskeletons



Wearable haptics



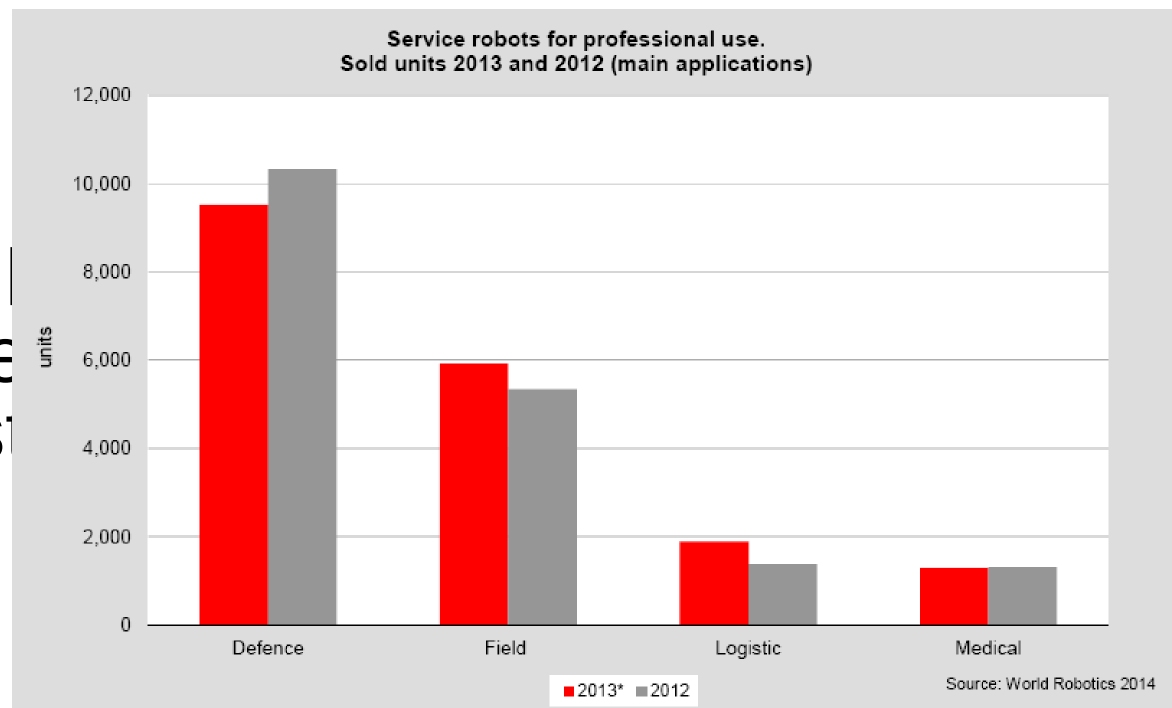
Campi applicativi della robotica

- Robotica industriale
  - Applicazioni industriali ed automazione industriale
- Robotica di servizio
  - Robotica riabilitativa per disabili ed anziani
  - Chirurgia assistita da robot
  - Interfacce multimodali
  - Operazioni in ambienti pericolosi o sottomarini
  - Sorveglianza e ricognizione
  - Robotica mobile
  - Sistemi di amplificazione di forza
  - Umanoidi

Robotics Market

20 B$ is the size of Swiss watch industry

- Industrial robotics (~10 B$)
- Service robotics (5 B$).
  - The market for service robotics can be broadly categorized in to two application segments
    - personal service robotics
    - professional service robotics
      - Defense
      - Field
      - Logistic
      - Medical
- Medical robots l
  acceptance due
  and robot assis



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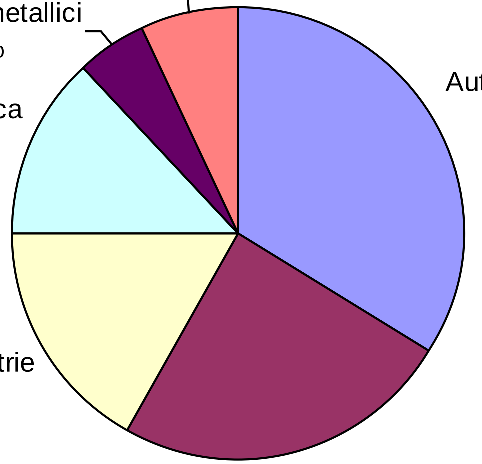
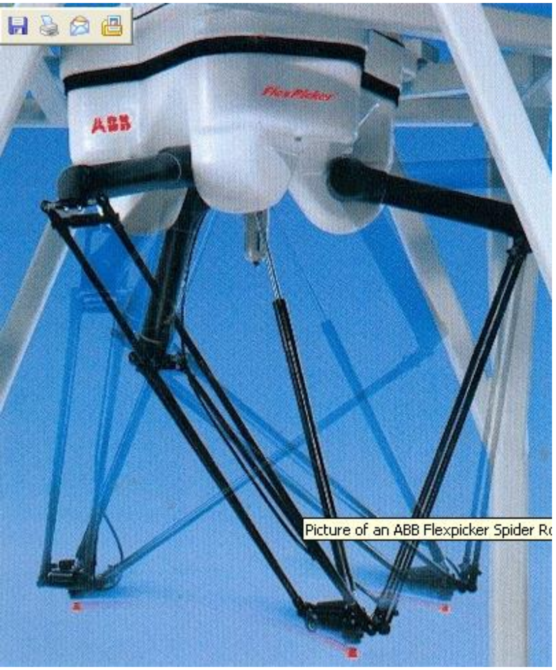
Applicazioni robots

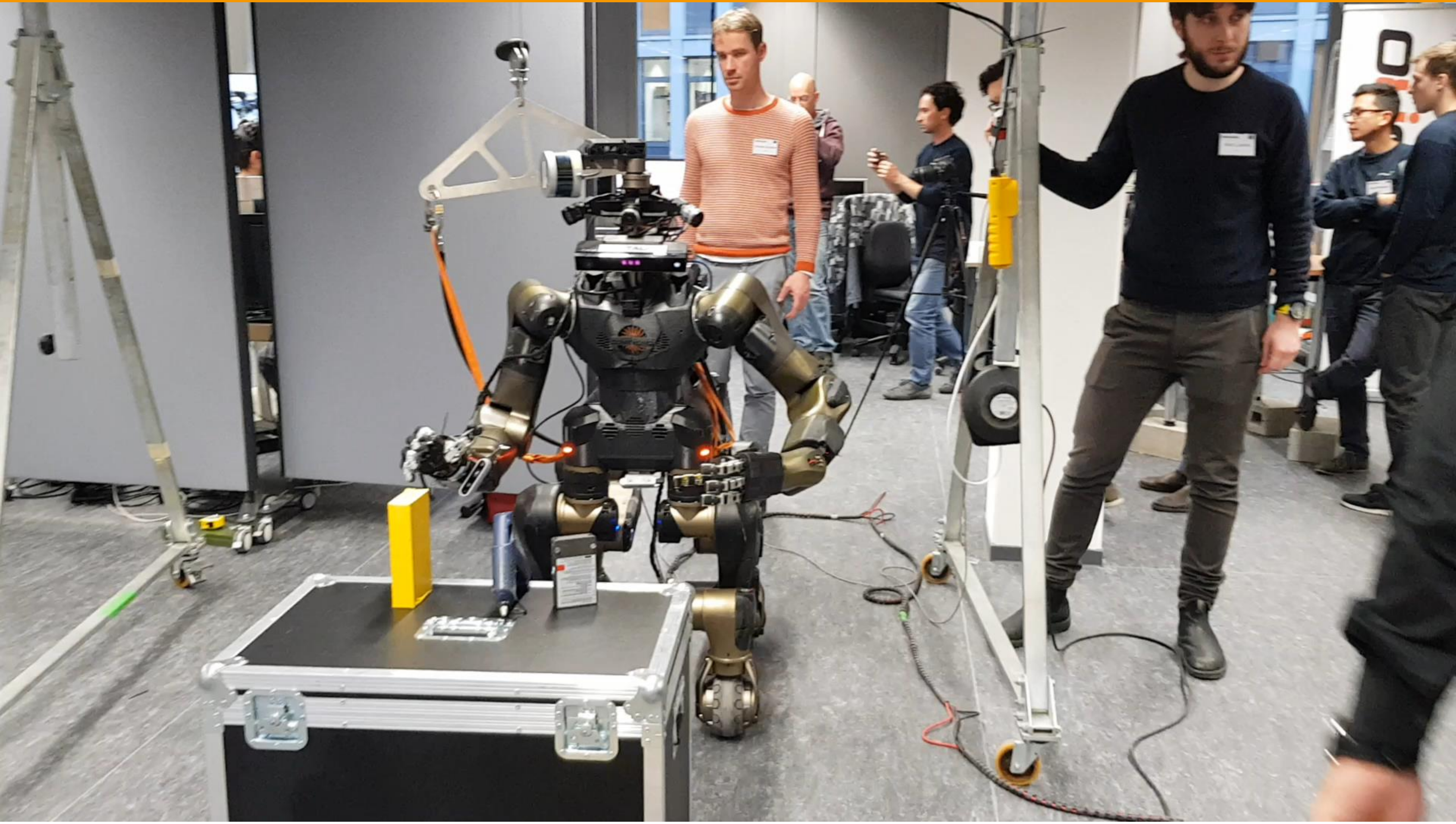


- Si vede come il mercato automobilistico rappresenti ancora il campo dove l’impiego dei robots presenta ancora il maggior impiego. In questo settore applicativo il
- robot sostituisce l’operatore anche in operazione a rischio per la salute dell’operatore.
- Così i robots si trovano nelle stazioni di fonderia, di saldatura e di stampaggio delle lamiere. In generale i robots impiegati in queste operazioni sono robots di potenza.
- A seguire il secondo settore è rappresentato dal montaggio di apparecchiature elettriche: in questo caso i requisiti sono sostanzialmente diversi. Il robot va ad eseguire operazioni di estrema precisione con elevata velocità: è il caso ad esempio del montaggio di componenti elettronici nell’industria dei semiconduttori.

Applicazioni industrali ed automazione industriale

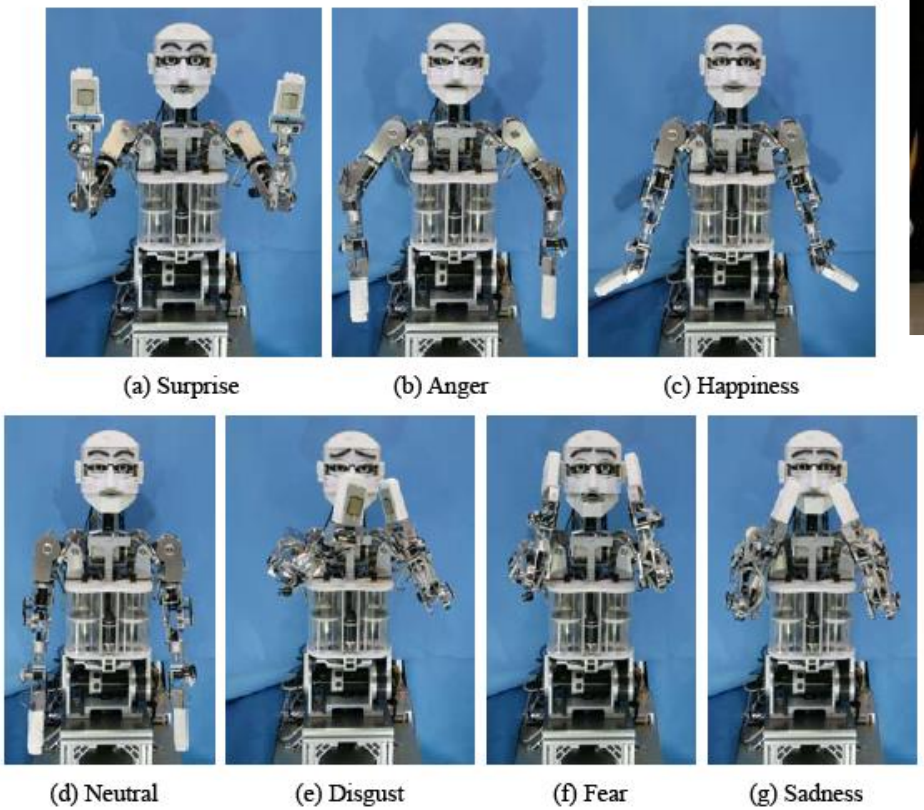


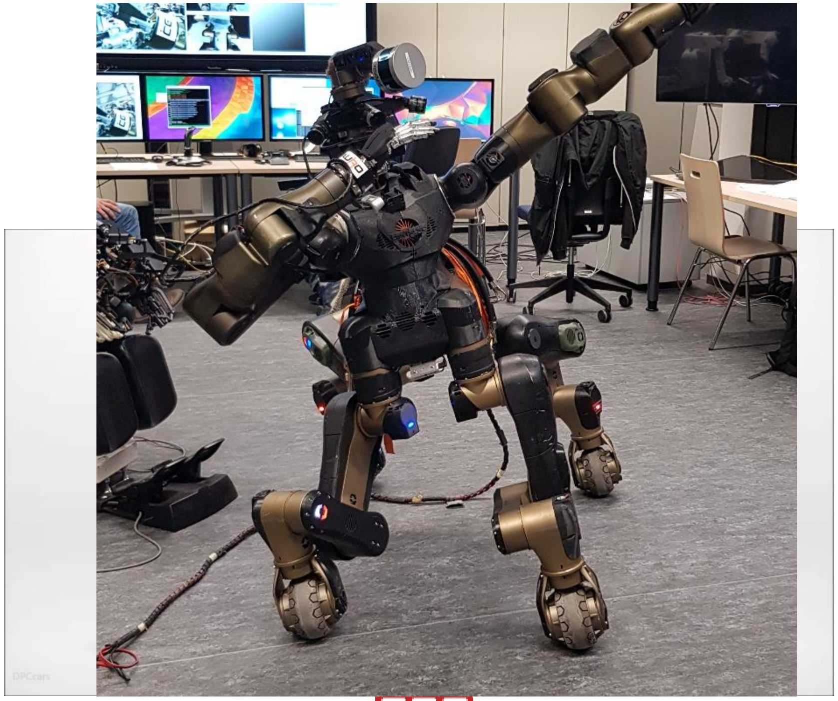
Sistemi di manipolazione

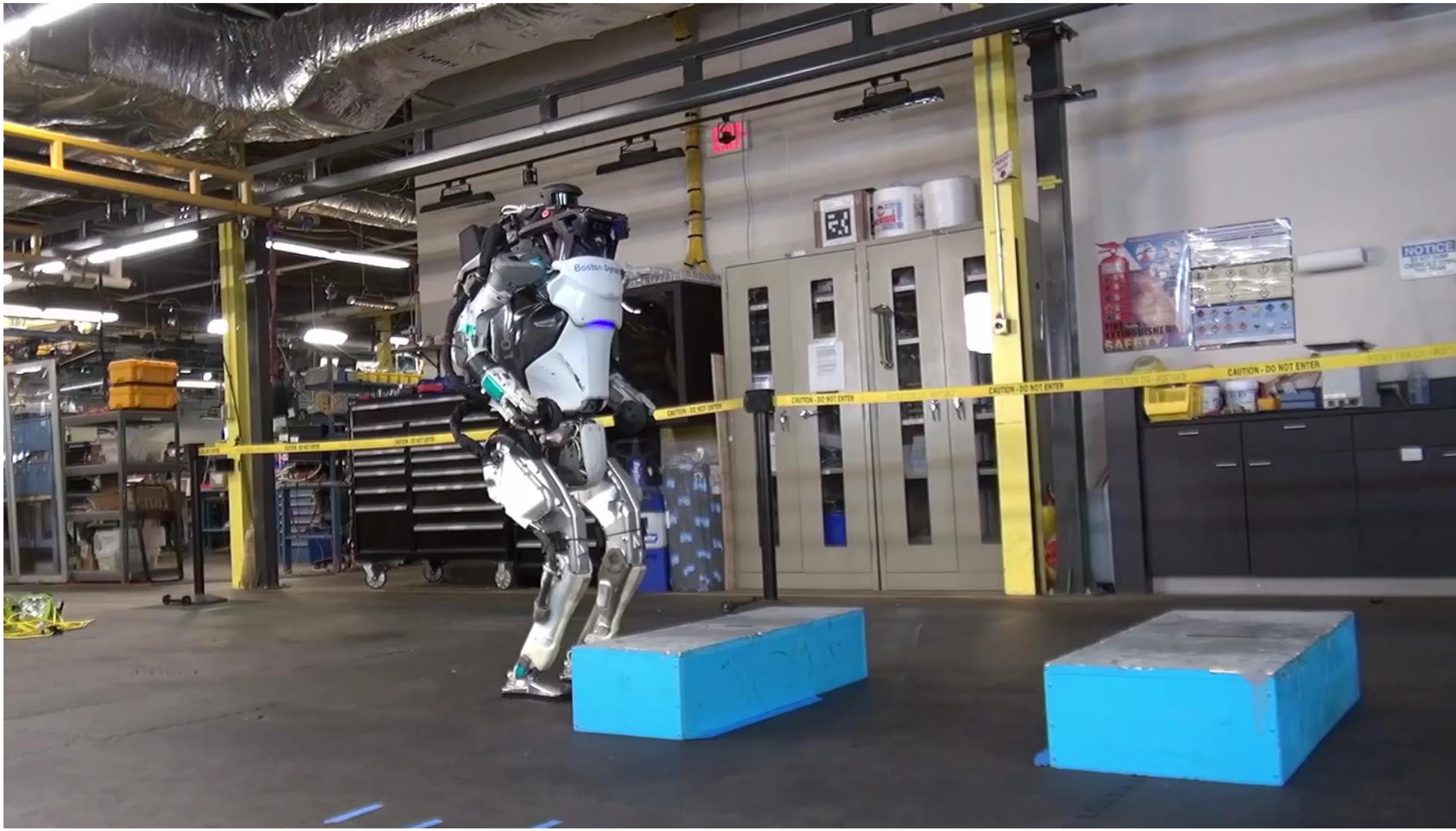


Sistemi per la domotica e per l'intrattenimento

Umanoidi


(a) Surprise
(b) Anger
(c) Happiness
(d) Neutral
(e) Disgust
(f) Fear
(g) Sadness

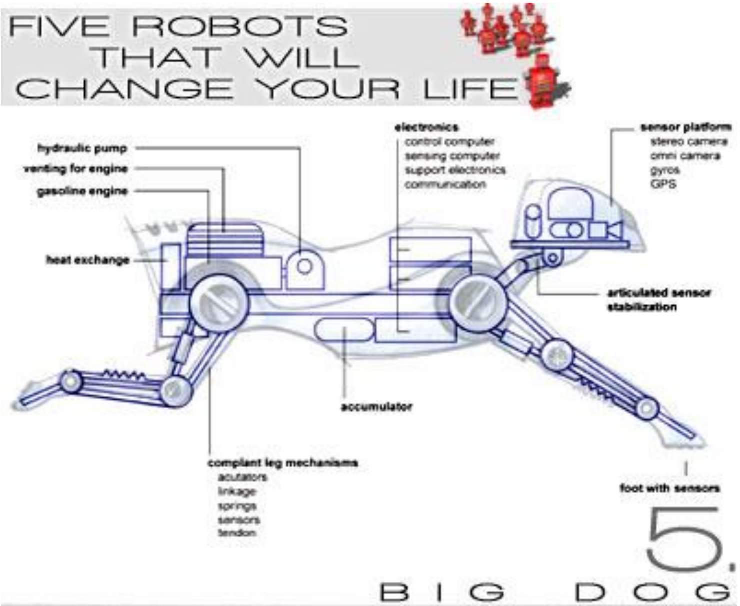


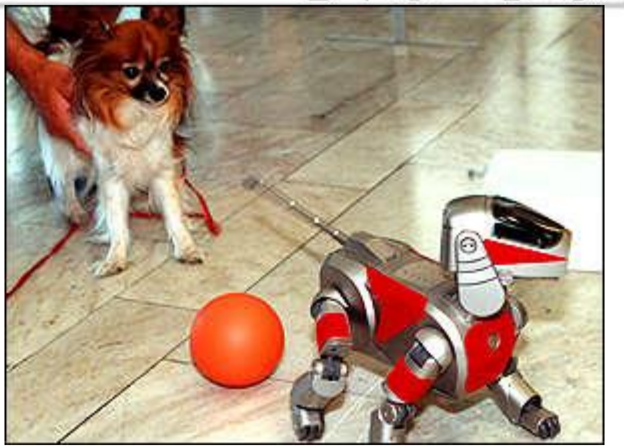

CAUTION - DO NOT ENTER
NOTICE

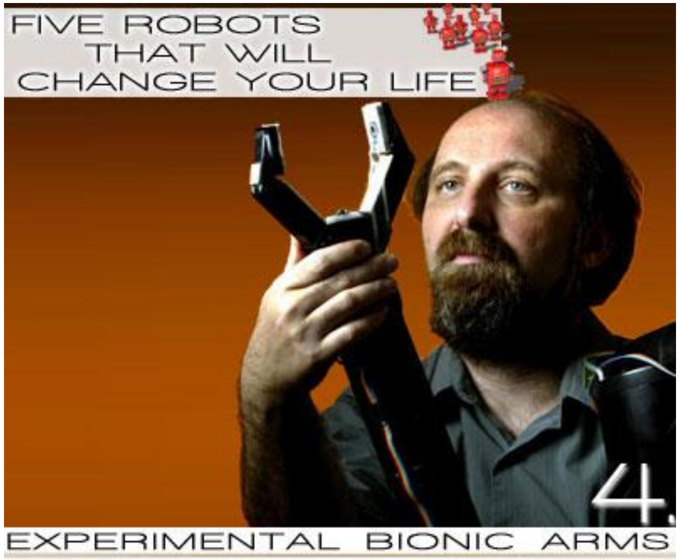
DPCcars

Chirurgia assistita da robots

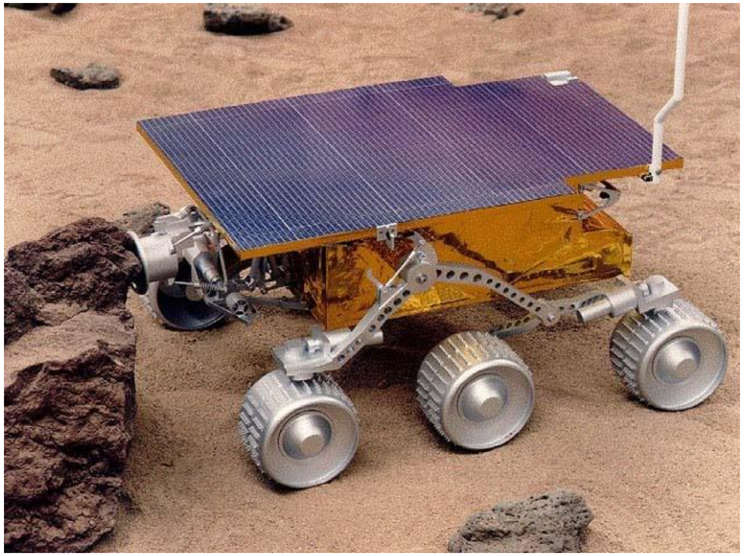
Bio-inspired robotics

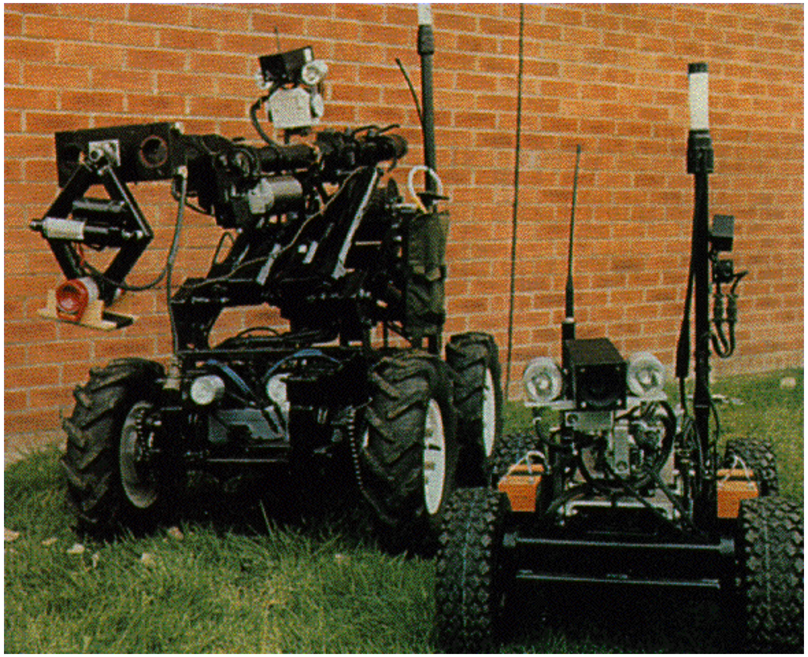


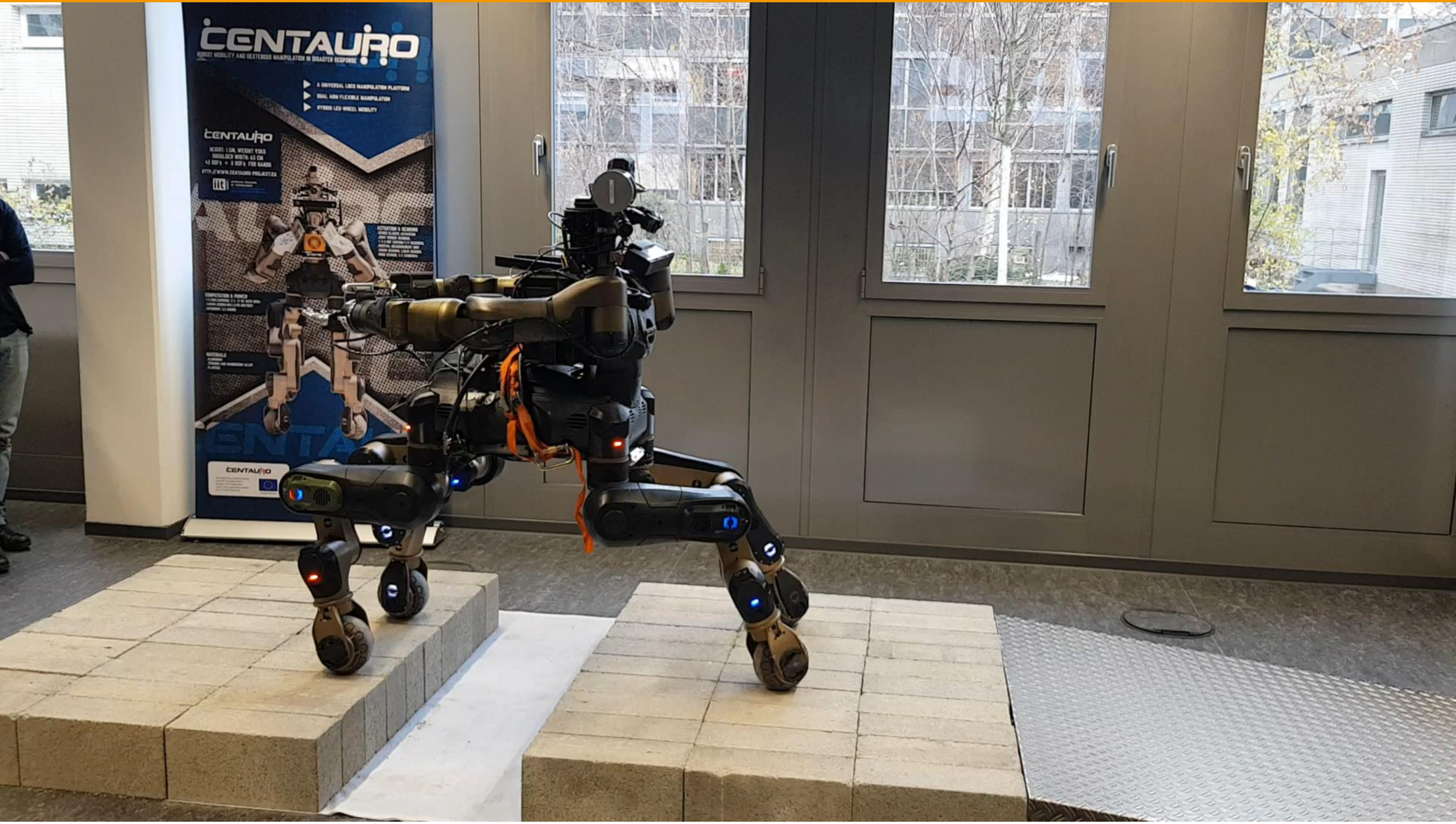




Robotica mobile






CENTAURO

Sistemi di potenziamento corporeo

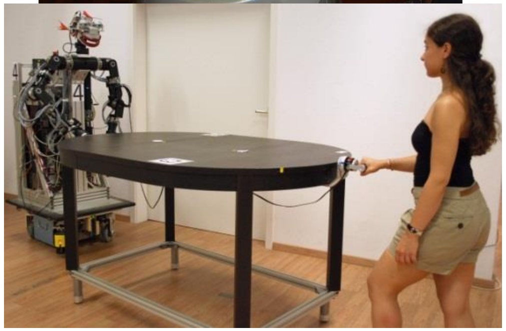
Gli esocheletri ed i robots indossabili

Dal Personal Computer al Personal Robot?

L'introduzione negli anni '70 del concetto di personal computer ha radicalmente cambiato il modo di intendere l'uso del pc e determinato un'evoluzione tecnologica senza precedenti

- Verso robots indossabili e che interagiscono con l'uomo
- Il robot interagisce con l'uomo su due livelli
  - _cHRI: **[Cognitive Human-Robot Interaction]**, riguarda la comunicazione tra uomo e robot attraverso I caniali di comunicazione disponibili (displays video, suoni, movimento, linguaggio parlato, espressione facciale, direzione dello sguardo)
  - _pHRI: **[Physical Human Robot Interaction]**, robots si distinguono dai computers perchè realizzano fisicamente un legame tra azione e percezione. Nella Interazione fisica i robots condividono lo stesso spazoi dell'uomo e sono addirittura in contatto fisico.

Korean museum guide



Technical University of Munich

NH1, il robot COMAU per le linee di montaggio

Dal robot industriale…

verso

…il personal robot

HRP4 and HAL from Japan

Il personal robot è sempre con te,
coopera nei compiti,
ti assiste, ti aiuta,
ti fa compagnia

Aumento della prestazione mediante sistemi robotici: the X-Man Paradigm

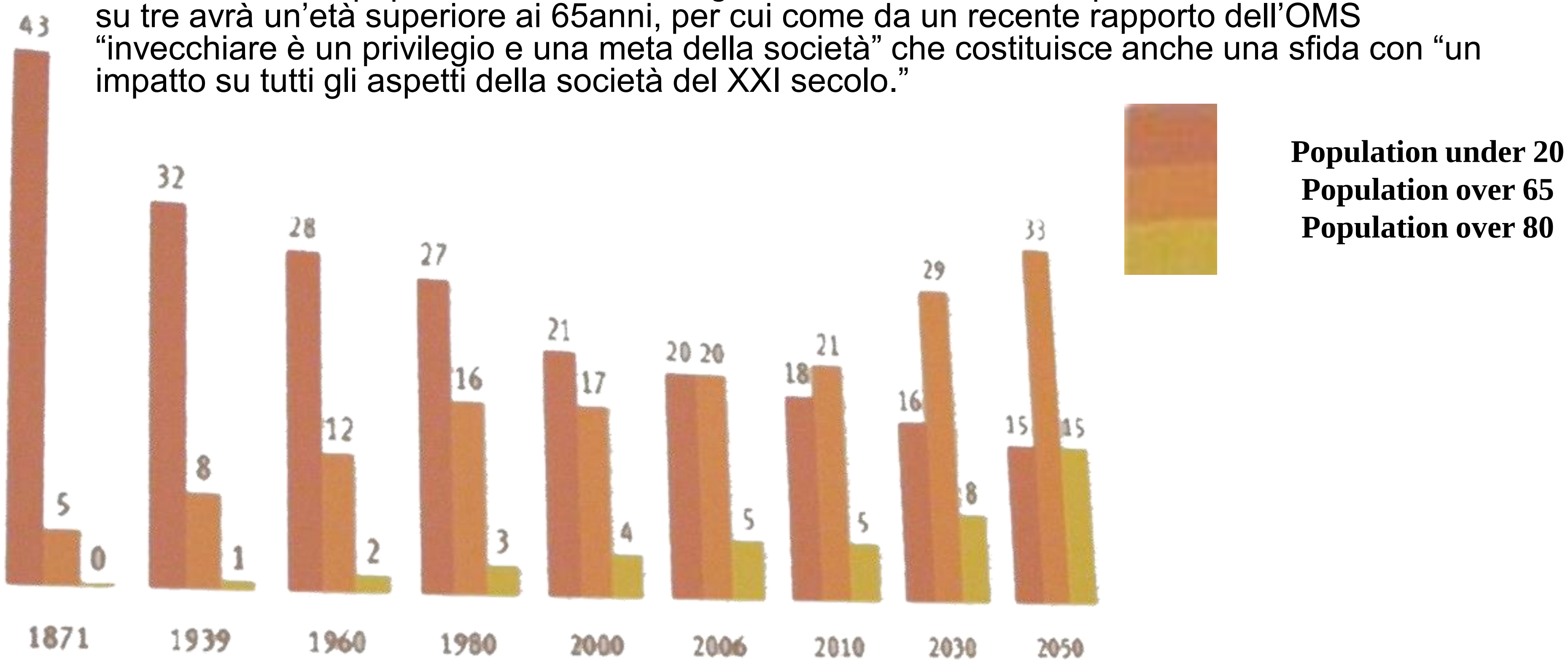
- E' possibili aumentare le proprie prestazioni fisiche attraverso l'utilizzo di sistemi robotici?
- Tre campi applicativi
  - Applicazioni labor-intensive o di aumentazione delle capacità umane
  - Sport
  - Disabilità

Fin dagli anni '60, la "General Electrics" inseguì questo sogno cercando per prima di realizzare una vera e propria armatura robotica indossabile, Hardiman.

Ma nell'era dell'elettronica analogica i tempi non erano ancora maturi per garantire la sicurezza e la capacità di funzionamento ed il progetto fu abbandonato senza successo.

Una società che invecchia

- Inoltre nei Paesi a sviluppo avanzato l'invecchiamento della popolazione conduce ad un incremento della popolazione anziana, e.g. nella sola Italia ci si aspetta che nel 2030 un italiano su tre avrà un'età superiore ai 65anni, per cui come da un recente rapporto dell'OMS "invecchiare è un privilegio e una meta della società" che costituisce anche una sfida con "un impatto su tutti gli aspetti della società del XXI secolo."



- In questo caso la tecnologia robotica viene in aiuto. Diverse patologie neuromuscolari sono associate all'invecchiamento, portando nel tempo ad un decadimento delle funzioni motorie. I robots riabilitativi possono fornire un valido aiuto, in termini assistenziali e di riabilitazione.

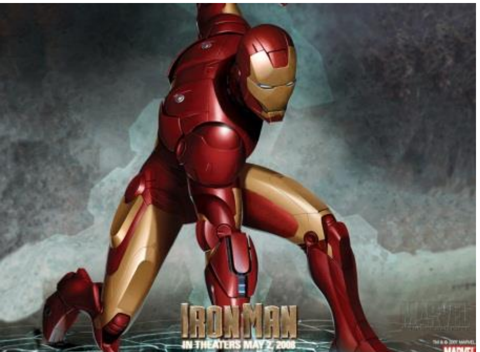
Si può indossare un robot?

- Qual è il massimo grado di integrazione e cooperazione che un uomo ed un robot possono realizzare?
  - Robot indossabili per
    - Potenziamento delle capacità corporee (Body Augmentation)
    - Recupero delle capacità motorie

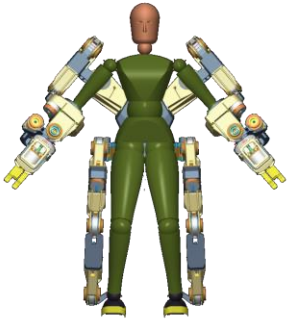
ROBOT INDUSTRIALE TRADIZIONALE

Robots indossabili di nuova generazione

From fiction….



… to real word



Una storia di successo: il sistema ReWalk

- L'inventore di questo innovativo sistema era un ingegnere meccanico israeliano dr. Amit Goffer che perse l'uso delle gambe in un incidente automobilitistico.
- Frustrato dalle limitazione dell'essere seduto in carrozzina, decide di mettere a punto delle gambe robotiche indossabili che gli consentissero di stare in piedi e di poter camminare, per poter finalmente rivedere la vita dallo stesso punto di vista degli altri. Il sistema utilizza sensori di movimento per decodificare i movimento di chi lo indossa e tradurli in spostamenti per le gambe.

- E' recente l'inizio della sperimentazione del sistema ReWalk in Italia presso la clinilca Villa Beretta (Agosto 2012) e presso Centro Protesi Inail (Ottobre 2012)

Ma quali sono i challenges:

- Autonomia
- Usabilità, versatiità
- Possibilità di utilizzare strategie semplici di contrololo

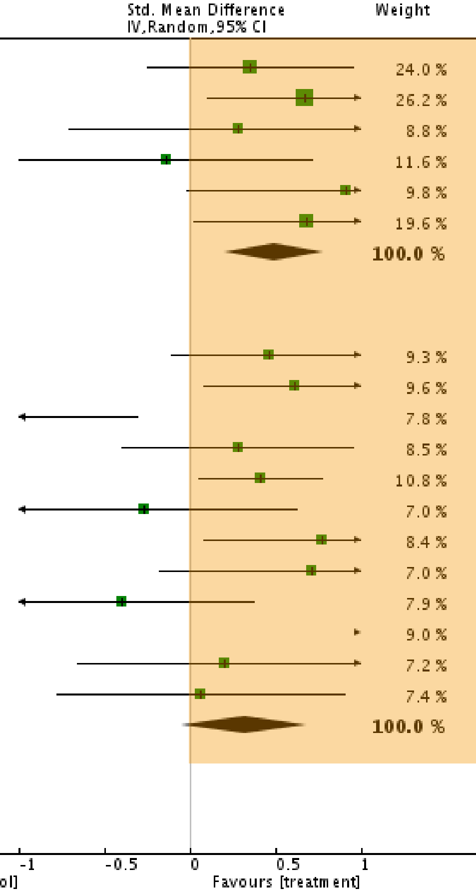
Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke

- Patients who receive electromechanical-assisted arm training after stroke are more likely to improve their generic activities of daily living and may improve arm function.

Review: Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke
Comparison: 3 Subgroup analysis by treatment approach
Outcome: 1 Activities of daily living at the end of intervention phase: subgroup analysis comparing different device groups

Study or subgroup	Experimental N	Experimental Mean(SD)	Control N	Control Mean(SD)	Weight	Std. Mean Difference IV,Random,95% CI
1 distal training (finger, hand and radio-ulnar joints)						
Hesse 2005	22	22.45 (15.14)	22	17.27 (13.95)	24.0 %	0.35 [-0.25, 0.95]
Hesse 2014	25	25.2 (11)	25	16 (15.7)	26.2 %	0.67 [0.10, 1.24]
Hsieh 2011	12	0.13 (0.19)	6	0.06 (0.32)	8.8 %	0.28 [-0.71, 1.27]
Kutner 2010	11	6.89 (9.995)	10	8.49 (11.33)	11.6 %	-0.14 [-1.00, 0.71]
Liao 2011	10	0.25 (0.17)	10	0.03 (0.28)	9.8 %	0.91 [-0.02, 1.84]
Wu 2012	14	3.26 (7.16)	28	-2.88 (9.56)	19.6 %	0.68 [0.02, 1.34]
Subtotal (95% CI)	**94**		**101**		**100.0 %**	**0.49 [0.20, 0.78]**
Heterogeneity: Tau² = 0.0; Chi² = 3.96, df = 5 (P = 0.55); I² =0.0%						
Test for overall effect: Z = 3.29 (P = 0.0010)						
2 proximal training (shoulder and elbow joints)						
Burgar 2011	36	19.6 (8.47)	18	15.9 (6.36)	9.3 %	0.46 [-0.11, 1.04]
Conroy 2011	41	3.98 (11.94)	21	-3.19 (10.72)	9.6 %	0.61 [0.08, 1.15]
Fazekas 2007	15	12.07 (9.26)	15	25.53 (14.32)	7.8 %	-1.09 [-1.86, -0.31]
Housman 2009	17	0.2 (0.4)	17	0.1 (0.3)	8.5 %	0.28 [-0.40, 0.95]
Lo 2010	49	6.31 (11.76)	78	1.37 (12.1)	10.8 %	0.41 [0.05, 0.77]
Lum 2006	24	2.85 (1.21)	6	3.2 (1.4)	7.0 %	-0.27 [-1.17, 0.62]
Masiero 2007	17	32.6 (7.2)	18	25.5 (10.5)	8.4 %	0.77 [0.08, 1.46]
Masiero 2011	11	1.83 (1.4)	10	1 (0.7)	7.0 %	0.71 [-0.18, 1.60]
Rabadi 2008	10	25.49 (7.23)	20	28.29 (6.72)	7.9 %	-0.40 [-1.16, 0.37]
Volpe 2000	30	9.1 (3.3)	26	4.4 (2)	9.0 %	1.67 [1.05, 2.29]
Volpe 2008	11	67.1 (7.96)	10	65.5 (7.59)	7.2 %	0.20 [-0.66, 1.06]
Yoo 2013	11	0.4 (6.1)	11	0.1 (3.2)	7.4 %	0.06 [-0.78, 0.90]
Subtotal (95% CI)	**272**		**250**		**100.0 %**	**0.32 [-0.05, 0.68]**
Heterogeneity: Tau² = 0.29; Chi² = 40.00, df = 11 (P = 0.00004); I² =73%						
Test for overall effect: Z = 1.70 (P = 0.089)						

Test for subgroup differences: Chi² = 0.52, df = 1 (P = 0.47), I² =0.0%



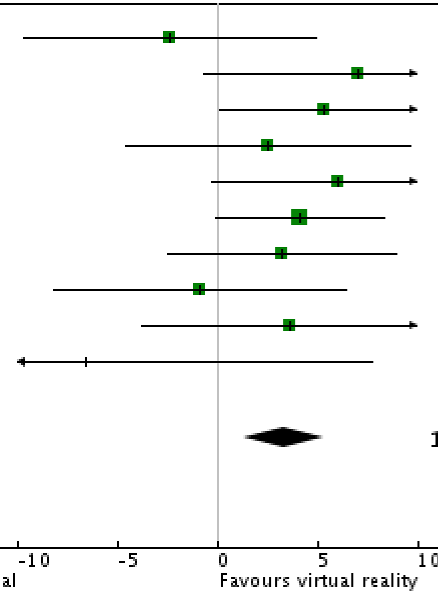
Cochrane Database of Systematic Reviews
7 NOV 2015 DOI: 10.1002/14651858.CD006876.pub4

EBM for Virtual Reality based therapy

- Results showed that there were benefits when the intervention was conducted in the first six months of stroke but not when conducted more than six months after stroke, suggesting that a virtual reality intervention is most useful in the subacute phase of rehabilitation. In addition, results suggested that higher doses of therapy (programs involving more than 15 hours of therapy) were more beneficial

Review: Virtual reality for stroke rehabilitation
Comparison: 1 Virtual reality versus conventional therapy: effect on upper limb function post-treatment
Outcome: 2 Upper limb function (Fugl Meyer)

Study or subgroup	Virtual reality N	Virtual reality Mean(SD)	Control N	Control Mean(SD)	Mean Difference IV,Fixed,95% CI	Weight	Mean Difference IV,Fixed,95% CI
Byl 2013	5	28.2 (4.6)	5	30.6 (6.92)		7.7 %	-2.40 [-9.68, 4.88]
da Silva Cameirao 2011	8	60.375 (7.614)	8	53.38 (8.087)		6.9 %	7.00 [-0.70, 14.70]
Housman 2009	14	24.9 (7.4)	14	19.6 (6.7)		14.9 %	5.30 [0.07, 10.53]
Kiper 2011	40	48.9 (15.2)	40	46.4 (17.1)		8.1 %	2.50 [-4.59, 9.59]
Piron 2007	25	51.4 (9.8)	13	45.4 (9.3)		10.1 %	6.00 [-0.35, 12.35]
Piron 2009	18	53.6 (7.7)	18	49.5 (4.8)		23.1 %	4.10 [-0.09, 8.29]
Piron 2010	27	49.7 (10.1)	20	46.5 (9.7)		12.5 %	3.20 [-2.51, 8.91]
Subramanian 2013	32	43 (15.2)	32	43.9 (14.7)		7.6 %	-0.90 [-8.23, 6.43]
Sucar 2009	11	30 (12.4)	11	26.36 (2.33)		7.3 %	3.64 [-3.82, 11.10]
Zucconi 2012	11	45.2 (20.3)	11	51.8 (13.1)		2.0 %	-6.60 [-20.88, 7.68]
Total (95% CI)	**191**		**172**			**100.0 %**	**3.30 [1.29, 5.32]**



Heterogeneity: Chi² = 7.80, df = 9 (P = 0.55); I² =0.0%
Test for overall effect: Z = 3.21 (P = 0.0013)
Test for subgroup differences: Not applicable

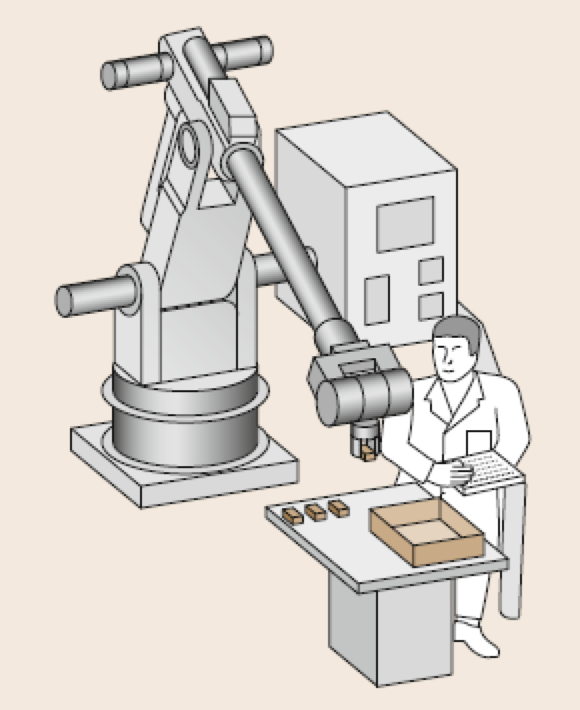
Cochrane Database of Systematic Reviews
12 FEB 2015 DOI: 10.1002/14651858.CD008349.pub3
http://onlinelibrary.wiley.com/doi/10.1002/14651858.CD008349.pub3/full#CD008349-fig-00102

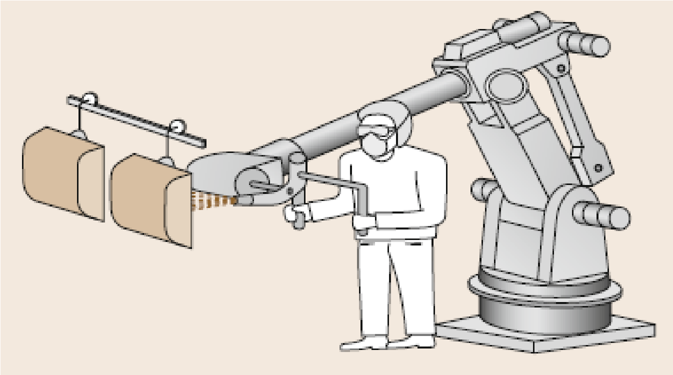
PERCRO Perceptual Robotics Laboratory

Nozioni di robotica

pHRI

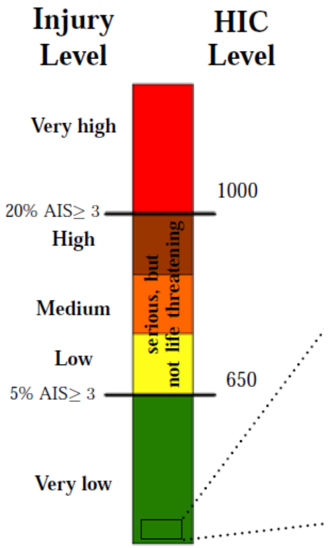
- pHRI robots will be designed to coexist and cooperate with humans in applications such as
  - assisted industrial manipulation
  - collaborative assembly
  - domestic work
  - entertainment
  - rehabilitation
  - medical applications.





Bicchi, Colgate et al 2007
Safety for human robot interaction, Handbook of Robotics

Safety

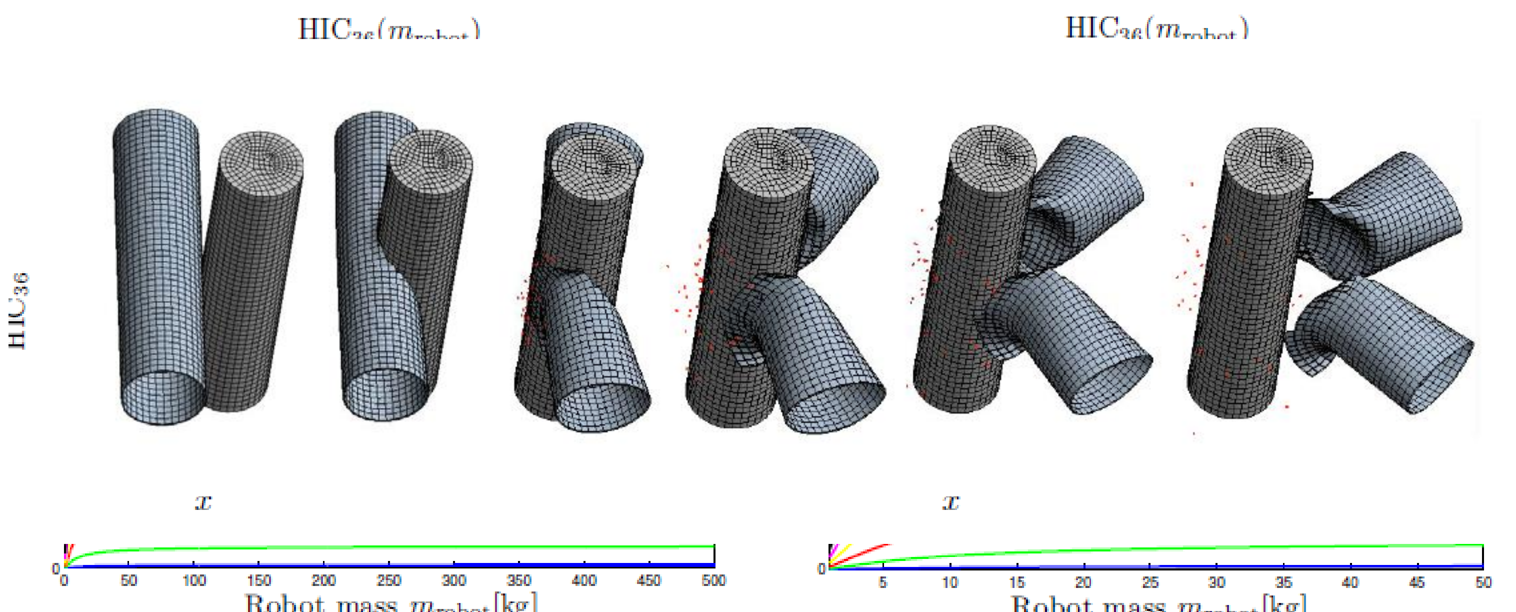


- Injury indicators used in the automobile industry which for the head usually focus on its acceleration.
- The most prominent measure in the literature is the Head Injury Criterion (HIC) [10], defined as, where Xh is the acceleration of human head to be measured in g

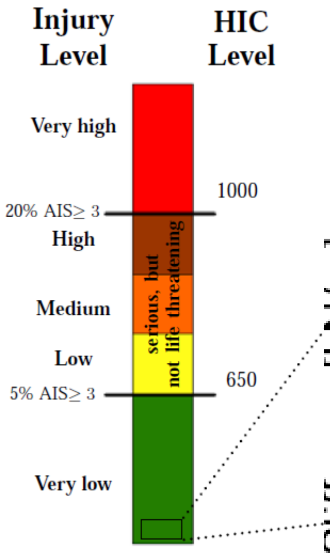
$$\mathrm{HIC}_{36} = \max_{\Delta t}\left\{\Delta t\left(\frac{1}{\Delta t}\int_{t_1}^{t_2} ||\ddot{\mathbf{x}}_H||_2 \mathrm{d}t\right)^{\left(\frac{5}{2}\right)}\right\} \leq 1000 \quad (1)$$

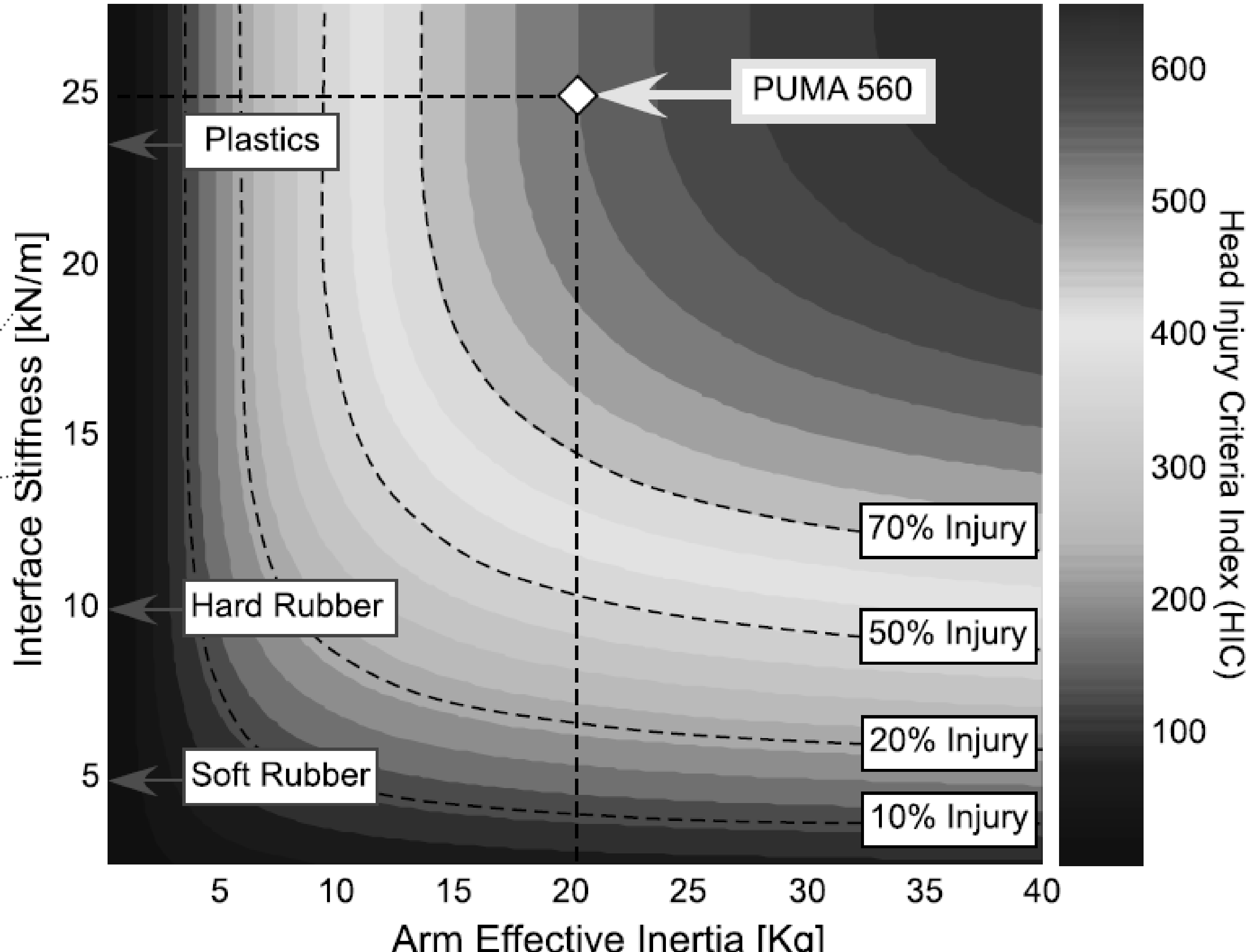
$$\Delta t = t_2 - t_1 \leq \Delta t_{max} = 36 \text{ ms}$$

Haddadin,2008 IROS



Understanding safety





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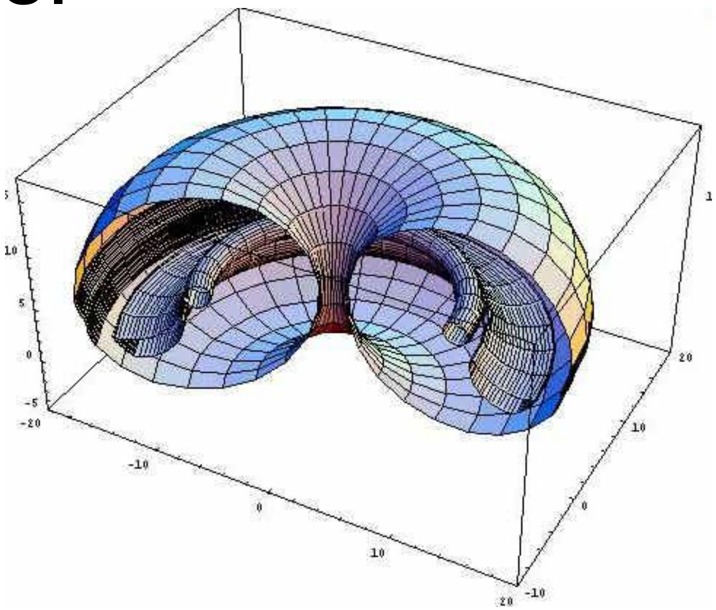
Zinn, Salisbury et al. ICRA and IJJR 2004
A new actuator approach for human friendly robot design

Definizione workspace

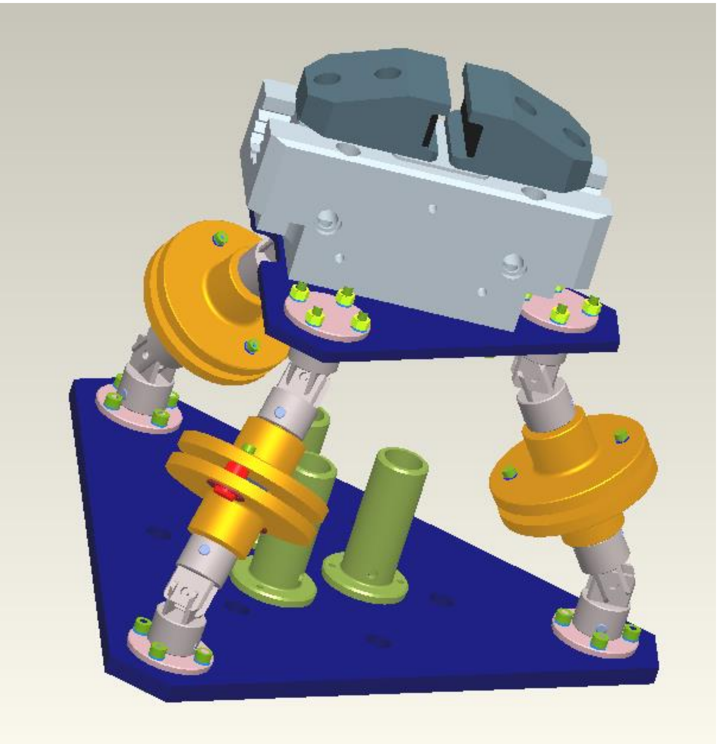
- *Workspace: Spazio di lavoro,* il volume spaziale che può essere coperto dall'end-effector del robot, sia in posizione sia in orientazione.



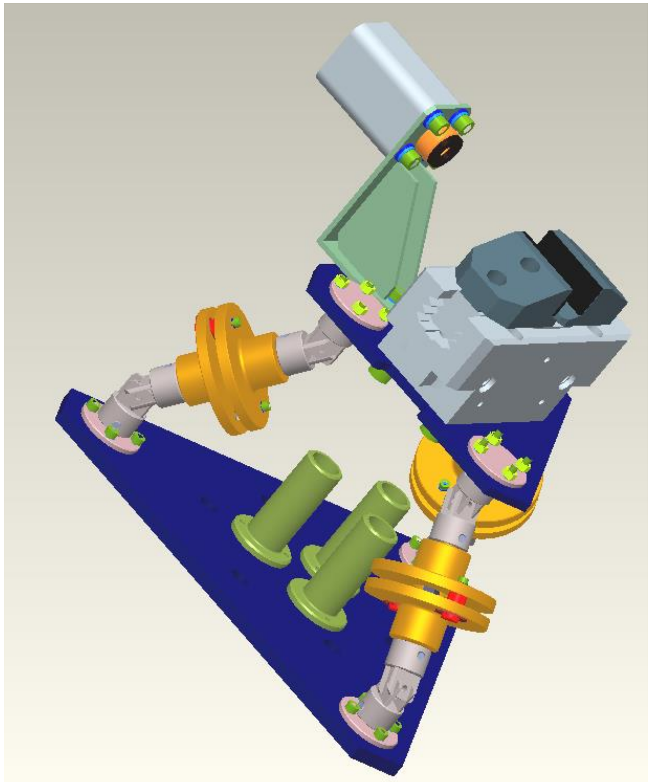
Metà del workspace di un robot cilindrico

Definizione end-effector

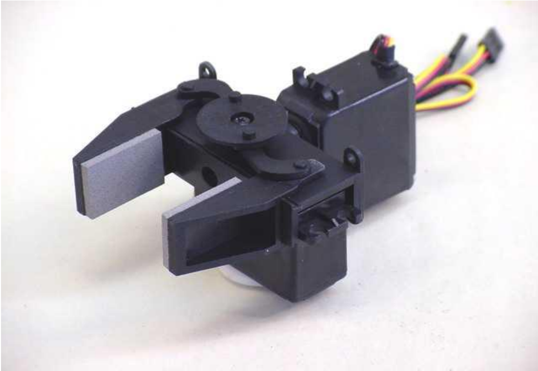
End-effector: L'utensile, il gripper o il dispositivo finale montato su un manipolatore per lo svolgimento di tasks utili.



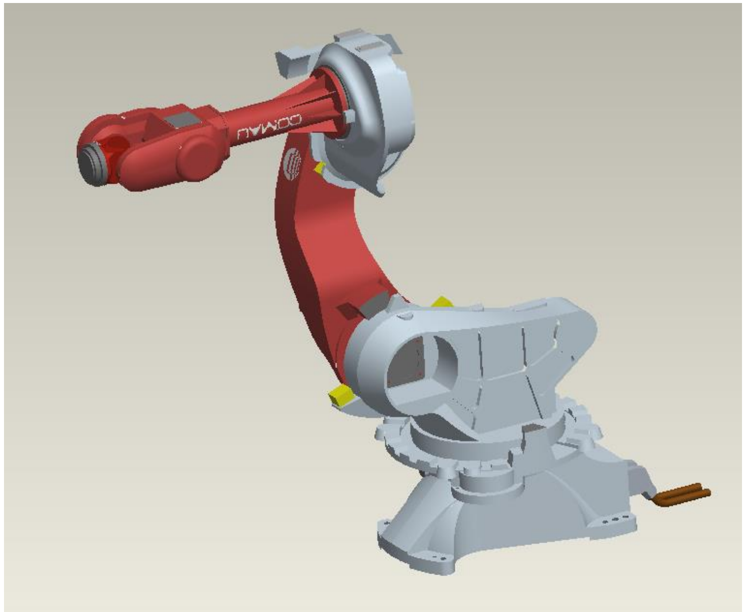
Struttura parallela montante un gripper pneumatico e 3 celle di carico



Sistema di afferraggio dotato di attuatore lineare

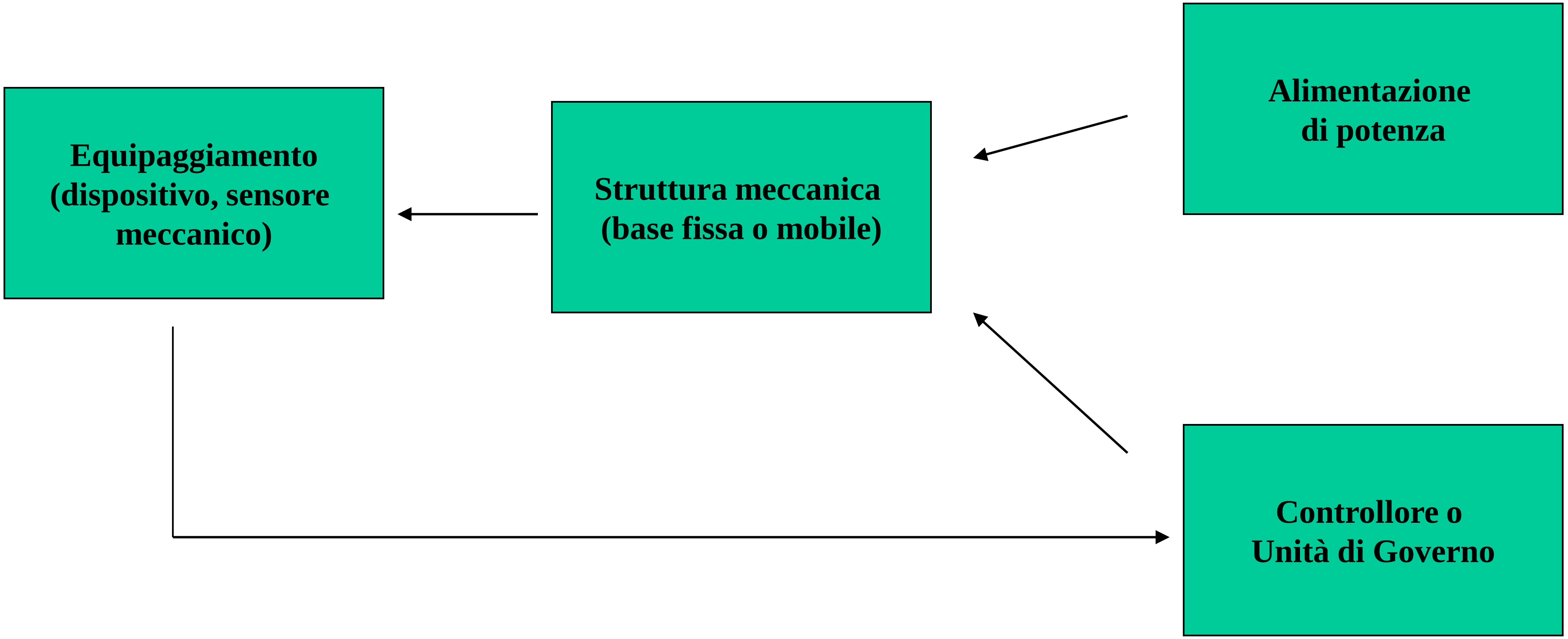


Esempio: Banco Prova Portellone
Scelta del manipolatore



Smart NH1-2.6

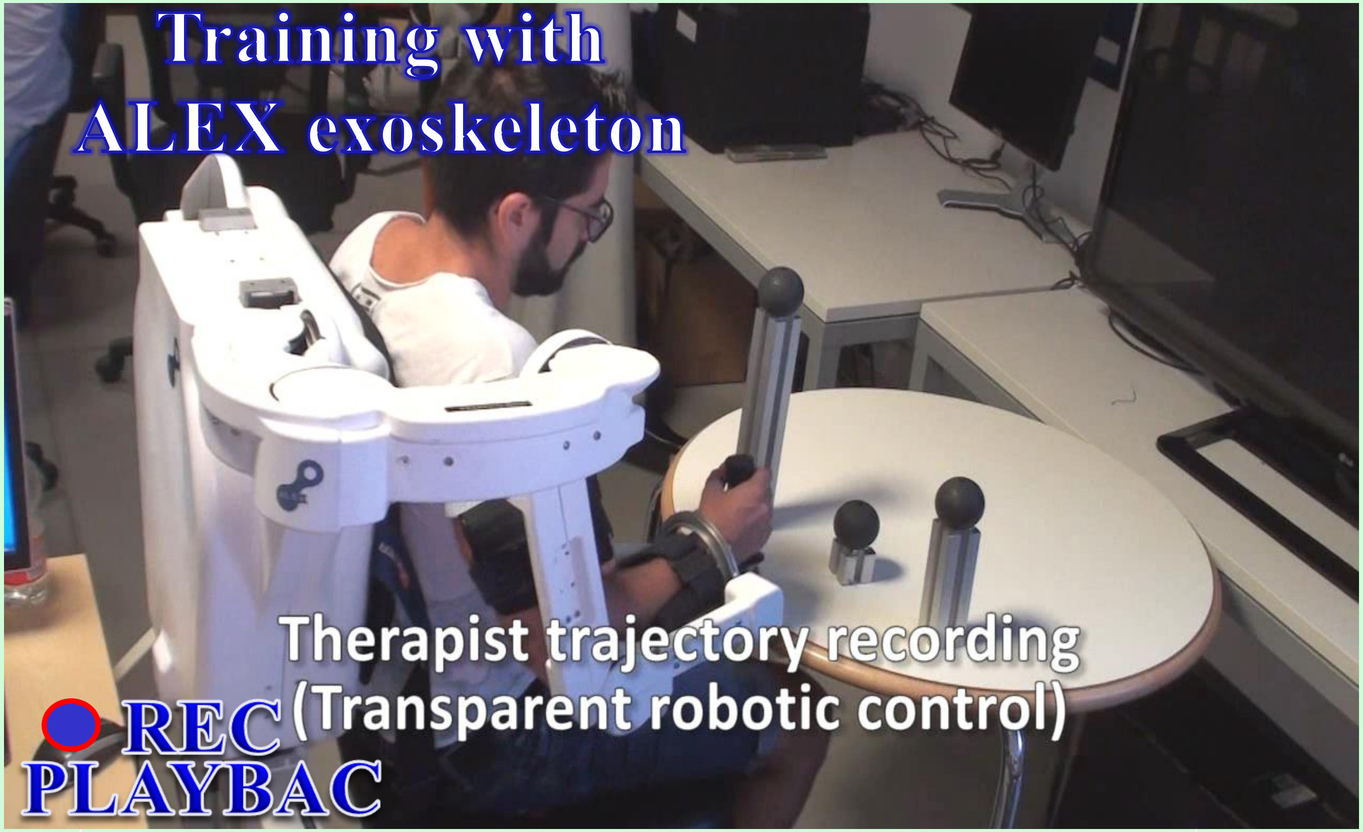
Le parti di un robot



Vantaggi della robotica?

The Proposed System – General Scheme

NEW (future work)



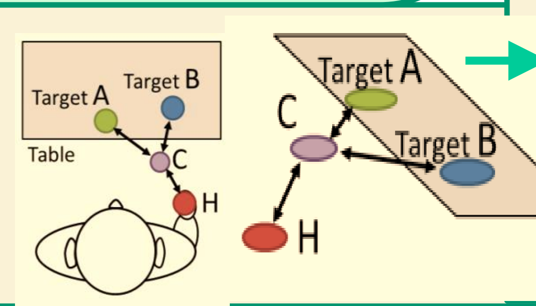
In the video ALEx exoskeleton shown

CURRENT

ARM + WRIST EXOS

Desired joint positions $q_d(t)$

ONLINE FULLY SINCHRONIZED BOUNDED JERK (OFSBJ) TRAJECTORY PLANNING
[Frisoli et al. 2012; Robotics and Autonomous system]



Stroke Patient

- Left CVA with right hemiplegia
- Non-ambulatory
- Lives in SNF

The benefits in SCI

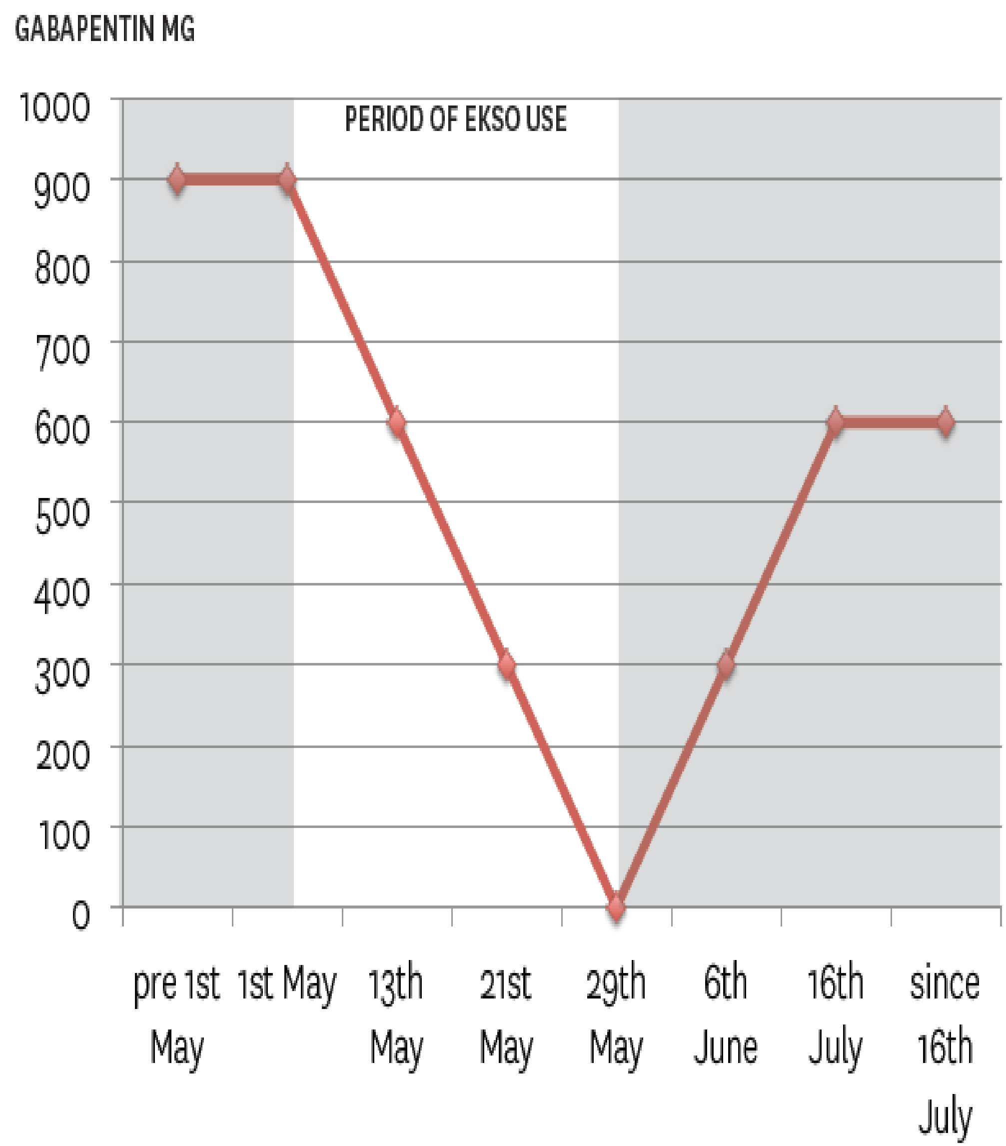
- Prolonged immobilization results in systemic de-adaptations, which include:
  - Cardiovascular deterioration
  - Urinary dysfunction
  - Gastrointestinal and bowel disorders
  - Respiratory depression and increased frequency of pneumonia and other respiratory tract infections
  - Pressure ulcers
  - Neuropathic pain
  - Musculoskeletal disorders and reduction in loss of bone density - osteoporosis

- **Weight bearing, over-ground ambulation has been shown to ameliorate many of these problems**
  - Improved circulatory response and Blood Pressure
  - Internal organ functionality
  - General body fitness
  - Minimizing decline in bone mineral density by periodic exposure to gravitational load and muscular loading forces

CASE STUDY – Reduction in Pain and Medication

FACTS

Subject's name:	Dale Messenger
Injury level:	L1 Incomplete SCI
Injury date:	27th October 2009
Age:	33
Nature of injury:	Gunshot wound
Protocol of Ekso use:	Gait Training/Pain Management
Time per treatment:	Varied
Treatments per week:	Varied
Crutches or Walker:	Crutches
Step mode:	Pro Step



EXOSKELETONS AS A TOOL TO ASSESS MOTOR LEARNING

The benefits in SCI

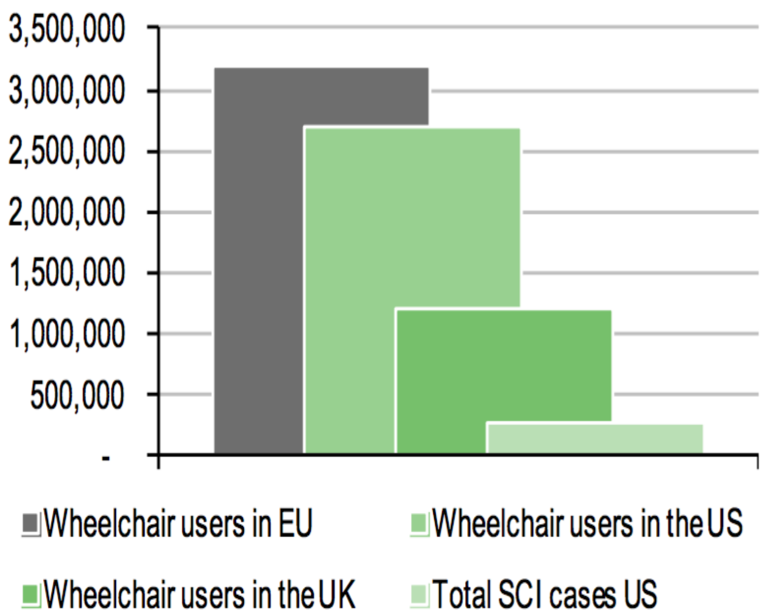
- Additionally, there are many psychological and social benefits to standing, including improved self-image, eye-to-eye interpersonal contact, increased vocational, recreational and daily living independence

The main competitor of exoskeleton

- What is the main competitor of exoskeleton technology for SCI patients?

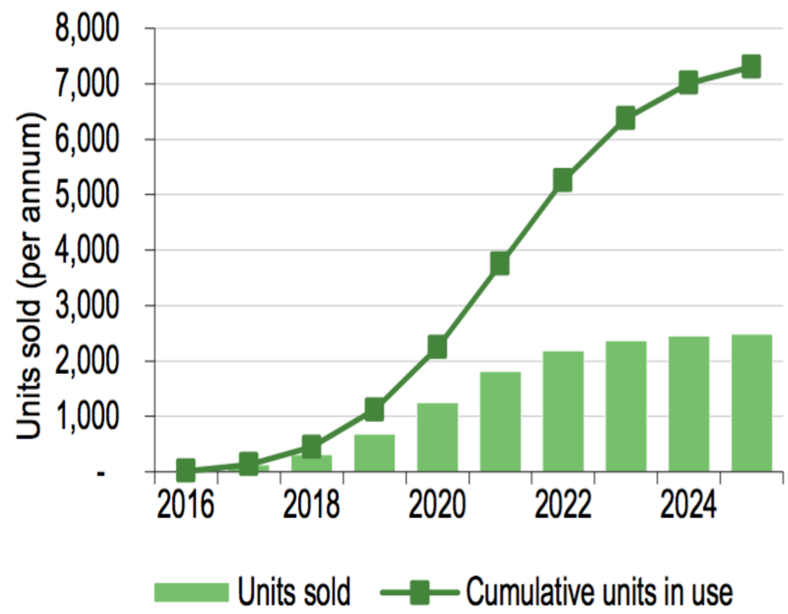
The adoption of technology

Exhibit 5: Units sales in context



Source: Edison Investment Research

Exhibit 6: Assumed adoption curve



Source: Edison Investment Research

Testimonials

Chris Tagatac

- Ekso™ user since February 2011
- Walking 6 times per week, nearly 120 hours total since injury
- Heard of Ekso™ 3 weeks after injury and sought out an Ekso Center right away
- Feels less pain in stomach and back; significantly fewer urinary tract infections and other health issues
- Prefers Ekso™ over other rehab because it offers mobile, weight bearing training

Amanda Boxtel

- Ekso™ user since October 2010; first person in the U.S. to receive an Ekso™
- Was told she would never be able to walk again after a ski accident
- *“While my spinal cord injury took away my ability to walk, it didn't take away my ability to dream. I'm turning my dream into my reality one baby step at a time”*
- Has taken over 35,000 steps in last 7 weeks

Mark Pollock

- Ekso™ user since February 2012
- Blind, paraplegic who has found a new hope through his use of the Ekso™
- *“I’m not scared anymore, just keen to continue exploring the boundaries of what is possible”*
- Able to complete over 3,000 steps in 60 minutes

Exoskeletons

Human power augmentation

Assistance

Rehabilitation

(a) Argo ReWalk exoskeleton.

(b) eLEGS exoskeleton.

(c) Walking Assistance Device Honda

(d) Indego Vanderbilt Exoskeleton

(e) Mindwalker

Current commercial exoskeletons

Ekso Bionics

Rewalk

Rex Bionics

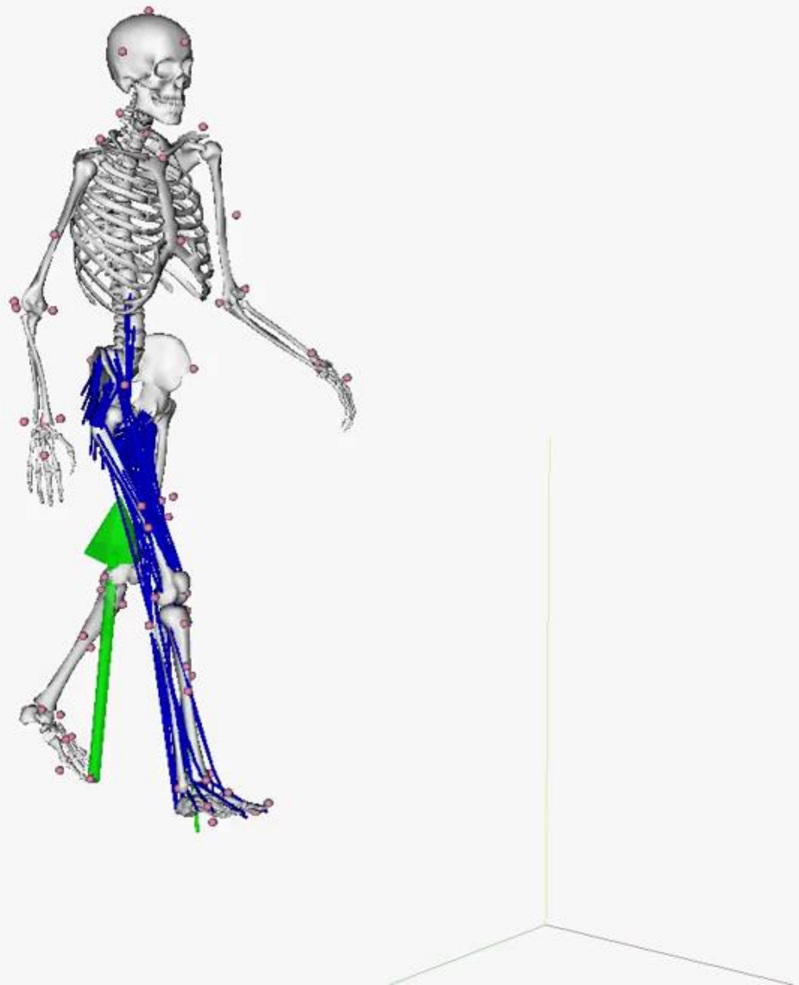
Cyberdyne

Main features of lower limb exoskeleton for rehabilitation

Features	REX-BIonics	Re-Walk	Ekso-Bionics	Indego-Parker	HAL Cyberd.
Steering modality	Joystick	Communicator & position control	Position control & variable assist	Position control & FES	Neuronal (EMG)
Possible body sizes (cm)	146–195	150–190	150–190	155–195	150–196
Maximum user weight (kg)	100	100	100	113	100
Battery life (hrs)	2	3,5	4	4	1–2
CE certification	Yes	Yes	Yes	-	Yes
Required tools	No	Crutches	Crutches /walker	Crutches/walk er	BWS

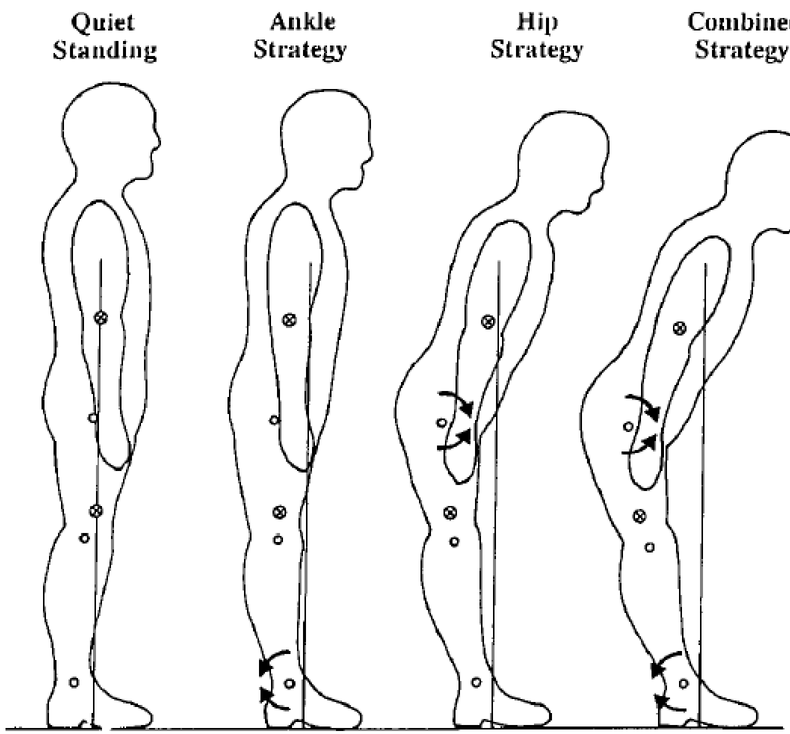
- Different exoskeletons are commercially available (ekso, rewalk, indego)
  - All have actuated hip and knee flexions/extension actuation
  - Dependence on crutches for stability
  - Limited ability to move quickly an easily
  - Limited ability to adapt or be adapted to many different function or activities

- Transfer of Center of Pressure location

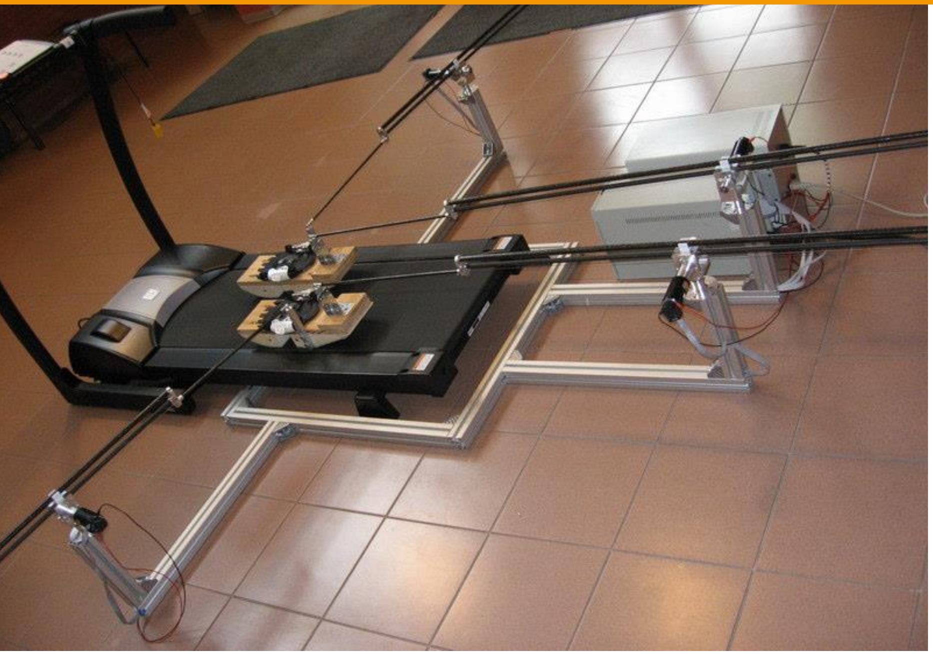


Strategia di equilibrio in human gait and standing

- Strategy 1: First strategy: modulation of CoP location by ankle torque, Ankle strategy
- Strategy 2: modulation CoP location by Hip strategy
- Strategy 3: exert moment by utilising inertial force: Stepping strategy



Realizzazione ed integrazione con il controllo



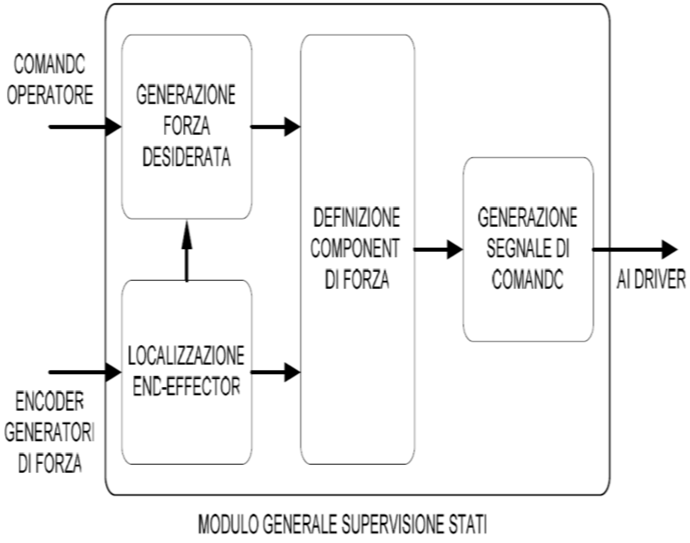
• **4 attuatori identici**

• **Ogni caviglia è collegata in parallelo a due attuatori**

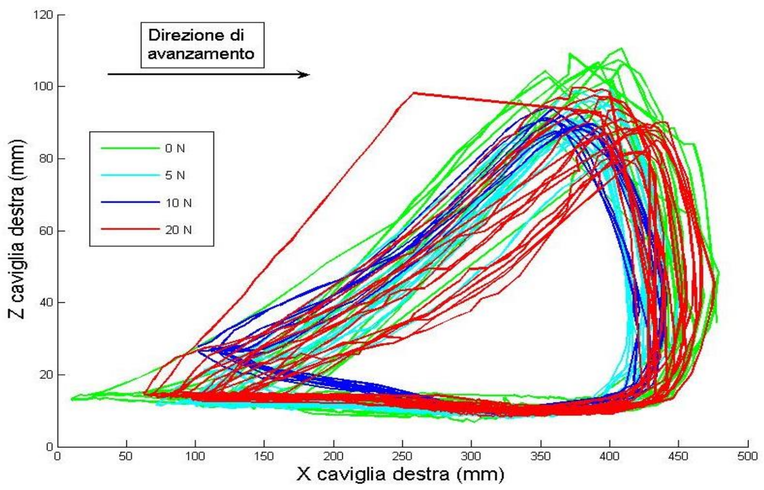
•**La struttura portante è regolabile**

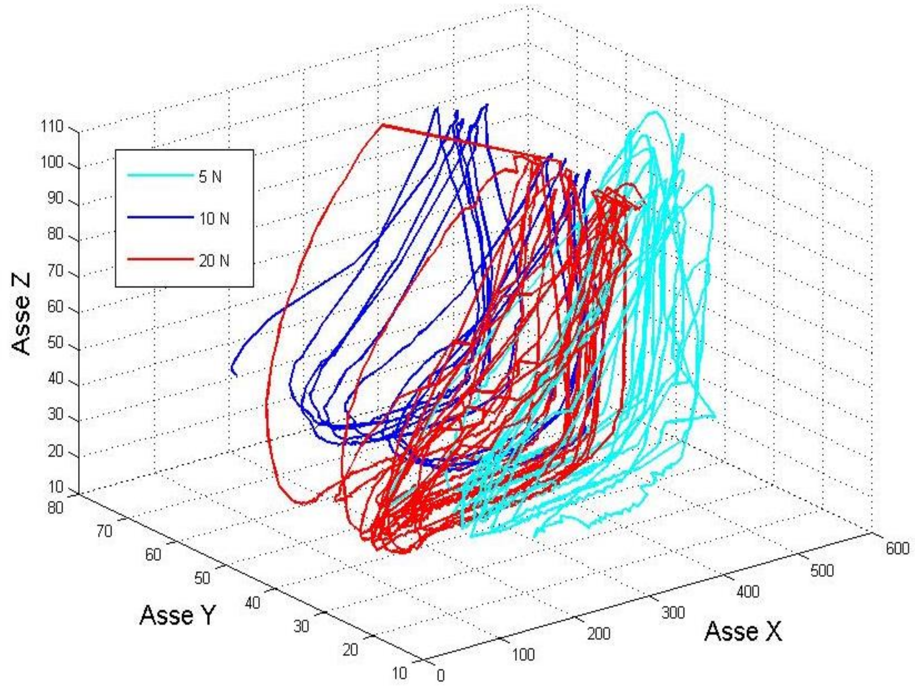
• **Per calcolo disturbo: stima posizione da sensori di posizione**

•**Per al valutazione: sistema di analisi del movimento**



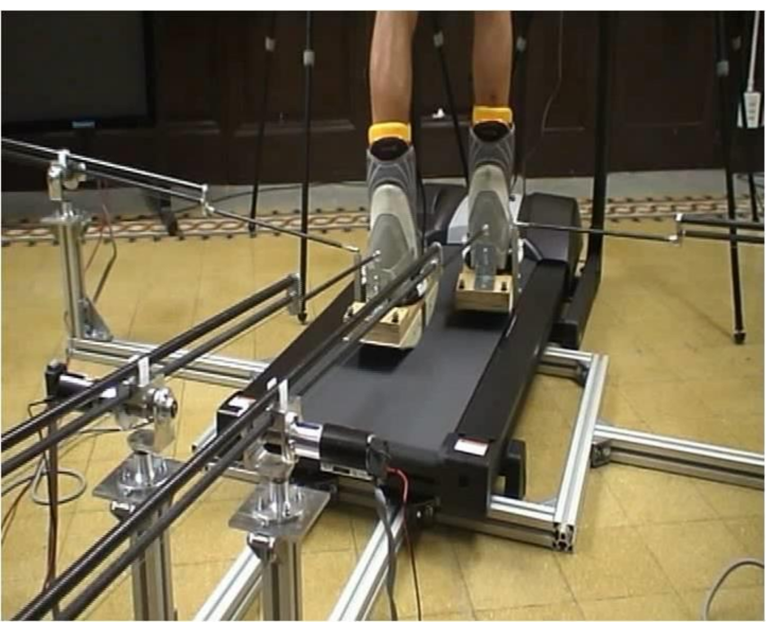
•Studio qualitativo dei dati

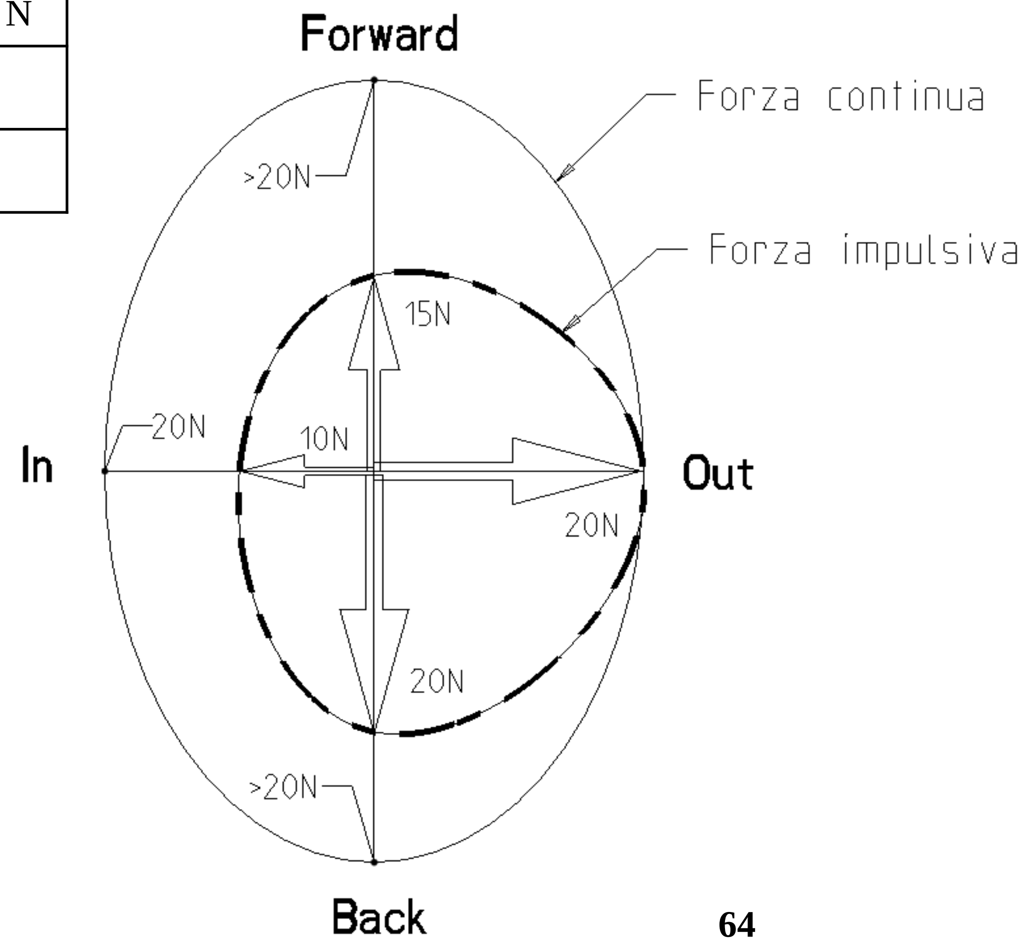




Valori di forza massimi ammissibili

Forza su caviglia	Continua	Stance	Swing
Back	>20 N	20 N	20 N
Forward	>20 N	10-20 N	10-20 N
Out	20	20	20
In	20	**10**	**10**

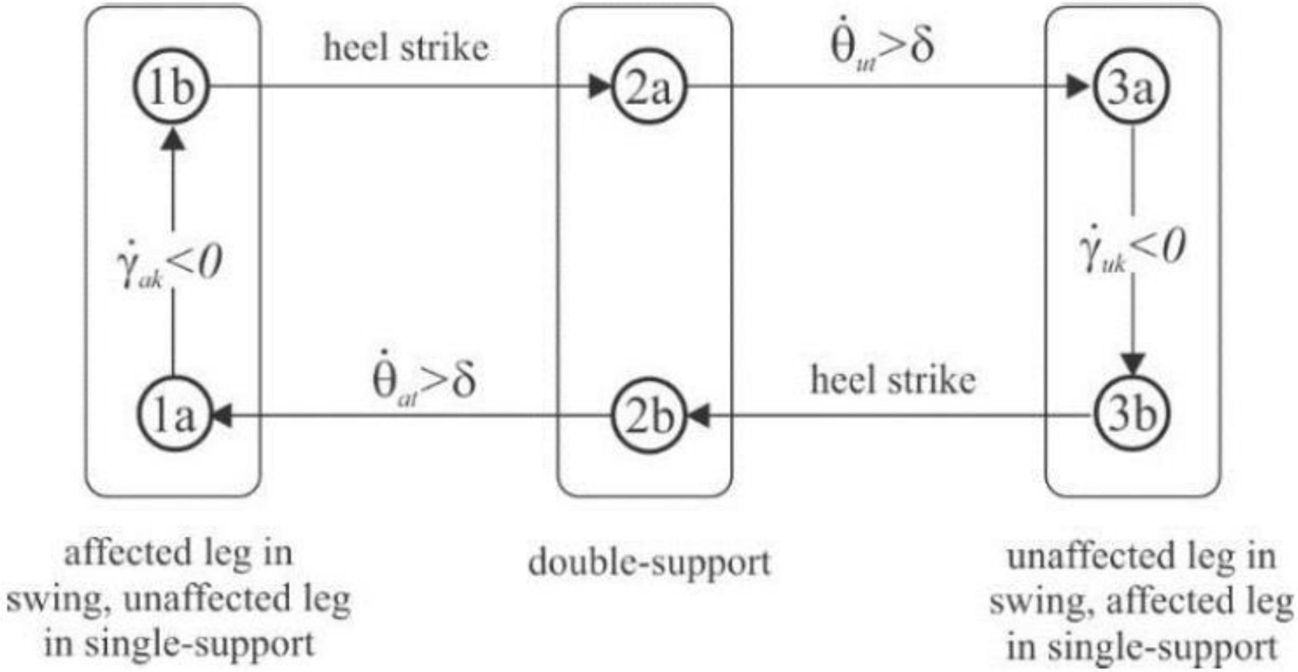




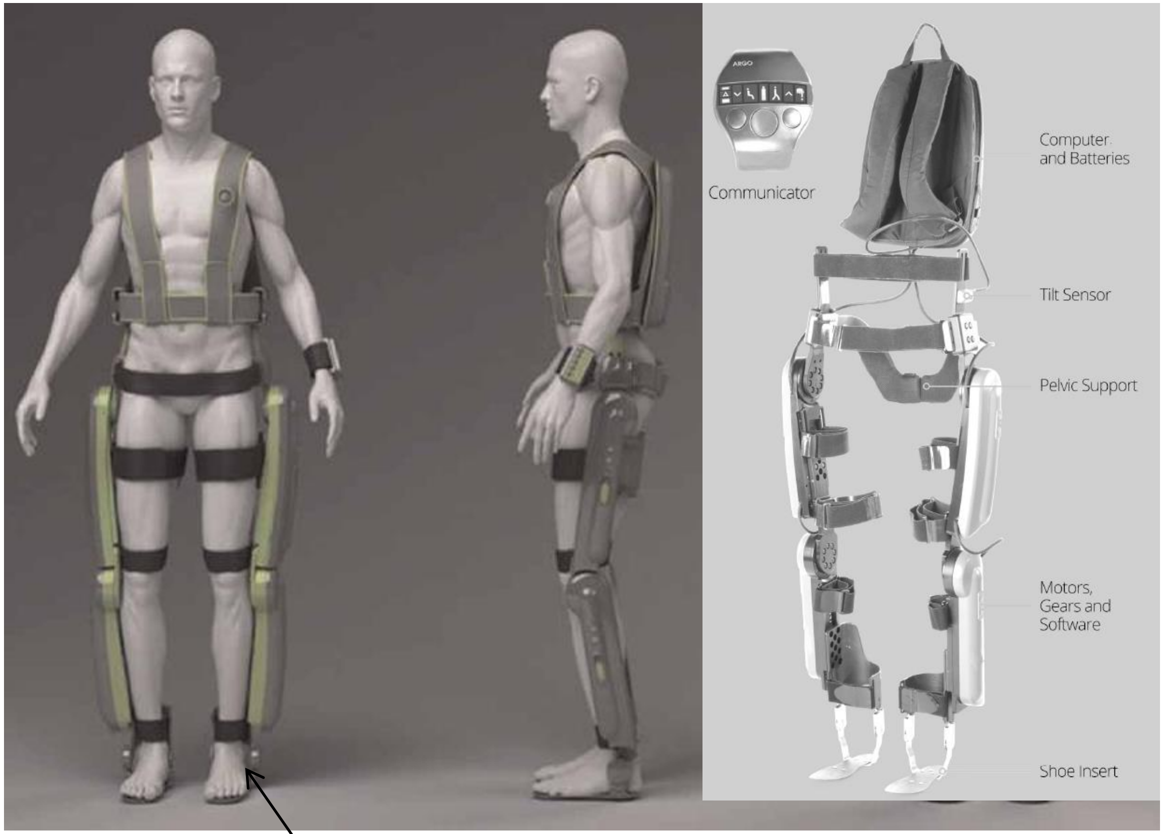
Modalità di funzionamento

- I sistemi sono in grado di riconoscere l'intenizone di movimento e lo stato del passo ed attivare diversi profili di movimento per le due gambe corrispondenti alla fase di oscillazione/doppio appoggio

ESEMPIO DI MACCHINA A STATI



The rewalk



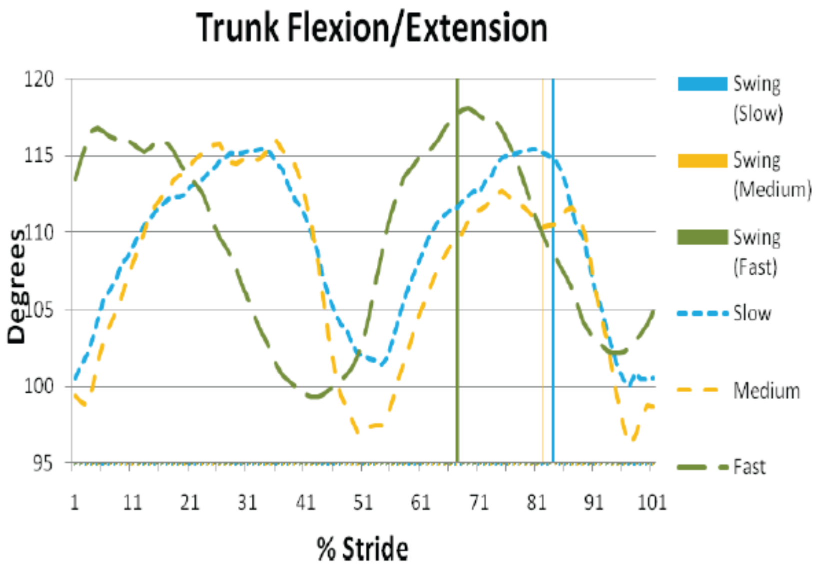
- Motorized at ankle and knee
- Array of sensors to measure
  - Upper body tilt angle
  - Joint angle
  - Ground contact
- Battery
- Main computer

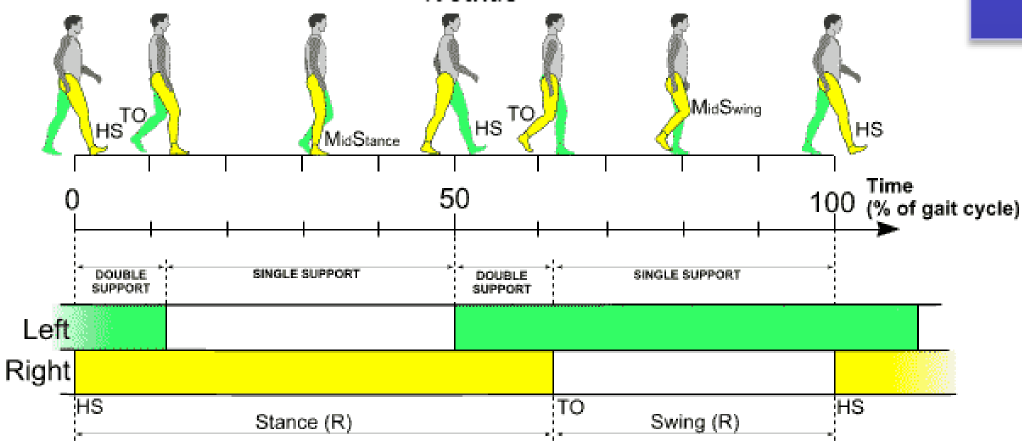
Spring assisted dorsiflexion

Control modalities: the re-walk case

- Weight shift
  - Each step is triggered individually by leaning forward through a predetermined degree of tilt
    - measured by a 3D accelerometer,
    - tilt sensor, located at hip-height on the powered exoskeleton
- The degree of tilt required to initiate a step is commensurate with amount of forward lean that the participant must perform to transfer from stance leg to swing leg.

Trunk movement





- The fast group showed a more flexed trunk at the start of swing phase (5-10 degrees over the medium and slow groups).
- In addition in the fast group, peak flexion occurred at the start of swing phase where as in the other groups peak flexion occurred just before swing phase and extension had already started at swing initiation

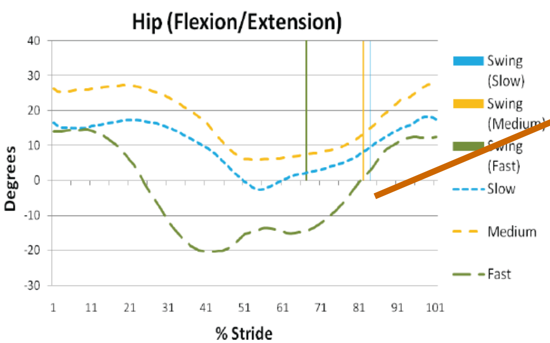
	Speed	n
SLOW	0.22- 0.31 m/s	19
MEDIUM	0.32 -0.41 m/s	22
FAST	0.42 -0.50 m/s	4

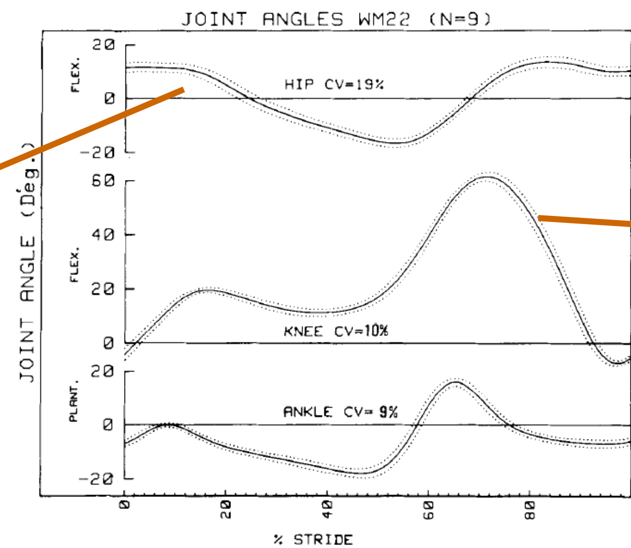
- Enrolled patients were Adults with chronic motor complete cervical and thoracic (C7-T12) spinal cord injury (according to American Spinal Injury Association (ASIA) guidelines)
- Adequate hip, knee and ankle range of motion and a spasticity level of 3 or less using the Ashworth scale.

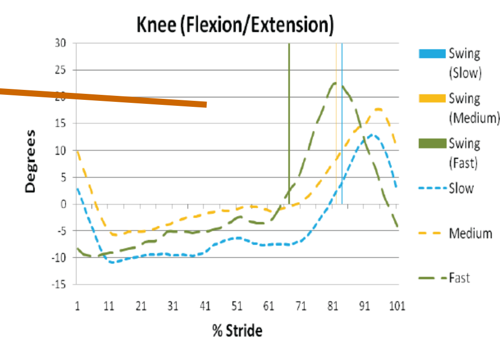
Talaty, Mukul, Alberto Esquenazi, and Jorge E. Briceno. "Differentiating ability in users of the ReWalk TM powered exoskeleton: An analysis of walking kinematics." *Rehabilitation Robotics (ICORR), 2013 IEEE International Conference on*. IEEE, 2013.

Knee and hip motion using an exoskeleton

- The fast group is quite close to walking at the speed necessary to cross a busy urban street safely during the red light, where a 0.1m/s drop may not allow this.
- On the opposite end of the spectrum, the slowest ReWalkers could be limited in terms of how far they can walk



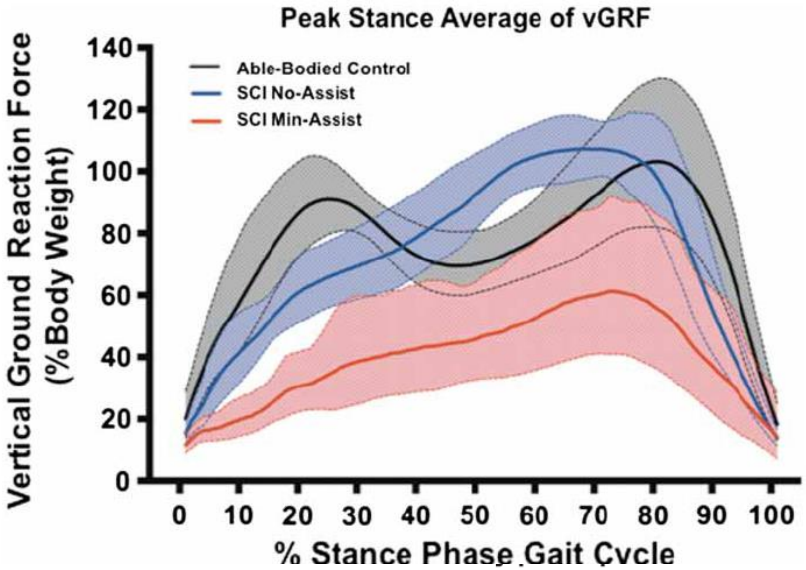


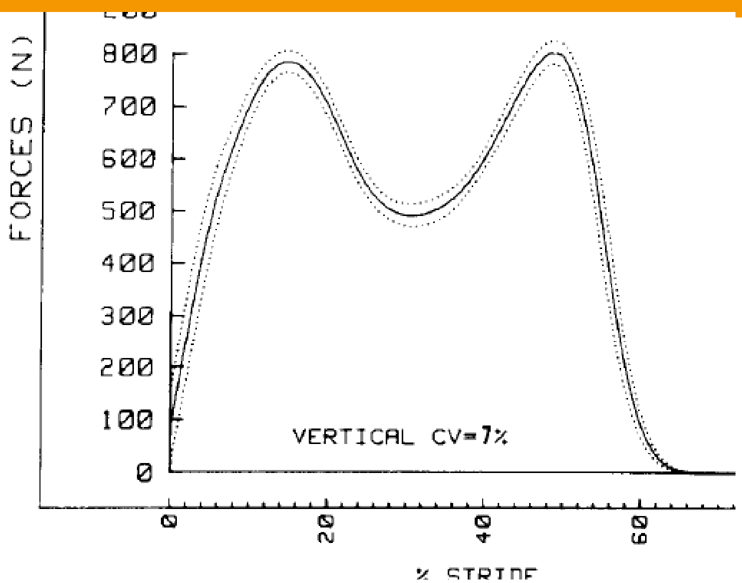


Talaty, Mukul, Alberto Esquenazi, and Jorge E. Briceno. "Differentiating ability in users of the ReWalk TM powered exoskeleton: An analysis of walking kinematics." *Rehabilitation Robotics (ICORR), 2013 IEEE International Conference on*. IEEE, 2013.

Winter, David A. "Kinematic and kinetic patterns in human gait: variability and compensating effects." *Human Movement Science* 3.1 (1984): 51-76.

Effects of ground reaction forces



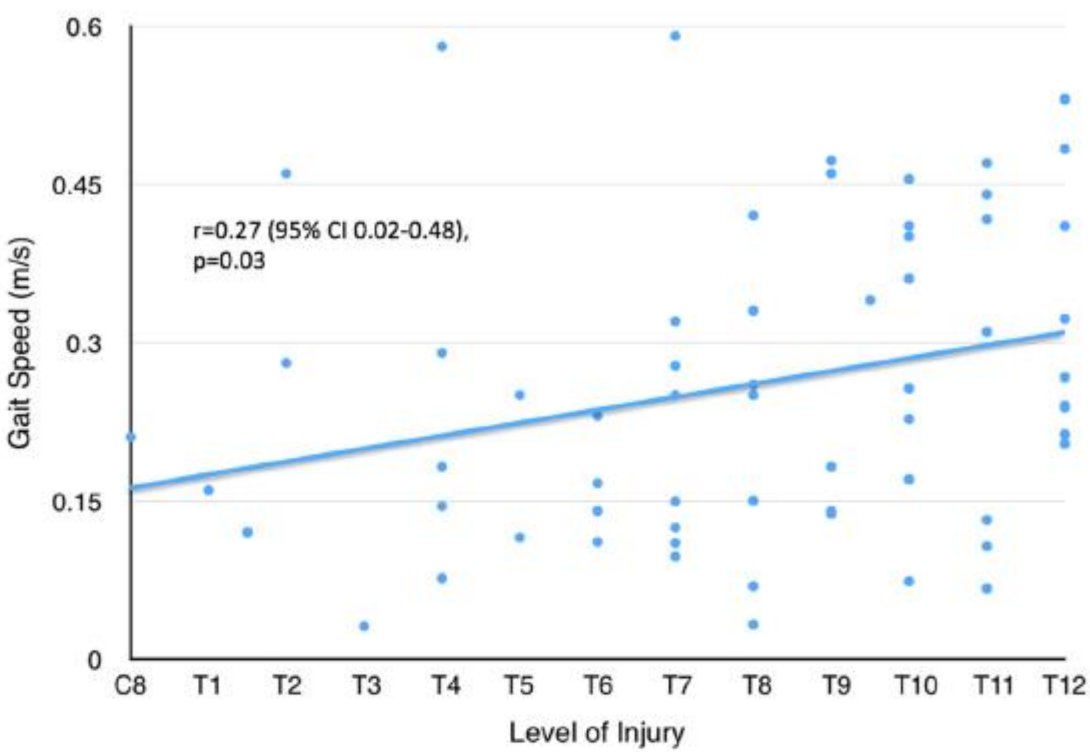


SID	Group	Gender	Age (years)	Height (cm)	Mass (kg)	LOI	AIS	DOI (years)	Level of assist
1	SCI	Male	34	175	66.6	T4	B	9.0	Minimal assist
2	SCI	Male	48	168	67.5	T1	A	4.0	Minimal assist
3	SCI	Male	43	183	78.8	T4	A	4.0	No assist
4	SCI	Female	58	160	64.8	T8	A	1.5	No assist
5	SCI	Male	62	175	72.0	T11	A	14.0	No assist
6	SCI	Male	24	185	74.3	T5	A	5.0	Minimal assist
7	AB control	Male	41	185	90.7	AB			
8	AB control	Male	32	183	88.5	AB			
9	AB control	Female	55	162	49.9	AB			

Fineberg, Drew B., et al. "Vertical ground reaction force-based analysis of powered exoskeleton-assisted walking in persons with motor-complete paraplegia." *The journal of spinal cord medicine* 36.4 (2013): 313-321.
Winter, David A. "Kinematic and kinetic patterns in human gait: variability and compensating effects." *Human Movement Science* 3.1 (1984): 51-76.

Review on current existing studies of gait speed

Authors	Exoskeleton	Use of the exoskeleton	Participants	Walking outcome measures	Training period
Aach et al. (2014) [13]	HAL	Training tool	8 (AIS A to D, T8 to L2)	6MWT, 10MWT, TUG	5d/wk for 90 days, 90 min per session



Authors	Exoskeleton	Use of the exoskeleton	Participants	Walking outcome measures	Training period
Yang et al. (2015) [26]	ReWalk	Assistive Device	12 (AIS A to C, C8 to T11)	6MWT, 10MWT	Up to 102 sessions, 1–2 h per session
Zeilig et al. (2012) [27]	ReWalk	Assistive device	6 (AIS A/B, T5 to T12)	6MWT, 10MWT, TUG	Until able to walk 100 m unassisted

HAL Hybrid Assistive Limb; *6MWT* Six Minute Walk Test; *10MWT* Ten Meter Walk Test; *TUG* Timed Up and Go Test; *IRGO* Isocentric Reciprocal Gait Orthosis; *2MWT* Two Meter Walk Test; *WPAL* Wearable Power-Assist Locomotor

Only 3 studies with incomplete SCI patients

Louie, Dennis R., Janice J. Eng, and Tania Lam. "Gait speed using powered robotic exoskeletons after spinal cord injury: a systematic review and correlational study." Journal of neuroengineering and rehabilitation 12.1 (2015): 1.

Ekso bionics

- 4 Electric Motors
- 2 48v Lithium Ion Batteries
- Battery Life: Full clinical
- 23 kg in Weight
- Multiple sensors and gyroscopes in the legs and torso to assist in balance and walking

Operating Ekso

With a Physio-Controller

Without a Physio -Auto Walk

STEP MODES

FirstStep™
A trained spotter initiates steps with the push of a button.

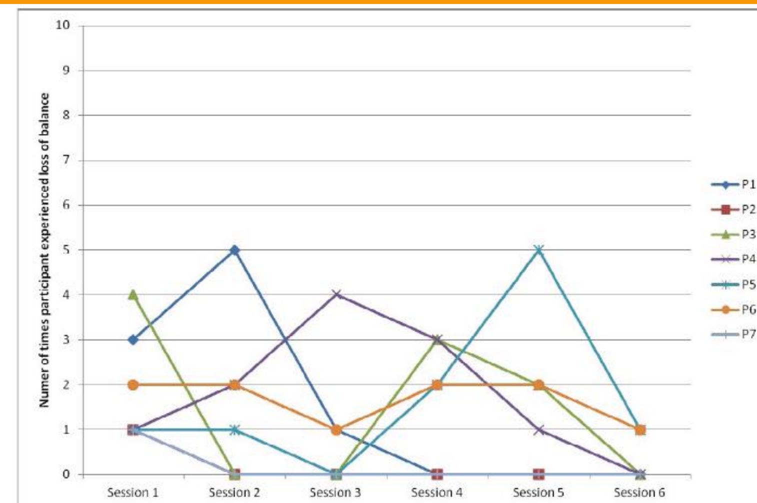
ActiveStep™
User takes control of initiating their own steps via buttons on the crutches or walker.

ProStep™
The user independently achieves the next step by moving their hips laterally and forward.

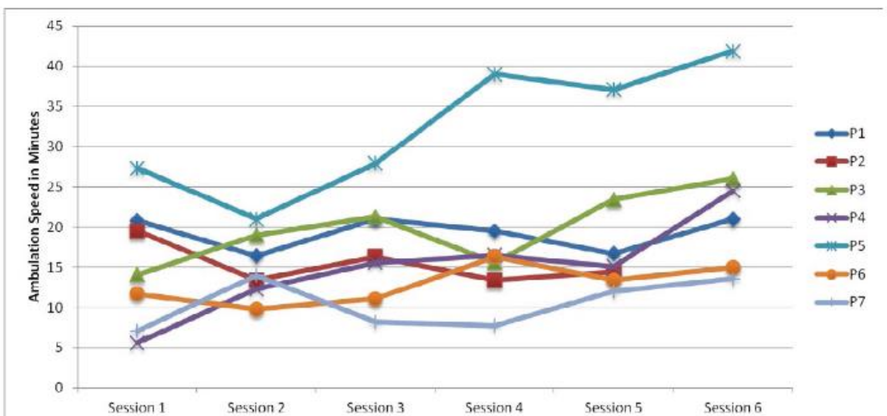
ProStep Plus™
Steps are triggered by the user's weight shift PLUS the initiation of forward leg movement.

Ekso bionics

- Steps can be triggered
  - By push button
  - by the user's weight shift + the initiation of forward leg movement
- Sensors monitor the balance shift and can initiate the step



Experience of loss of balance



Speed over sessions

Kolakowsky-Hayner, Stephanie A., et al. "Safety and feasibility of using the EksoTM bionic exoskeleton to aid ambulation after spinal cord injury." *J Spine S*4 (2013).

Ekso stepping and sit to stand features

Spatial targets
Set optimal lateral & forward weight shifts to achieve steps

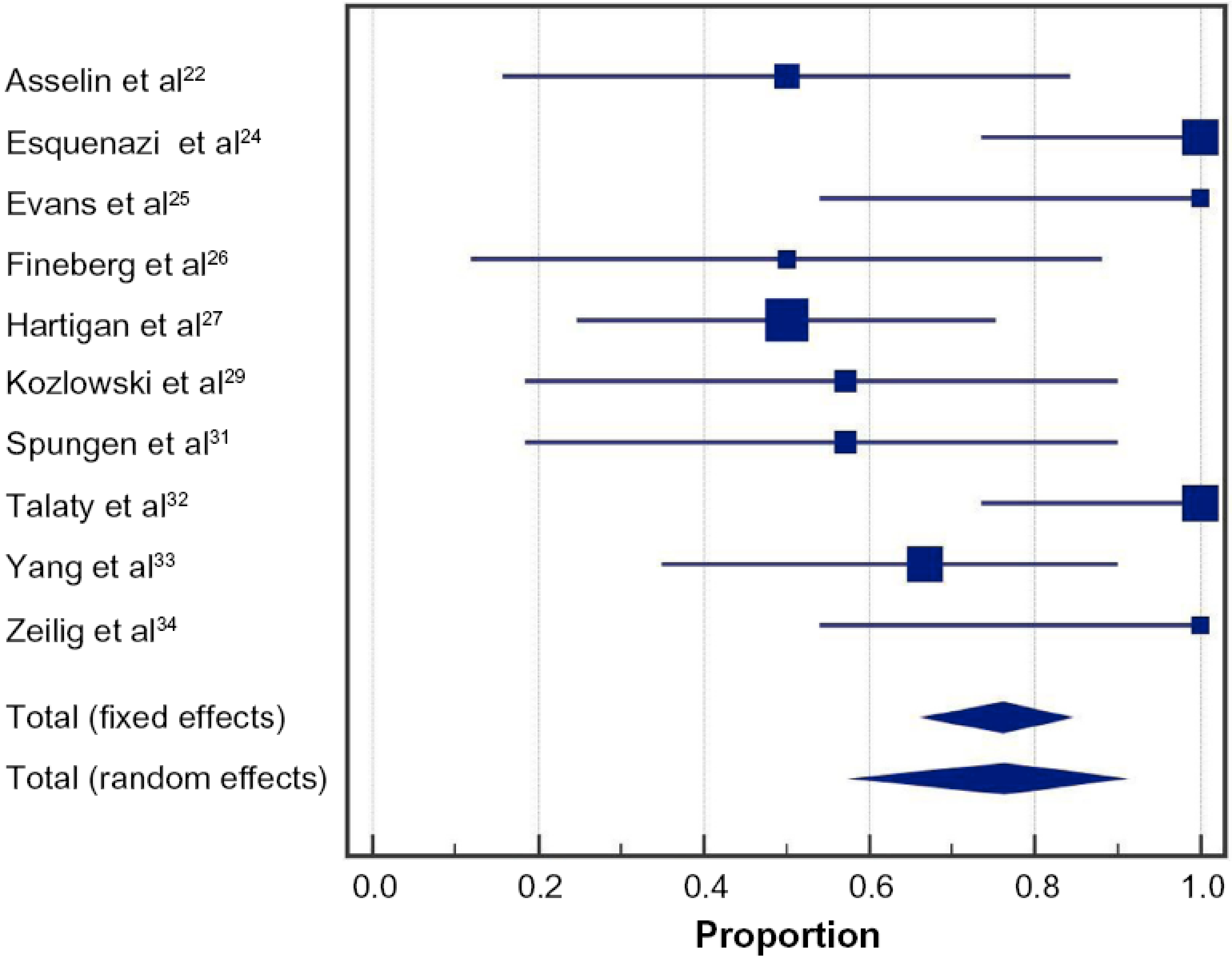
Speed of stand, sit & step swing
Accommodates spasticity & patient skill

Review of existing literature

Study	Study design	Exoskeleton	Training environment					Training volume			
			Indoor walking	Outdoor walking	Obstacles	Stairs	ADLs	No of sessions	Session length (min)	Sessions per week	Program duration (weeks)
Arazpour et al[21]	RCT	–	X					24	120	3	8
Asselin et al[22]	PCS	ReWalk	X					37	[75]	3	12
Benson et al[23]	PCS	ReWalk	X	X	X	X[a]	X[b]	20	120	2	10
Esquenazi et al[24]	PCS	ReWalk	X					24	[83]	3	8
Evans et al[25]	PCS	Indego	X					6	–	–	–
Fineberg et al[26]	PCS	ReWalk	X					[72]	[90]	3	24
Hartigan et al[27]	PCS	Indego	X	X[c]	X[d]		X[e]	5	90	5	1
Kolakowsky-Hayner et al[28]	PCS	Ekso	X[f]					6	58	1	6
Kozlowski et al[29]	PCS	Ekso	X		X[g]		X[h]	19	120	[1.5]	[13]
Kressler et al[30]	PCS	Ekso	X[f]					18	60	3	6
Spungen et al[31]	PCS	ReWalk	X	X[i]	X[j]	X[b]	X[k]	45	[90]	3	[15]
Talaty et al[32]	PCS	ReWalk	X					24	[75]	3	8
Yang et al[33]	PCS	ReWalk	X					55	90	–	–
Zeilig et al[34]	PCS	ReWalk	X					14	50	–	–

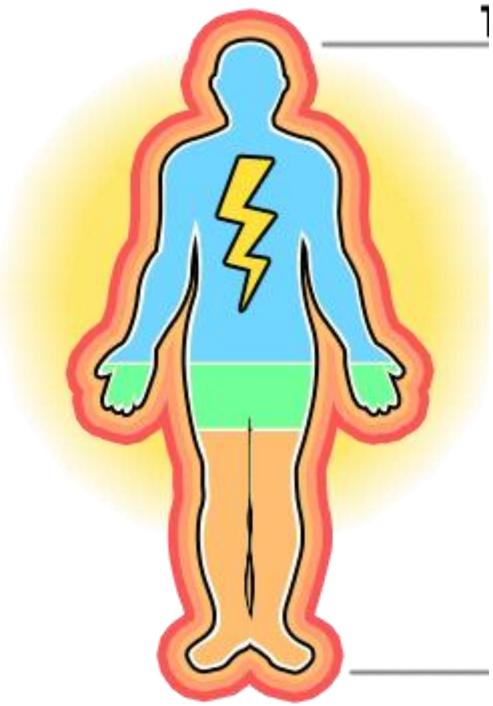
Notes: Brackets represent an estimate. Dash indicates unspecified, blank spaces indicate not utilized. [a]Includes walking up and down stairs; [b]includes visiting a café, upright cooking, shopping; [c]includes concrete walkway, city sidewalks, and grass; [d]includes ramps with slope ≤5°; [e]includes entering an elevator, riding to another floor, and exit without requiring the elevator door to be held open; [f]includes tethered indoor walking; [g]includes walking on carpet, rough concrete surfaces, and ramps with slope ≤8°; [h]includes opening doors, pushing button to summon, enter, and exit elevators, and standing at counter and retrieve an item from high cupboard; [i]includes walking on concrete and uneven ground surfaces; [j]includes walking on carpet, up and down a slight slope, and up and down a curb; [k]includes navigating a push button electric door, an elevator, and a revolving door.
Abbreviations: ADLs, activities of daily living; PCS, prospective case series; RCT, randomized controlled trial; min, minutes.

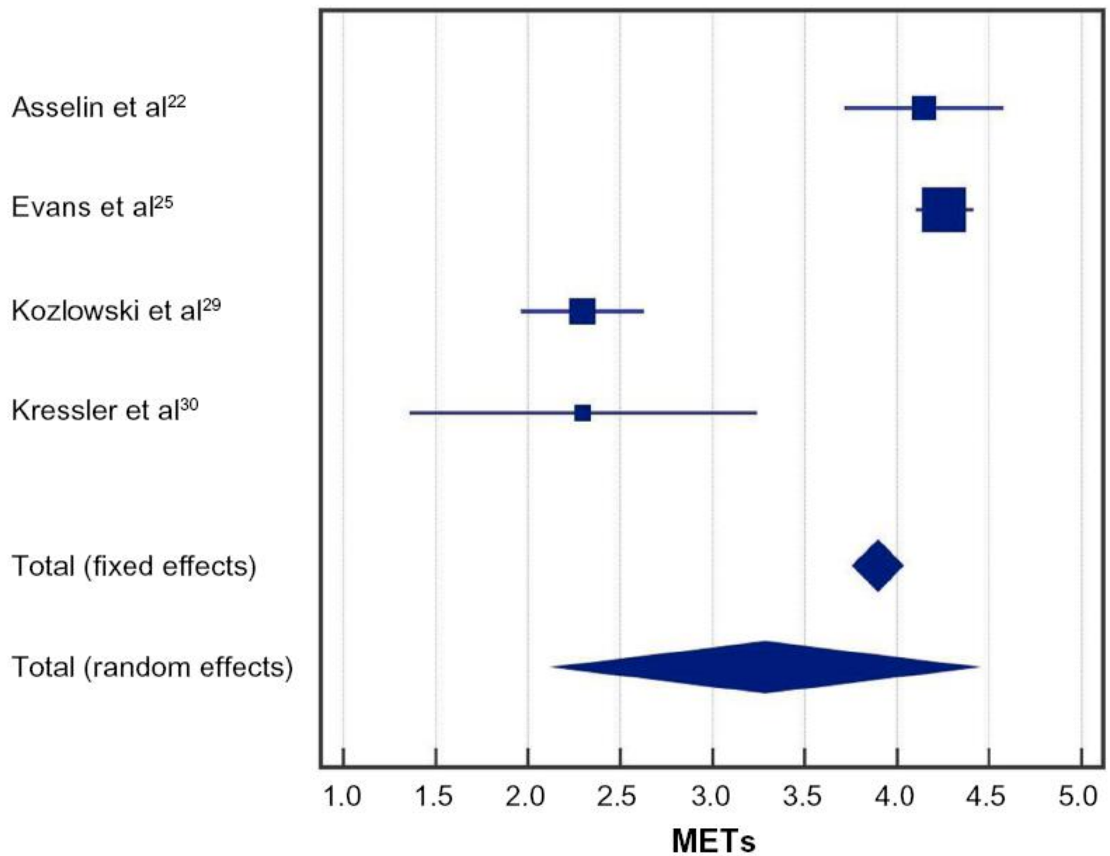
Ability to ambulate using a powered exoskeleton



Metabolic consumption

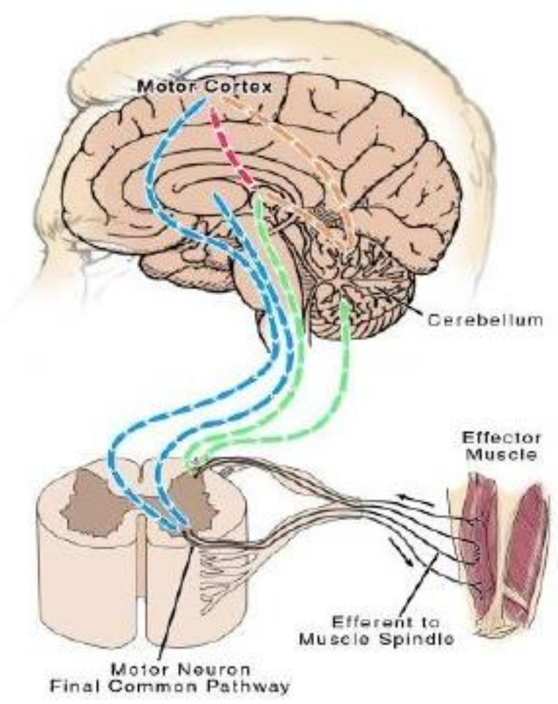
- MET (metabolic equivalent): he Metabolic Equivalent of Task (MET), or simply metabolic equivalent, is a physiological measure expressing the energy cost of physical activities and is defined as the ratio of metabolic rate (and therefore the rate of energy consumption) during a specific physical activity to a reference metabolic rate, set by convention to $3.5\ ml\ O_2 \cdot kg^{-1} \cdot min^{-1}$ or equivalently:

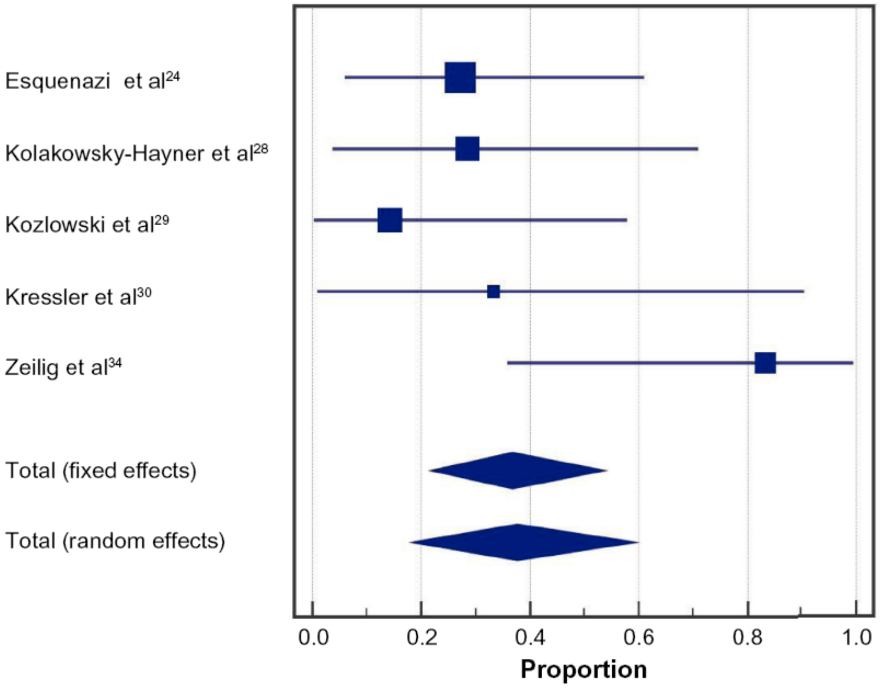




Reduction of spasticity

- Effects on spasticity
  - Spasticity might prevent the usage of some lower limb exoskeleton systems
  - Percentage of subjects that report reduced spasticity





thank you!

email: a.frisoli@sssup.it