Robot Assisted Rehabilitation After Stroke: Prototype Design and Clinical Evaluation

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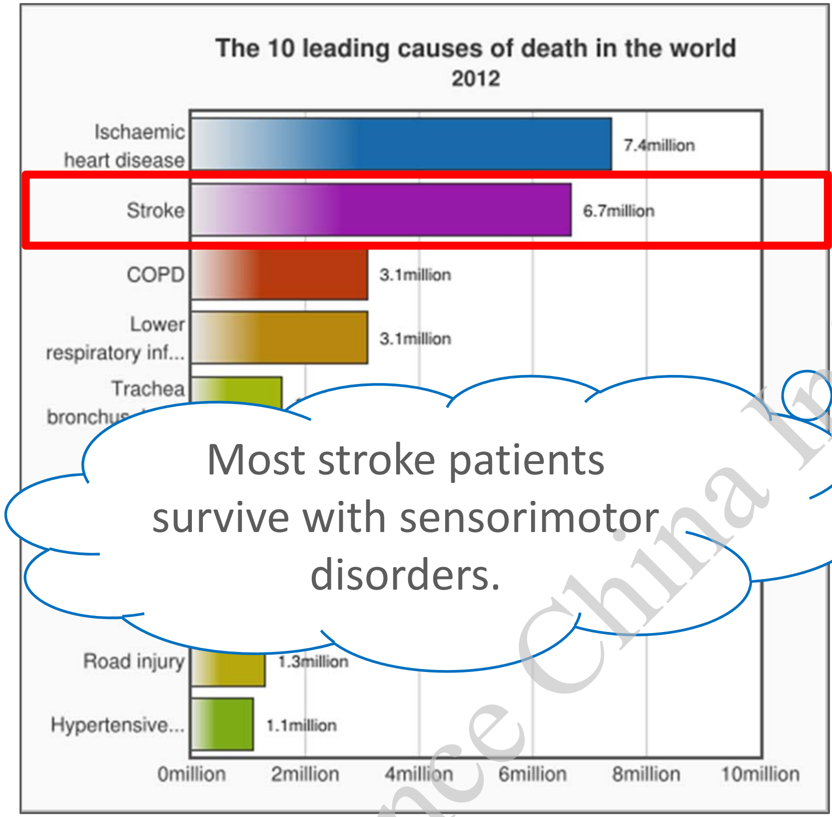
Neurological Injury —Stroke



Most stroke patients survive with sensorimotor disorders.

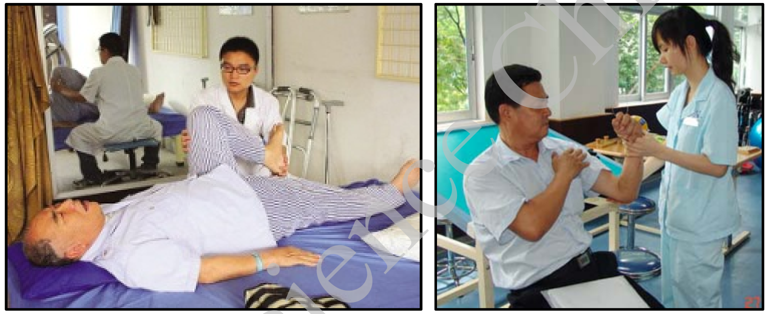
http://www.who.int/mediacentre/factsheets/fs310/en/

According to the US National Stroke Association:

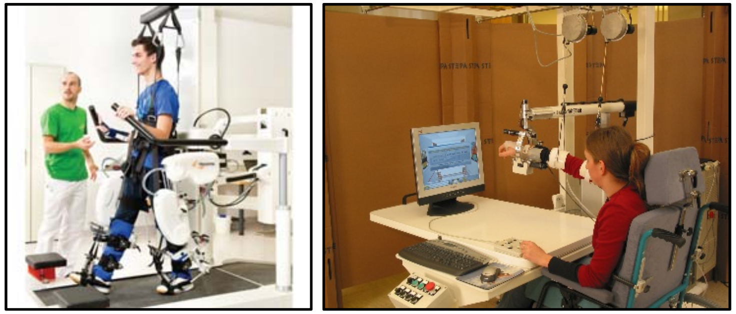
- 10% of stroke survivors recover almost completely.
- 25% recover with minor impairments.
- 40% experience moderate to severe impairments that require special care.
- 10% require care in a nursing home or other long-term facility.
- 15% die shortly after the stroke.
- Approximately 14% of stroke survivors experience a second stroke in the first year following a stroke.

Manual Therapy VS. Robot-aided Training

Manual Therapy	Robot-aided Training
Depends more on therapist's skill	Precise and consistent assistance
Tedious during long-term training	Interesting with video games
Large burden on therapist effort	Be able to work continuously without sacrificing accuracy
Rough notes after training by therapist	Real-time monitoring and recording during training
High cost	Low cost in use
…	…



VS



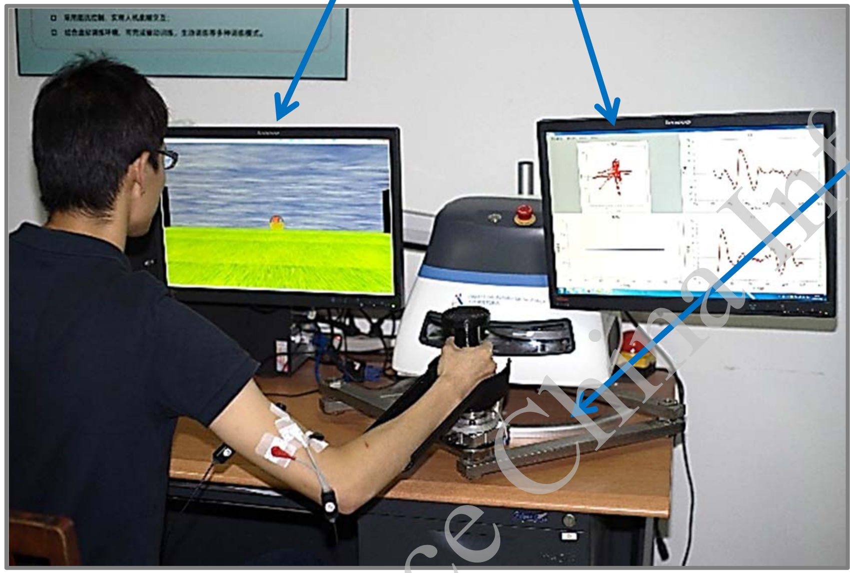
Upper-limb Rehabilitation Robot

Virtual Training Environment

Visual/Audio Feedback

Haptic Interface

Force Feedback



Robot-aided Training Scenario

CASIA-ARM Rehab Robot

Prototype Design

Prototype

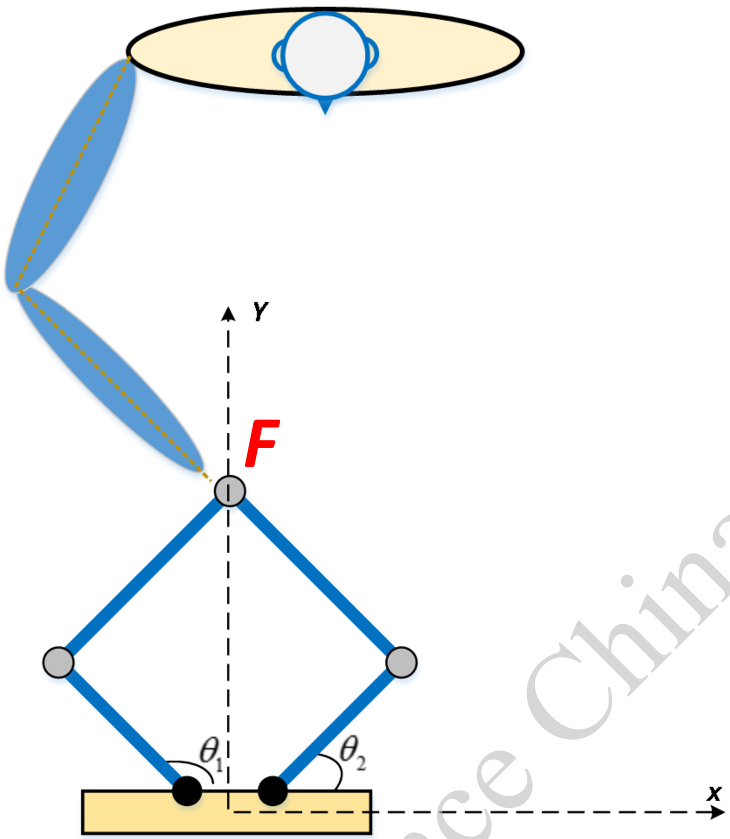
Technical Specification

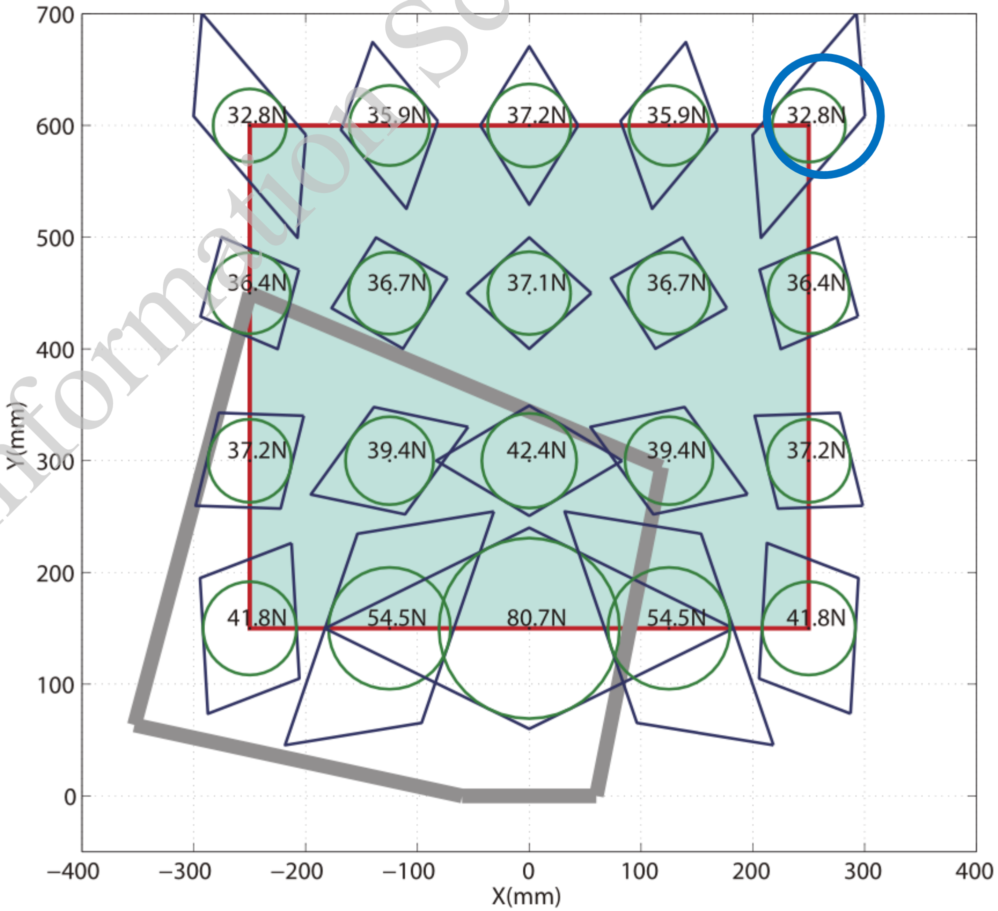
Degrees of freedom	2
Actuation	2 DC motors
Sensors	2 rotary encoders
Range of joint motion	80°~220°, -40°~100°
Workspace	500 mm * 416 mm
Motor Torque	~ 450 mNm
Reduction Ratio	20:1
Force Capability	>32.8 N

Features:

- **5-bar parallel structure**
  (Compact, stiff joint)
- **DC motor driven, steel cable transmission**
  (Smooth torque regulation, no backlash, back-drivable)

Force Feedback Analysis





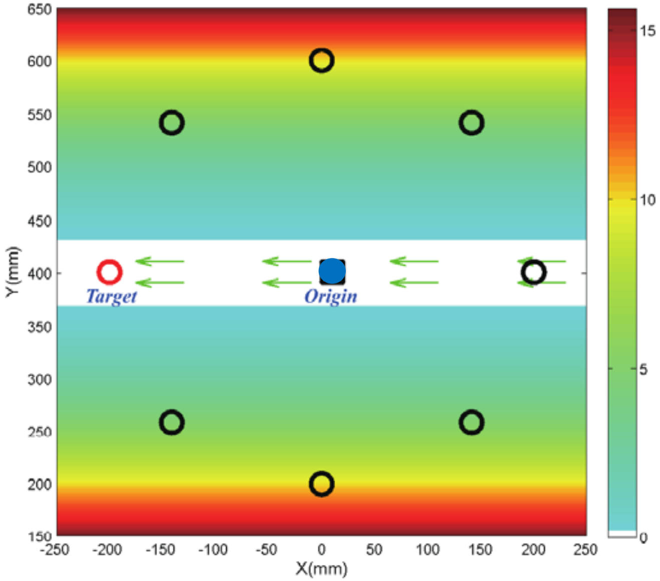
$$F = J(\theta_1,\ \theta_2)^{-T}[nT_{m1},\ nT_{m2}]^T$$

High Level Controller
—Reaching Task Example

- Trajectory Planning (mimic normal human movement)

Minimum jerk trajectory between two points (x_i, y_i) and (x_d, y_d):

$$\frac{x(t)-x_i}{x_d-x_i} = \frac{y(t)-y_i}{y_d-y_i} = 10(t/\tau)^3 - 15(t/\tau)^4 + 6(t/\tau)^5$$



- "Assisted as Needed" Force Controller
  - Forward direction:

$$F_x = \begin{cases} -k_x\,(x - x_{ref}) - b_x\dot{x} & x_{th} < x < x_{ref} \\ 0 & x < x_{th}\, or\, x > x_{ref} \end{cases}$$

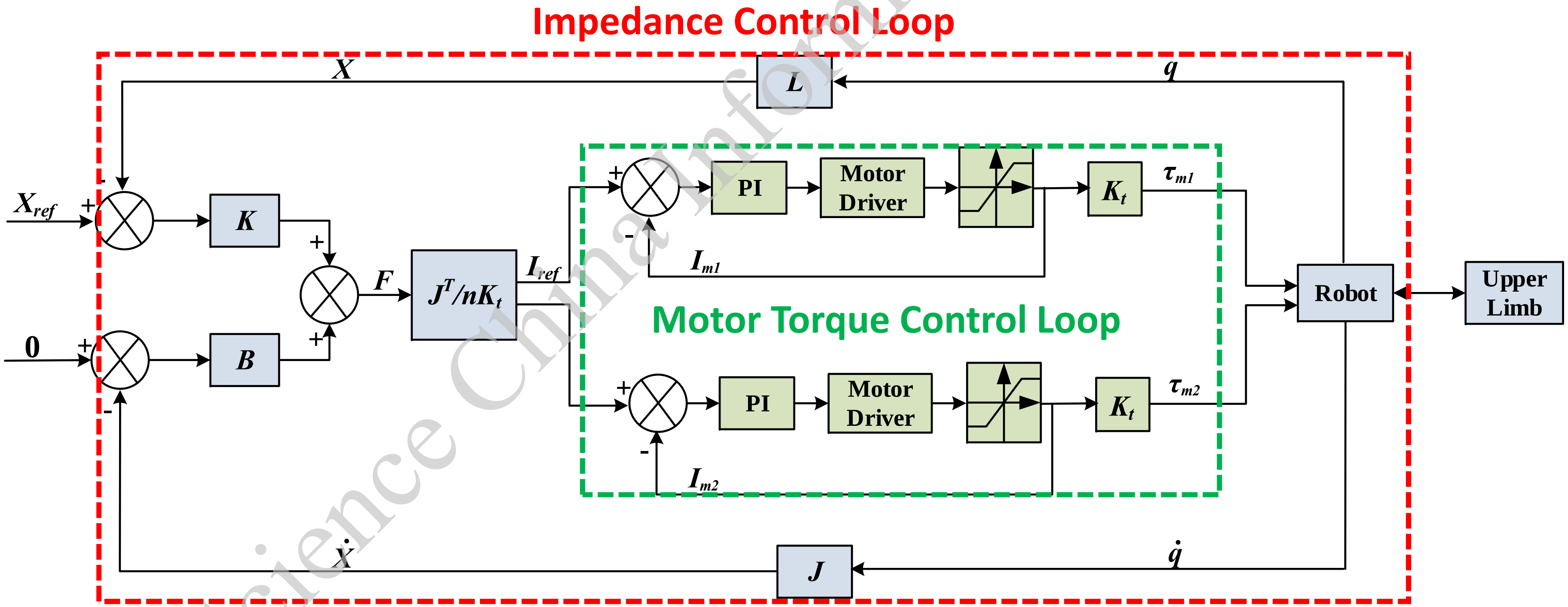
  - Vertical direction:

$$F_y = \begin{cases} -k_y\,(|y| - |y_{wall}|) - b_y\dot{y} & |y| > w_{wall} \\ 0 & |y| < w_{wall} \end{cases}$$

Low Level Controller

Impedance Controller

$$\begin{cases} F = -K(X - X_{ref}) - B\dot{X} \\ T = J^T F \end{cases}$$



Clinical Trials

- 20 min× 20 sessions (5 days/week × 4 weeks)

Experiment Group
robotic therapy

Control Group
conventional therapy

Results

- Fugl-Meyer score upper limb part (FMA-UE) is used to reflect the outcomes.
- Two evaluations are performed before trial and after trial, respectively.
- Both groups had significant gains in FMA-UE scores
- Robotic therapy group patients have more gains than those assigned to conventional therapy, but have no significant differences.

Table 2 Baseline sample characteristics and FMA-UE outcomes

	Cases	Sex	Age (years)	Before trial	After trail	Z^*	p^*	Change
Robotic therapy	12	M(10)F(2)	46.1±15.8	27.6±10.7	37.9±10.5	-3.063	0.002	10.3±6.3
Conventional therapy	12	M(9) F(3)	46.9±10.1	26.2±6.0	32.8±7.0	-3.064	0.002	6.7±3.1
Z^{**}				-0.289	-1.245			
p^{**}				0.772	0.213			

* Mann-Whitney U-test is used to analyze data in the same group.
** Wilcoxon rank-sum test is used to analyze data between groups.

For more details please refer to the paper.

Thank you!