Potential of robotics for surgery and rehabilitation

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My objectives.... My messages

Robotics is a matter of **Motion** and **Interaction**

Help us to imagine the applications of tomorrow
Potential of robotics for surgery and rehabilitation

- Rehabilitation
- Lower Limb Exoskeletons
- Surgical robotics
- Cobotics

Robotics....

iRobot, the movie
Robotics....
The Pyramid of development

You do say “Mechatronics”
The Pyramid of development
Direct Drive Actuated Delta realized for **BOSCH Packaging Technology**

WO2012152559

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*In the late ten years…. Robotics has been closest to more disciplines*

- Surgery and rehabilitation
- Cognitive neurosciences
- Gaming
- Building manufacturing

....

- Education
Rehabilitation Robotics for lower limbs

Prototype-0 In clinical trial (2003 – 2005)
Product certified (2008)

Concept – (2007)
Prototype-0 In clinical trial (2008-2009)
Product certified (2013)

The MotionMaker

Force sensors
Motor+ Incremental Encoder

Knee
Ankle
Hip
**Proof of concept**

**Knee Orthosis**

**Concept:**
- Mobilisation
- Force control through electrostimulation

**Knee Orthosis Setup**

- 8 subjects participated –
- 6 finished the CT-
- 2 Stopped: they completely retrieved their voluntary forces.
- 1 did not respond to ES

[Schmidt, IFES, 2004]
[Bouri, Springer, 2014]

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**Closed loop Muscle Electrostimulation**

Total of 7 muscles have been used in the loop:
- RF Rectus Femoris,
- VM, L Vastus Medialis and Lateralis, GM Gluteus maximus.
- HA Hamstring,
- GA Gastrocnemius,
- TA Tibialis Anterior

The Electrostimulation Control loop
CT Results

Progress of the Voluntary and electrically induced expended power for one subject

Progress of the mean and standard deviation of spasticity

Unfortunately, this development is no more commercialized – Fortunately, the IP is now public

LHS from LHS SA
LegoPress: device for lower limb Leg-Press
Developed as an openRehab device

- **Fully actuated** for **foot flexion-extension**
  and ankle plantar & dorsi flexions

- **Fully instrumented** with force sensors and redundant position sensors.

- Control capabilities for impedance control and several multi-modal strategies (EEG, FES, ...)

[Olivier, EuroHaptics, 2014]
[Liu, J. Neuro Eng, 2017]

Safe Freeze of Gait
(current)
Safe Freeze of Gait (current)

Introduction

• Problem
  - Freezing of gait (FoG) is a common condition in Parkinson’s disease (PD) patient.
  - Neural mechanism of FoG is not well-known, and its treatment is a clinical challenge.
  - Safety and walking support are key factors in laboratory-level experiments and clinical Assessment.

• Research objectives
  Explore how to assess and treat FoG in a safe way to avoid falls.

• Solution
  We propose a leg-press sitting position robotic setup combined with an immersive virtual reality (VR). Flexion-extension movements are encoded to control an avatar and allow simulated walking.

Setup

• Experimental Setup
  - LegoPress: A custom robotic device that allows leg-press movements in sitting position
  - Immersive VE (Unity engine)

• VR Environment
  - User friendly interaction
  - First-person view
  - Four scenarios: open space, wide corridor, dark narrow corridor and room
  - Session information (force, # of steps, time, distance) is visible on PC screen but not in VE

Verticalized Systems for gait rehabilitation

The Lokomat from HOCOMA, ZH, CH

• Actuated Hip and Knee for each leg.
• Following Ankle joint
• Use of a treadmill
• BodyWeight support
• …
• First prototype that has been sold (more 200 pieces around the world) was totally passive
• An impedance control is also implemented

[ref. the Lokomat, company HOCOMA, ZH]
[Jezernek, tech Neur. Interfaces 2003]
Overview [Riener et al, 2010]
The WalkTrainer: The Movie

Unfortunately, this development is no more commercialized – Fortunately, the IP is now public

The best is the enemy of the good

Closed-Loop Functional Electrical Stimulation for Gait Training for Patients with Paraplegia...
More with brain control and Sensory substitution

[Selfslagh et al, in revision SciRep 2019]
Closed-Loop Functional Electrical Stimulation for Gait Training for Patients with Paraplegia...
More with brain control and Sensory substitution

Patient P2 (40 years)
ASIA B T7/L/R
Time since lesion: 6 years
Body weight support: 70%

Exoskeletons

Definition
An external covering or integument, especially when hard, as the shells of crustaceans (opposed to endoskeleton). [Ref, Dictionary.com]

EXO + SKELETON
External + Rigidly (attached)
rigidly interfaced to the limb through dedicated components to transmit motion or torques.

Classified by IFR as personal service robot or a service robot for personal use
IFR, 2012

Benoit Thvenaz, tetraplegic, walking with ekso (Ekso Bionics)
Powered Lower limb exoskeletons / orthoses
Terminology (tentative)

- Hip is a spherical joint
- Knee
- Ankle

[Vitiello et al., 2015] [Schrade et al., 2018] [Loko Station, from Woodway]

TWICE, Vouga, ICORR 2017
Baud, ICORR 2019
Fasola, ICORR 2019

HiBSO, Olivier et al. Rob & Aut Sys, 2015

Autonomyo, Ortlieb et al, ICORR 2017
Daily living activities

**targeted tasks**

- **Overground Walking**
- **Transitions**
  - Sit-Stand
- **Climbing stairs and slopes**
- **Obstacles**

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**TWIICE™** A light exoskeleton for people with paraplegia

- Lightweight structure <14kg
- Brushless motors with belt transmission and harmonic drive.
- Adjustable segments length.

*After 18 months, 3 PhD students and 1 Engineer

*Patented*
Backdrivability
Daily living activities

Evaluation in collaboration with CFF (Swiss train transport company)
Human-inspired standing balance controller

[Fasola et al, 2019, 2020]
[Baud et al, 2019]
autonomyo: A lower limb exoskeleton to assist gait and balance
Human-inspired balance control

4 Handed manipulation to enhance robotic surgery [2017-2022]

Four Arm Laparoscopic Surgery Via Foot Interfaces

8X Speed
Haptic intervention for intelligent thrombectomy

Force sensing
Precise positioning

Hofmeister et al., 2017

Laparoscopic Surgery
Requirements for force feedback [2016]
Part 1
Examples of REHAssist implementations

From Motion to Interactions with Human
From Robotics to Collaborative robotics

Delta Direct drive for fast pick and place
What is mechanical impedance?

Mechanical impedance concerns interaction. The simplest way to feel/implement interaction is a spring.

\[ F = K \cdot D_x \]
\[ F = K \cdot D_x + K_v \cdot d(D_x)/dt \]

Is oscillatory

Is stable

a spring \( \oplus \) a damper
Simulated impedance using an electrical actuator

\[ F_{\text{mot}} = K_p \times D_x + K_d \times D_x'/dt \]

Mechanical Impedance denotes the quality of compliance: stiffness of the interaction \((K_p, K_d)\)

Simulated impedance using an electrical actuator

Examples of behaviors

Stiff  compliant  damped
Did you say “Impedance” or “Admittance”?

Impedance mode
- Reaction is force
- Action is displacement

Admittance mode
- Action is force
- Reaction is displacement

Part 3
Tell me about “Cobots”

La « Cobotique » concerne l’implémentation d’une solution robotique centrée autour de la collaboration avec l’humain.

La Cobotique est la science d’ingénieur qui traite de la « Robotique Collaborative »: Collaborative Robotics.

Il s’agit souvent
- d’une [interaction robot-humain] [partageant une tâche donnée],
- d’une programmation du robot appris de l’humain.

Dans tous ces cas, la proximité du robot avec l’humain est importante et la sécurité de ce dernier l’est encore plus.

M. Bouri, 2021
Part 3
Tell me about “Cobots”

“Cobotics” concerns the implementation of robotic solutions centered around collaboration with humans.

Cobotics is the engineering science that deals with "Collaborative Robotics".

It is often
• about a robot-human interaction [sharing a given task],
• a robot programming learned from the human.

In all these cases, the proximity of the robot to the human is important and the safety of the human is even more important. Translated with www.DeepL.com/Translator (free version)

M. Bouri, 2021


Cobots - examples
Franka emika

One of cheapest “cobots”
Link to Franka
Cobots
Part 4 – Values and applications

Collaboration
- Shared workspace
- Learn from employee
- Direct collaboration

Footprint
- Easy to implement
- Need less space (no cage)

Safety
- The higher the collaboration the higher the safety

Collaborative industrial robots are a class of robots that perform tasks in collaboration with workers in industrial settings.

The IFR defines two types of robots designed for collaborative use.

[1] One group that complies with the International Organization for Standards (ISO) norm 10218-1 which specifies requirements and guidelines for the inherent safe design, protective measures and information for use of industrial robots.

[2] The other group that does not satisfy the requirements of ISO 10218-1. This does not imply that these robots are unsafe. They follow different safety standards, for example national or in-house standards, other applications (for example healthcare, food preparation and in public spaces) are covered by separate ISO norms and will therefore not be included in the IFR statistics on collaborative industrial robots.

[Ref. ifr.org]
Cobots

[Value 3] Safety – in collision

not even afraid

Cobots

[Value 1.1] Collaboration: Shared workspace
Cobots

- [Value 1.2] Collaboration: Programming by learning / from operators

- [Value 1.3] Collaboration: co-working / co-manipulation
Cobots

[Value 2] Footprints

- More relevant for bi-manual cobots

- Siasun DSCR3
- Kawasaki duAro1 dual SCARA
- ABB Yumi

[Other values] Open to implement new control strategies / using ROS

- Server application
- Franka Emika
- ROS application
Cobots

Example of 2-scenarios

Scenario 1- Being more specific in defining workspace limits

Scenario 2- admittance control/ robot guidance

Numbers

Growth of the market
- 22'000 of newly deployed cobots which is 6% growth from 2019-2020
- 5.7% share of the industrial robot installations

Competitiveness and opportunities
- New suppliers have entered the market
- COVID-19 provided excellent conditions for growth
Collaborative robots will shape the future of medicine

Automation in medical technology

Sep 17, 2019 — Robots are being increasingly utilized in the medical field. For over 50 years, they have been supporting patient care in healthcare facilities worldwide. Despite this “traditional,” however, the age of medical robotics has only just begun, as a new breed of sensitive and collaborative robots is poised to shape the future of robotics in medicine.