Frontiers of Robotics in Health Care

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TOKYO

Convergence

- Anesthetics
- Antiseptics
- Anticoagulants
- Antibiotics
- Analgesics

Modern surgery
Convergence

- Anesthetics
- Antiseptics
- Anticoagulants
- Antibiotics
- Analgesics
- Endoscopic instruments

Modern surgery

- Anticoagulants
- Antibiotics
- Analgesics
- Endoscopic instruments

Minimally invasive surgery

- Anticoagulants
- Antibiotics
- Analgesics
- Endoscopic instruments
- Medical imaging

Computer-assisted surgery
The “Da Vinci” system

The operating room of the year 2030 will be a totally different environment than today.

MASS Screening and EARLY diagnosis will have a major impact on the type and invasiveness of required surgical procedures.

Sir Alfred Cuschieri, MD
Prevention: the role of modern medicine

- Symptoms
  - Predisposition
  - Focused screening
  - Therapy
  - Follow-up

- Diagnosis
- Clinical symptoms
- Molecular Diagnostics
  - Gene Chip
  - Biosensor
  - PET-CT

Tomorrow’s technology: Molecular diagnosis and imaging & molecular therapy

Sir Alfred Cuschieri, MD

The operating room of the year 2030 will be a totally different environment than today

MASS Screening and EARLY diagnosis will have a major impact on the type and invasiveness of required surgical procedures

The combination of micro/nano technologies and microrobotics will enable to perform active monitoring and diagnostics in advanced and early manners, and will be also one of the key technologies enabling future high quality, early and minimal invasive surgery
Isaac Asimov predicted endoluminal surgery..

The Evolution of Surgery

- **Traditional Surgery**
- **Minimally Invasive Surgery**
- **Endoluminal Surgery**
- **Fetal Surgery**
- **Cell Surgery**

- Micro-endoscope for spinal cord
- Force-feedback scapar for fetal surgery
- Artificial virus for cell therapy
The case of gastro-intestinal cancers

1. Traditional endoscopy: mechanisms, actuation and control all outside the body
2. New scenario for endoscopy: some components inside the body, some outside

**Inside the body**
- Bellows (Motion Converter)
- Pressure, Suction and Mechanical Grasping (Motion Converter)

**Outside the body**
- CCD (Sensor)
- Human control (Controller)
- Pneumatic distributor (Power Supply and Energy Converter)

**Painless Colonoscopy**

Semi-autonomous inchworm-like locomotion
Painless Colonoscopy

Semi-autonomous inchworm-like locomotion

3. A new scenario for endoscopy: miniature/micro endoscopes inside the body

Inside the body

- CMOS camera
- On-board microbattery (Power Supply)
- Bellow (Motion/Torque Converter)
- On board Energy Converter (minimotor, SMA, EPAM, etc.)
- Contact and position sensors

Outside the body

Human monitoring and Diagnosis (Controller)
Capsular endoscopy in the gut

“ALL ON BOARD” PHILOSOPHY

- microgripper
- microsyringe
- microoptics
- temperature sensors
- pH sensors
- chemical sensors
- microbattery
- locomotion mechanisms
- RF module
- drug-delivery microsystem

Outside the body

Human monitoring and Diagnosis (Controller)

Wireless endoscopic capsule with an active locomotion system: legged locomotion
Capsule Design and Working Principle

Frontal Gears actuation System

Rear Gears actuation System

Capsule with CMOS camera (L=40 mm)

8-Legged Capsule

Capsule without camera (L=30 mm)
Legged capsule at work

Locomotion Performance

4-legged capsule with frontal balloon vs 8-legged capsule without frontal balloon

Previous prototype Current prototype
The objective of SSSA is to develop a truly practical and working solution for active capsular endoscopy. The development of an active endoscopic capsule is strictly related to the development of its subsystems, such as the vision system, the actuation system, the power supply system etc., not directly available on the market.

SSSA Capsule Roadmap

Towards wireless prototype...

End of I YEAR  End of II YEAR  End of III YEAR  End of IV YEAR

SSSA Capsule Roadmap

Capsule Type 1:
- Size: 12 mm x 43 mm (without motor driver and with camera)
- Coupled front legs and coupled rear legs (6 legs):
  - 4 DC commercial micromotors

Capsule Type 2:
- Size: 11 mm x 30 mm (with motor driver and without camera)
- Coupled front legs and coupled rear legs (12 legs):
  - 2 DC commercial micromotors
VECTOR – Versatile Endoscopic Capsule for gastrointestinal TumOr Recognition and therapy

Eliminating gastrointestinal cancers through breakthrough medical microtechnology

VECTOR project consortium represented by:
Prof. Dr. Marc Schurr
Prof. Dr. Paolo Dario
Prof. Dr. Robert Puers
Dr. Lou Hermans
Backup:
Dr. Arianna Menciassi

Project hearing
European Commission
Unit of Micro and Nanosystems

Brussels 21. November 2005
A "cybernetic" prosthesis controlled by the brain

Extraction of brain commands from the motor nerves

Stimulation of the sensory nerves to provide a sensory feedback

CyberHand Architecture

1. Biomechatronic Hand

2. Embedded Biomimetic sensors:
   - within the structure
   - within the glove

3. Regeneration-type electrode (afferent nerve)
4. Regeneration-type electrode (efferent nerve)

5. Implanted neural interface:
   - ENG efferent signals recording (patient’s intention detection)
   - Afferent nerves stimulation (to provide sensory feedback to the patient)

6. Receiver
7. Transmitter
8. Decoding patient’s intentions and Embedded closed-loop control of the artificial hand
Artificial hands @ ARTS Lab (2000-2006)

- RTR1 Hand (2000-01)
- Cyberhand (2005)
- RTR2 Hand (2002)
- ROBOCASA hand (2004)
- WABIAN hand (2007)
- GENIE Hand (2007)
- ROBOTCUB hand (2006)
- Smart Hand (2008)
- RPP Hand (2007)

The CyberHand

Hand mechanical specifications
- 16 d.o.f. total – 6 d.o.m. total
- Underactuated fingers, each driven by a single cable actuated by a motor
- 6 d.o.m.: one for each finger (flexion/extension) + one for thumb positioning (adduction/abduction) 6 DC 6V motors
- Trapezo-metacarpal thumb joint abduction/adduction range: 0°-120°
- Finger joints flexion range: 0-90°
- Weight: Palm+fingers about 400 gr., Socket interface (actuation and transmission system) about 1400 gr.
- Grasping force: 35 N.
- Tip to tip force: 15 N.
- Anthropomorphic size, and kinematics.
Cybernetic prosthesis (from the EU-FET “CYBERHAND” Project): a cybernetic prosthesis controlled by the brain

Electrodes for Recording and Stimulation in the PNS

- Sieve Electrode
- Sieve silicon electrode
- Sieve Head with Counter Electrodes
- Shaft Electrode
- Tripolar Cuff Electrodes
- LIFE Electrodes
- Platinum Electrodes on the Shaft
Clinical trials are planned in two steps:

- Phase 1: Acute implant of new generation (8-contact) tf-LIFE interfaces
- Phase 2: Chronic implant of the full CyberHand/Beyond Prostheses platform
Phase 1: Acute implant of new generation (8-contact) ti-LIFE interfaces:

- 2 patients, to start in JUNE 2007
- UCBM multi-disciplinary equipe including neurologists, orthopaedic surgery, hand microsurgery, neurorehabilitation, radiology, brain imaging, neuropsychology, bioengineering:
  - Prof. Paolo Maria Rossini, Prof. Vincenzo Denaro, Prof.ssa Silvia Sterzi, Prof. Bruno Beomonte Zobel, Dr. Luca Denaro, Dr. Mario Tombini, Dr. Franca Tecchio, Dr. Paola Chiovenda, Dr. Giuseppe Curcio
  - Eugenio Guglielmelli, Loredana Zollo, Giovanni Di Pino

Patient selection criteria:

- Up to 2 chronic subjects (>2 years from the amputation); volunteers
- Both subjects clearly unsatisfied from the previous clinical application of cosmetic and/or myoelectric hand prostheses
- Strong motivation
- No other significant cognitive or physical problems (WAIS-R, MMPI-2)
In order to preliminarily assess the cortical response during imagination of movements of the missing limb and the level of cortical representation of the distal upper limb areas close to the amputation, both recruited subjects will undergo:

- high resolution electroencephalogram = hrEEG
- magnetoencephalography = MEG
- functional Magnetic Resonance Imaging = fMRI
- Transcranial Magnetic Stimulation = TMS

In unilateral amputees comparative analysis with the contralateral limb will be also carried out.
Our strategy

- Robotic and mechatronic systems can be used to implement a three-phase approach
  - the motor (and cognitive) abilities are assessed in labs by exploiting the potentialities of advanced technologies and systems in order to identify and address major deficits
  - when at home, the performance of elderly people are continuously evaluated by using wearable systems to recognize immediately the onset of possible problems related to reduced performance
  - technological aids are used to compensate possible deficits, thus increasing the level of autonomy especially at home

Wearable systems for biomechanics investigation in elderly subjects
Manoplandum for the analysis of upper limb motor control (MIT-Manus)

- Ongoing activities at SSSA:
  - Definition of rehabilitation protocols “customised” on the motor functions of hemiplegic subjects
  - Analysis of the modifications on motor control strategies due to the aging process
  - Understand how the aging process can modify the motor performance and the learning abilities of senior people, especially while dealing with increasing cognitive efforts

The Rehabilitation Process

- Functional Assessment
  - Functional Recovery
  - Functional Substitution
  - Functional Surgery
  - Motor Therapy

- Assessment of Residual Abilities
  - Assistive devices
  - Professional Training

- Reintegration into social life and working activity
Neurophysiological basis for neurorehabilitation after stroke

- Brain motor areas which are "not used" but can generate upper limb movements if properly stimulated (Kwan, 1978)
- The same motor function can be activated by multiple (different, non contiguous) brain motor areas (Humprey, 1986, Sato e Tanji, 1989, Huntley & Jones, 1991)
- Multiple representations of the cortico-spinal output have been shown in the motor cortex. These representations are related to different motor functions and can present several spatial and temporal overlaps (Sanes, Donoghue et al., 1995)

This situation proves the flexibility of the motor output organization and is a key issue to promote functional recovery after stroke. *Motor learning and plasticity can be exploited for neurorehabilitation therapy, i.e. to promote functional recovery*
MIT-MANUS system: clinical trials at ASL12

Prof. A. Battaglia, Dr. F. Posteraro

Reparto di Medicina Riabilitativa - Centro di Alta Specialità per la Riabilitazione dei Traumi Cranici e delle Gravi Cerebrolesioni Acquisite

MIT-MANUS system: clinical trials

- 20 patients (53.35 ± 11.17 yrs)
- 7 right, 13 left
- 11 ischemic, 6 hemorrhagic, 3 others (brain injuries, cerebral neoplasia extirpation)
- >1 yr from stroke onset
- Able to understand simple instructions
- Minimum performance of active movement (even through compensation)
MIT-MANUS system: clinical evaluation

- **Clinical-functional assessment**
  - Passive ROM
  - Cutaneous sensitivity
  - Joint reflex
  - Pain (4 points verbal scale)

- **Questionnaire about system acceptability**
  - 7 questions (score 0..7)

MIT-MANUS system: robotic therapy

- **3 times/ week, 6 weeks**
- **Each session:**
  - 16 free movement
  - 3 series of 320 movements (adaptive)
  - 16 free movement
All patients improve, except flaccid patients (i.e. no active motion)

Preliminary analysis of smoothness

Results from 20 patients
The MEMOS system: A MEchatronic system for upper limb MOtor recovery after Stroke

- The MEMOS system has been developed by the ARTS Lab of the Scuola Superiore Sant’Anna
- Two DoF cartesian robot with a workspace of 500x700 [mm]
- Three different control modalities:
  1. completely servo-assisted movements;
  2. shared control (task completion);
  3. completely voluntary movements

The handle is sensorised with four strain gauges in order:
  1. To allow the user to voluntarily control the movements (the position reached by the robot is proportional to the force produced by the subject in the same direction);
  2. To record the force produced during the movements as a (possible) figure of merit for functional assessment.

Clinical Validation of the MEMOS system

Clinical trials (2003 – 2004) at Fondazione Maugeri, Veruno (Italy) – Prof. Fabrizio Pisano, Division of Neurology

Colombo et al, 2004
Micera et al., 2004
Clinical validation: preliminary results

An example of tracking of the squared trajectory for one subject

Design methodologies towards the NeuroEXOS HBS

The final objective

How coupling human arm with robotic arm? We develop a model of the human arm

To design and develop neuro-robotics experimental platform (NEURArm anthropomorphic arm-hand system)

To design and develop the NEUROExos

Joint experiments for validating control and learning models, and for testing HMI
The NeuroEXOS elbow module

- The elbow is the simplest joint of the human upper arm
- The range of axis displacements is limited

Preliminary Prototype

NeuroExos Elbow Design

Machines for neurorehabilitation
State of the art and future perspectives

- Severely disabled subjects
- Moderately disabled subjects
- At the hospital
- Exoskeletons
- (Partial) Motor Recovery
- Operational Class I
- Tele-rehabilitation (at home)
- Operational Class II

Colombo et al., IEEE Trans Neural Sys Rehab Eng, 2005
Micera et al., Autonomous Robots, 2005
A POSSIBLE FUTURE:
Neuro-rehabilitation: closing the loop with the brain

Brain injury / Neurological impairment

(Sensory-) Motor impairment

Recovery of motor function (motor outcome)

Limb motor rehabilitation

Neuro-rehabilitation

Cognitive rehabilitation

Recovery of brain functions (through motor learning and plasticity)

On-line brain imaging (assessment)

Dario at ICRA 2002

Neuro-developmental engineering

TACT - Thought in Action
NEST Project #15636

Early diagnosis of autism and ASD by monitoring neuro-motor development

- Mechatronic sensorized toys for monitoring sensory-motor behaviour
Thank you for your attention