A Robotic Cane as Supernumerary Robot Limb for Assistive Elderly Motion Transition at Home

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Southern University of Science and Technology

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Background

Background

The Population 65 Years and Older: A Worldwide Aging Trend

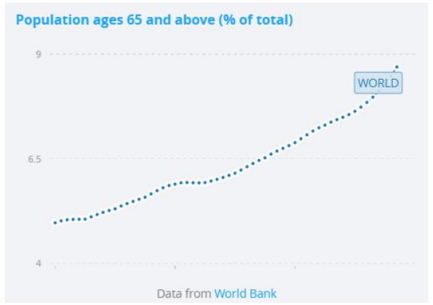
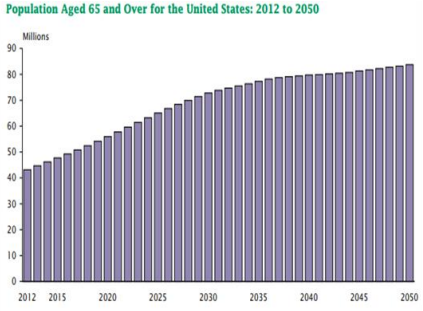


Fig.1 | Population percentage ages 65 and above of total (The World Bank Group)



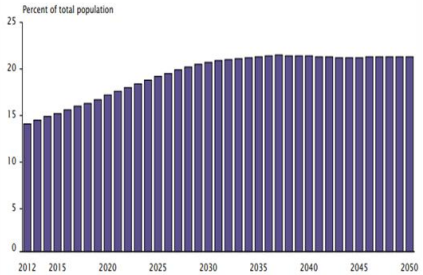


Fig.3 | Old age population in the total U.S. from 1950 to 2050 (US Census Bureau)

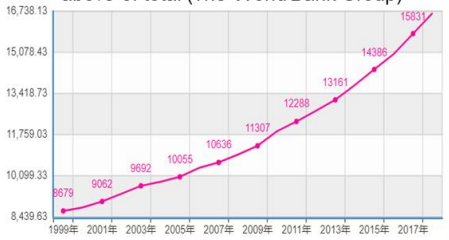


Fig. 2 | Old age population in China from 2009 to 2019(National Statistics Bureau of China)

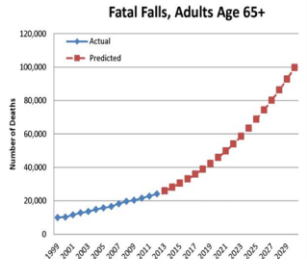
- Over the last 5 decades, the old age population in percentage of world total population is 1.748 times in 2017 than that in 1960.
- And it seems to continuously increase at a higher rate in recent years, indicated in Fig.1.

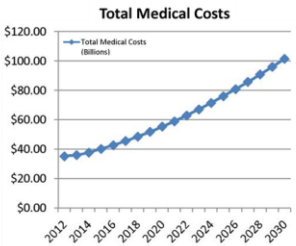
Mobility of Elderly People

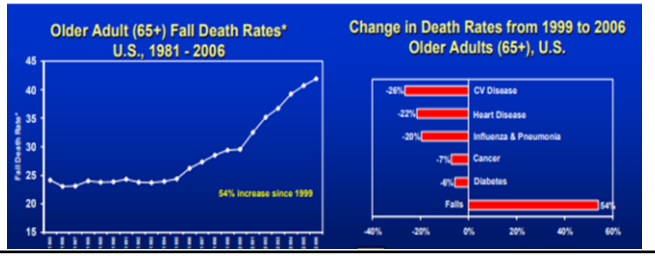
- For independent mobility, one generally must be able to, at least, perform "**basic mobility skills**" (Isaacs) of getting in and out of a **bed** and **chair**, on and off a **toilet**, and walking a few feet.
- 42% to 43% of the elderly subjects had difficulty getting up from a chair according to Chamberlain and Munton's survey.

Fall Risks of Elderly People

- Falls affect one in three adults over the age of 65 annually, and 50% of adults over the age of 80.
- Intrinsic risk factors that may cause a fall: muscle weakness, gait and balance disorder. (CDC)







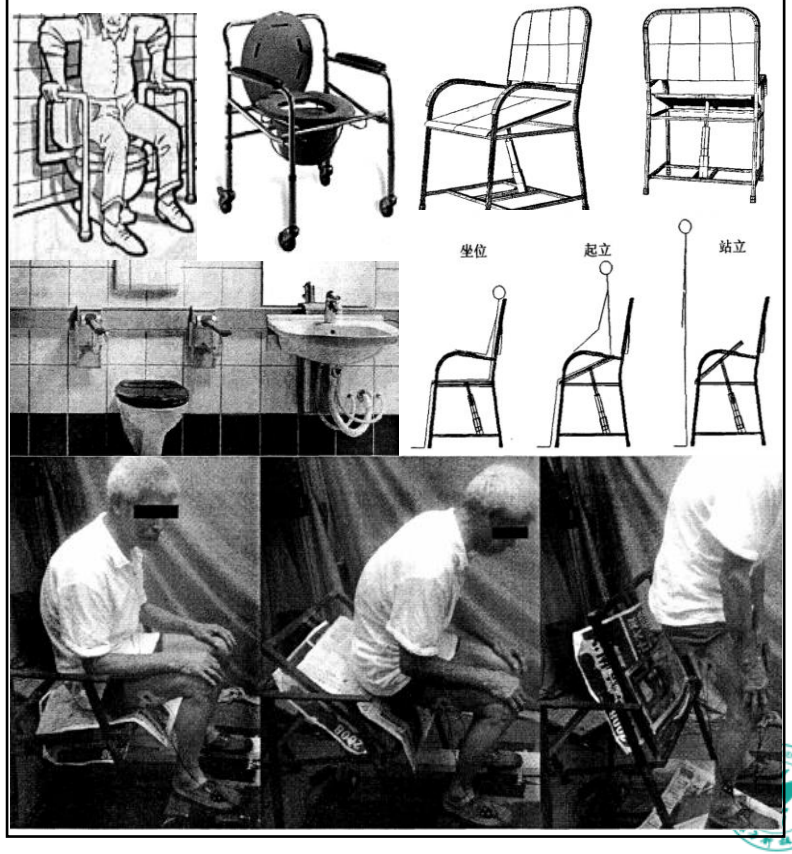
Background

Existing Solutions for The Elderly

- Exoskeleton

- Normal Cane & Walker

- Assisted Chair in Standing Up

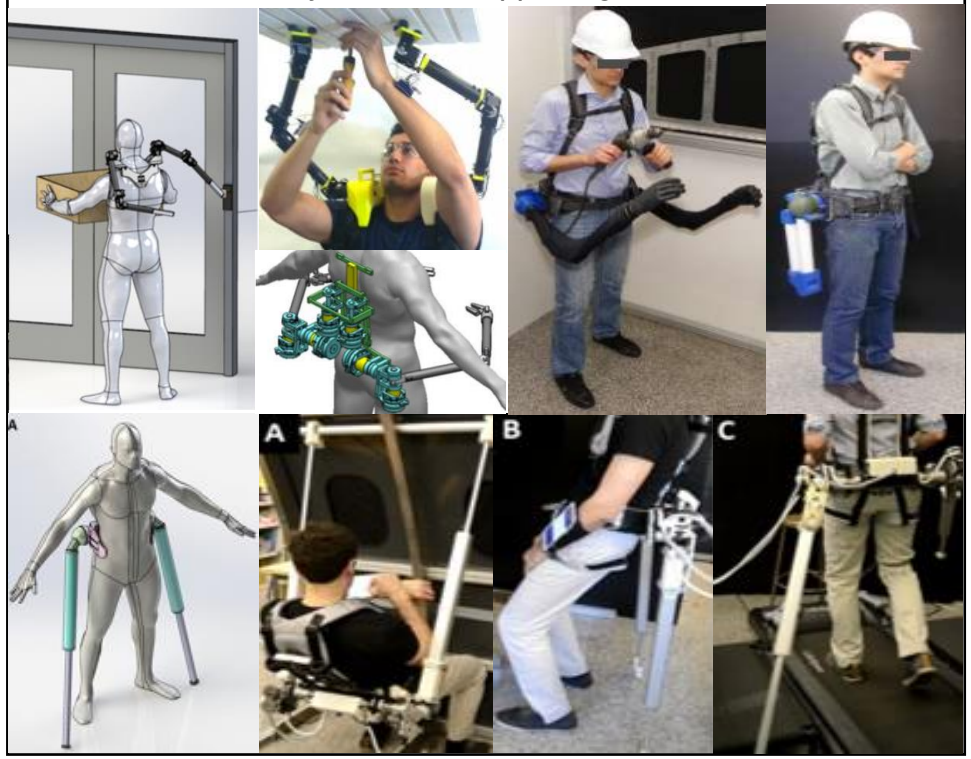


Background

Concept of Supernumerary Robot Limb

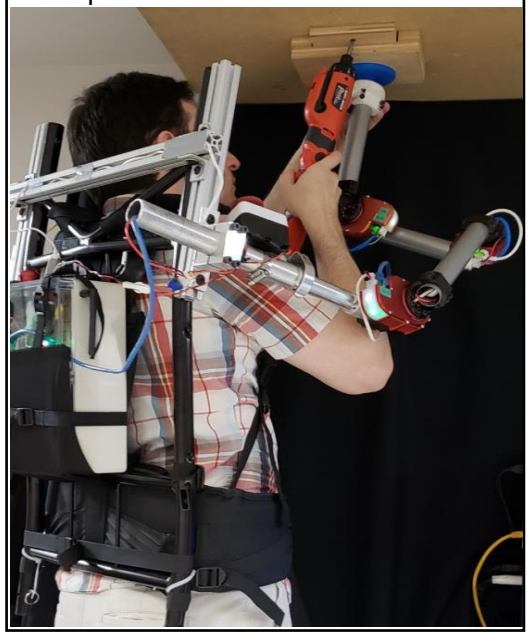
Proposed by Prof. Harry Asada at MIT

- Extending robotic arm.
- robotic systems for supporting a load.



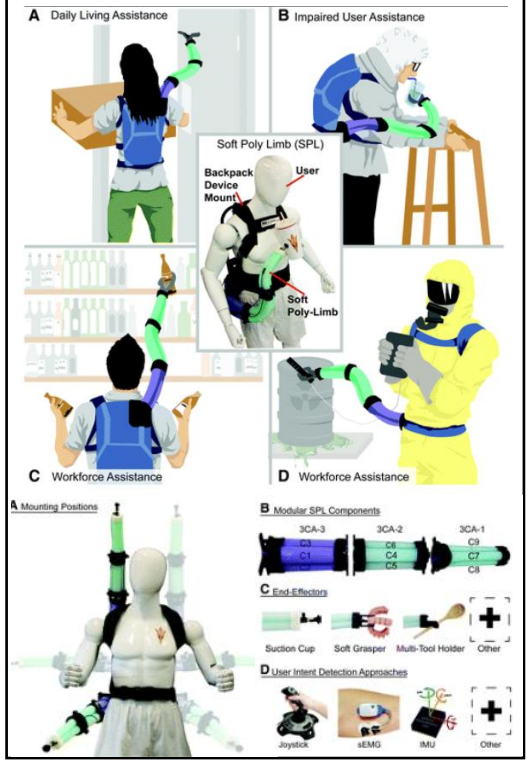
Carnegie Mellon University:

[Related Design] Supernumerary arm implemented in hardware, reaching one of the targets on the overhead workpiece.



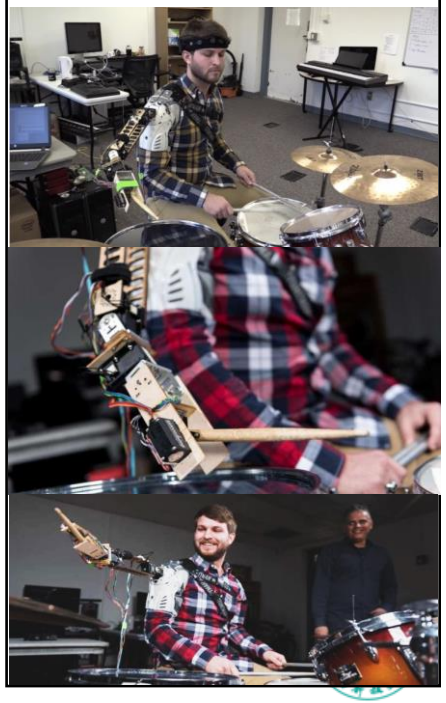
Arizona State University:

[Related Design] Soft poly limb for daily living tasks.



Georgia Institute of Technology

[Related Design] A robotic arm to give drummers a helping hand.



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Background

Project Goal

- **We propose a robotic cane as a supernumerary robot limb mainly for assisting the elderly in sit-to-stand and also stand-to-sit motion transition at home, among bed, chair and toilet.**
- Target Group:
  - Elderly people (65 years and older).
  - Has basic motion ability, which means they are able to get in and out of a bed and chair, on and off a toilet, and walk a few feet by themselves. The whole process can be finished with the use of customary walking aid (cane, walker, etc).
- Robotic Cane:
  - With length variable so that the elderly doesn't need to adjust their normal posture to fit in the constant height handle.
  - Can attach to the body to make motion transition process hand free.
  - Works as a normal cane during walking.

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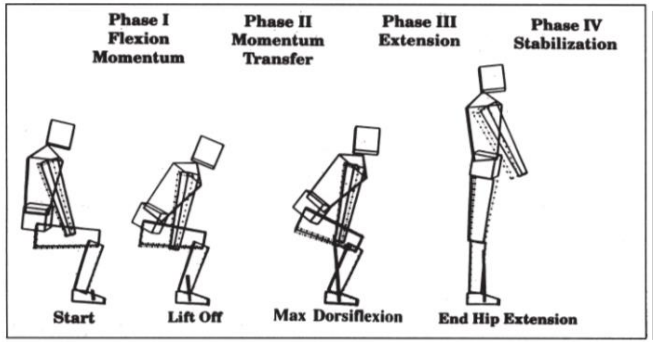
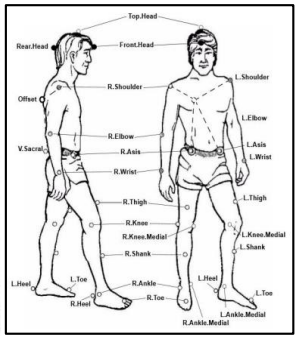
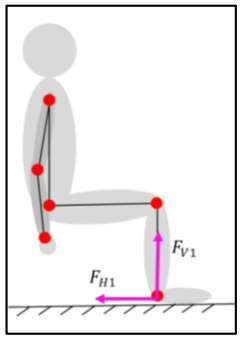
Sit-to-Stand Analysis

Sit-to-Stand Analysis

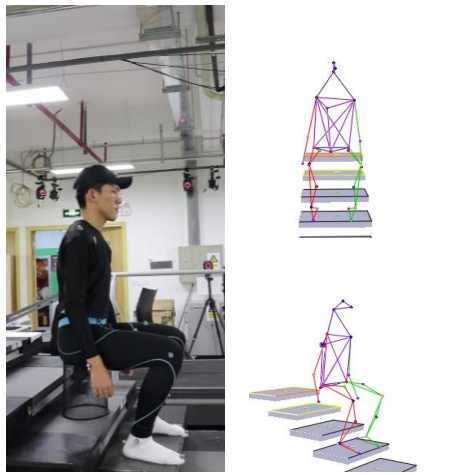
4 Phases during Sit-to-Stand Process



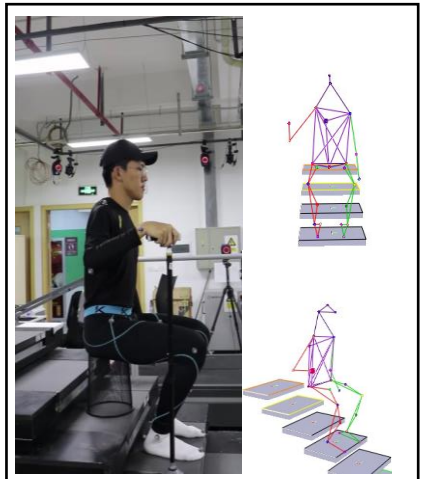




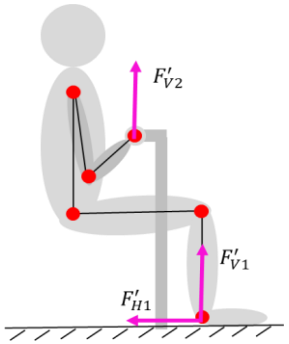
- Total **peak vertical forces** were also found **just after lift from the chair**.
- **Forces at the knee** approximating **7 times body weight** were reported just after lift from the chair.

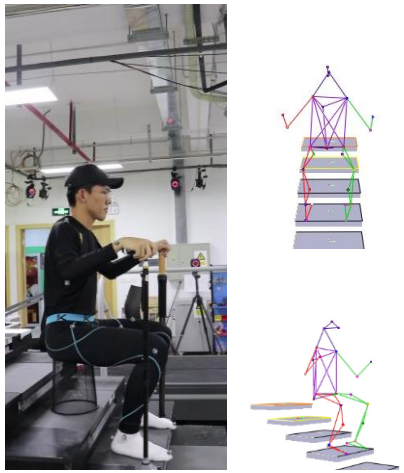


Stand up in natural state

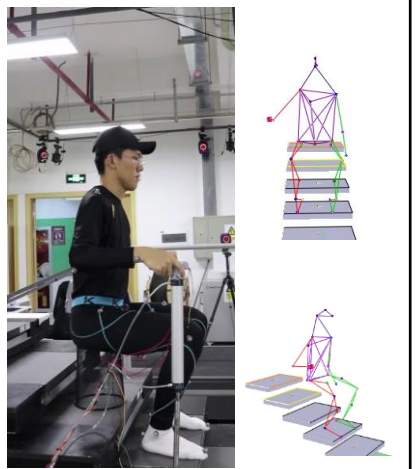


Stand up with 1 cane

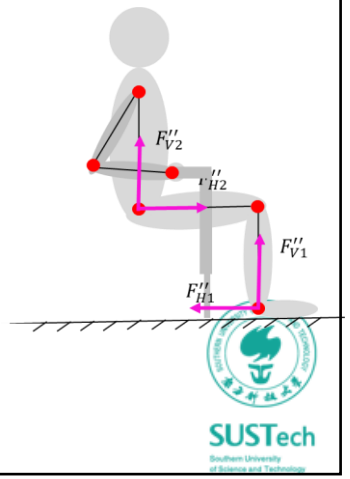




Stand up with 2 canes



Stand up in 1 air cylinder



Experiment 1: The Cane's Role During Motion Transition

Results:

1. Vertical Ground Reaction Force (VGRF)

- Physical aid device helps to reduce peak vertical force just after lift from chair.
  - Ranking by usefulness:

    2 canes > 1 air cylinder > 1 cane> without any aid device

Subject	Weight(N)	Average Peak VGRF							
		With NO customary walking aid		With 2 canes		With 1 cane		With 1 air cylinder	
		Peak Force (N)	Percent of Weight (%)	Peak Force (N)	Percent of Weight (%)	Peak Force (N)	Percent of Weight (%)	Peak Force (N)	Percent of Weight (%)
CMD	606.62	942.09	1.55	704.39	1.16	732.04	1.21	724.93	1.19
LZQ	698.02	1002.8	1.44	806.53	1.16	/	/	891.91	1.27

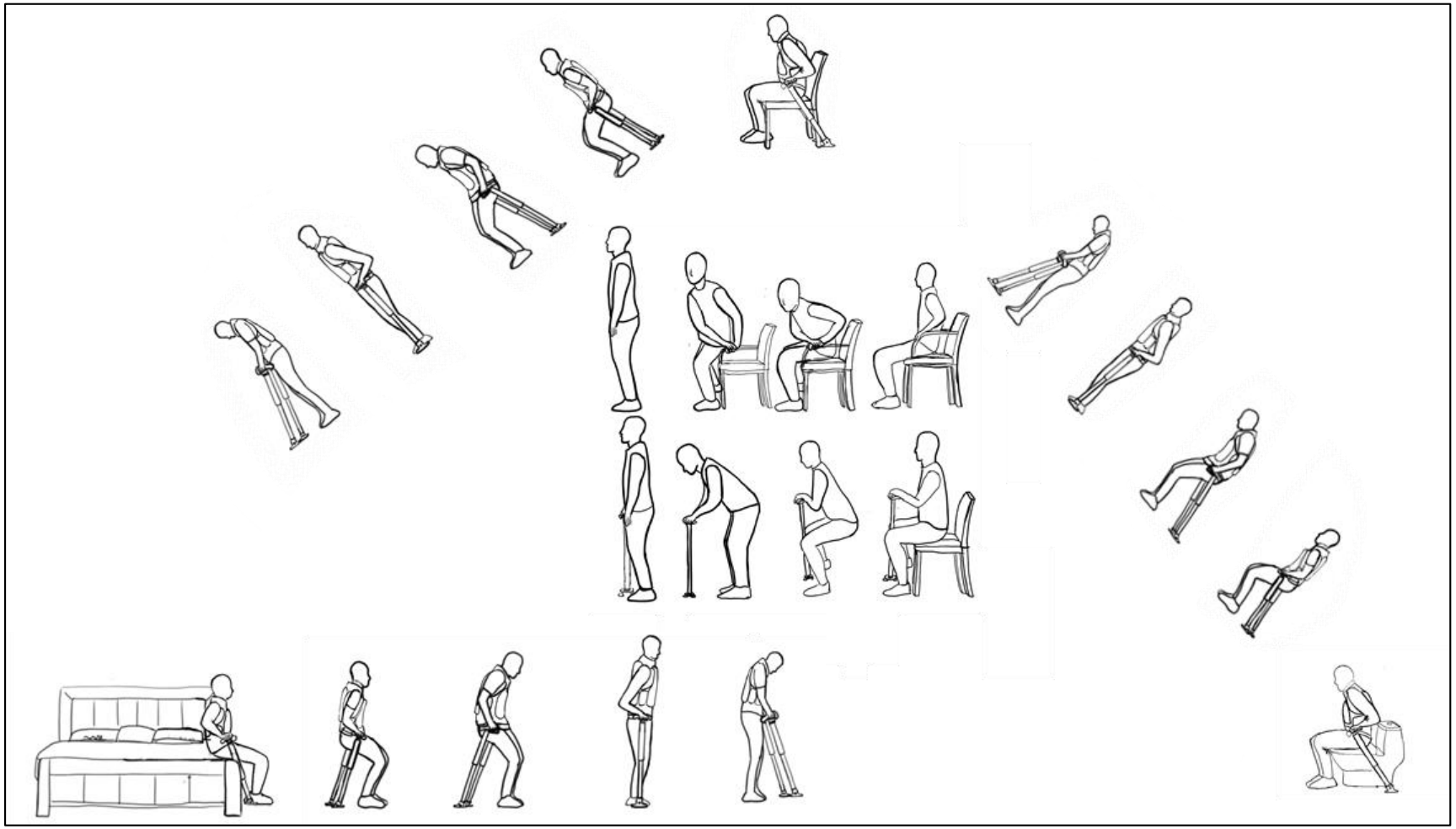
2. Average Joint Power in Each Motion Transition Period

- Peak power of hip, knee and ankle is reduced.
- More experiments are needed.

Robotic Cane Design

Robotic Cane Design

Design Concept: Schematic Diagram



Three reasons of motivation for robotic cane:

- Maximum releasing both hands during assistant during motion transition.
- Still served as a normal cane during walking, which broadens the cane's application scope, but doesn't influence other functions of the cane.
- Having a similar appearance to normal cane makes it acceptable for the elderly.

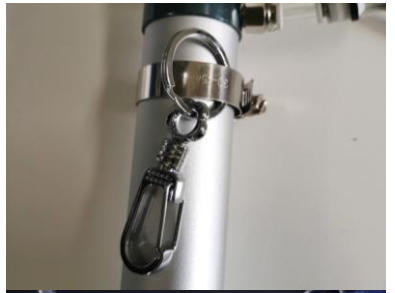
Robotic Cane Design

Design Concept: Vest & Cane System

Vest as the first contact between human and robot.

- Increasing underarm area to reduce pressure.
- Tight the user's body to enhance the force transfer efficiency.

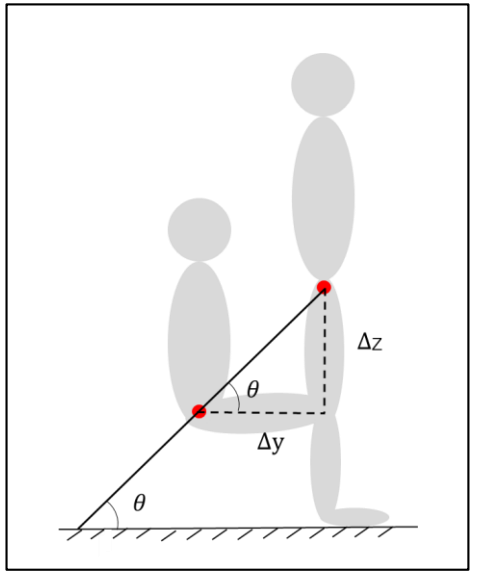
- **Robotic cane** elongates in the direction the upper body movement.
  - Pneumatic actuation satisfies the requirements for both speed and load.
- **Connection** between vest and robotic cane.
  - Transfer the force from the robotic cane to the vest, thus assisting during motion transition.

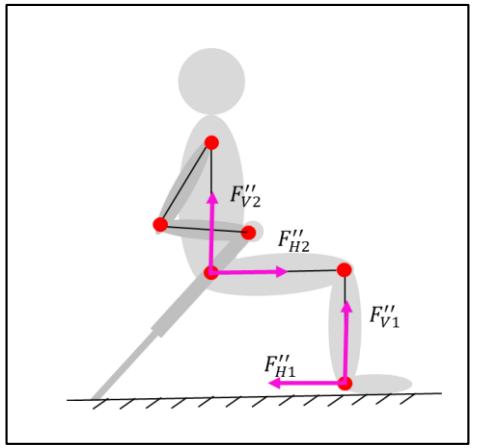


Robotic Cane Design

Design Specifications: Data From the Experiments

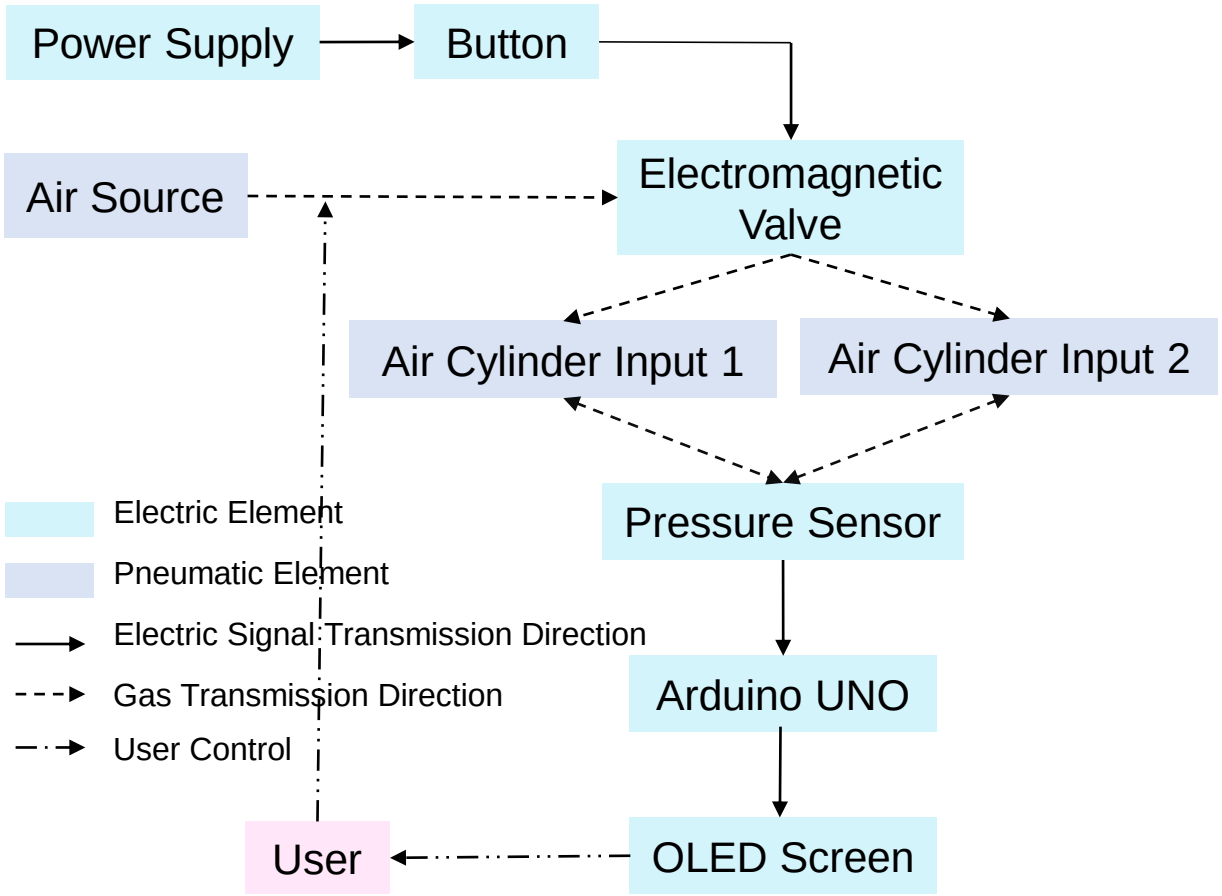
- Travel distance
  - 34.6cm (average height changes Δz of hip marker point)
- Angle relative to the ground
  - 47.3° ($tan\theta = \frac{\Delta z}{\Delta y}$, where Δy stands for the range difference in the forward direction)
- Force (% of weight) on the cane
  - 44% at maximum
  - Considering safety factor: 50% of 80kg is set, under the pressure of 3.5 bar.
    - $80 * 9.8 * 50\% = 350{,}000 * \pi * R^2, R \approx 16cm$
    - Therefore, 32cm as the cross-sectional diameter and 3.5 bar as the air pressure.

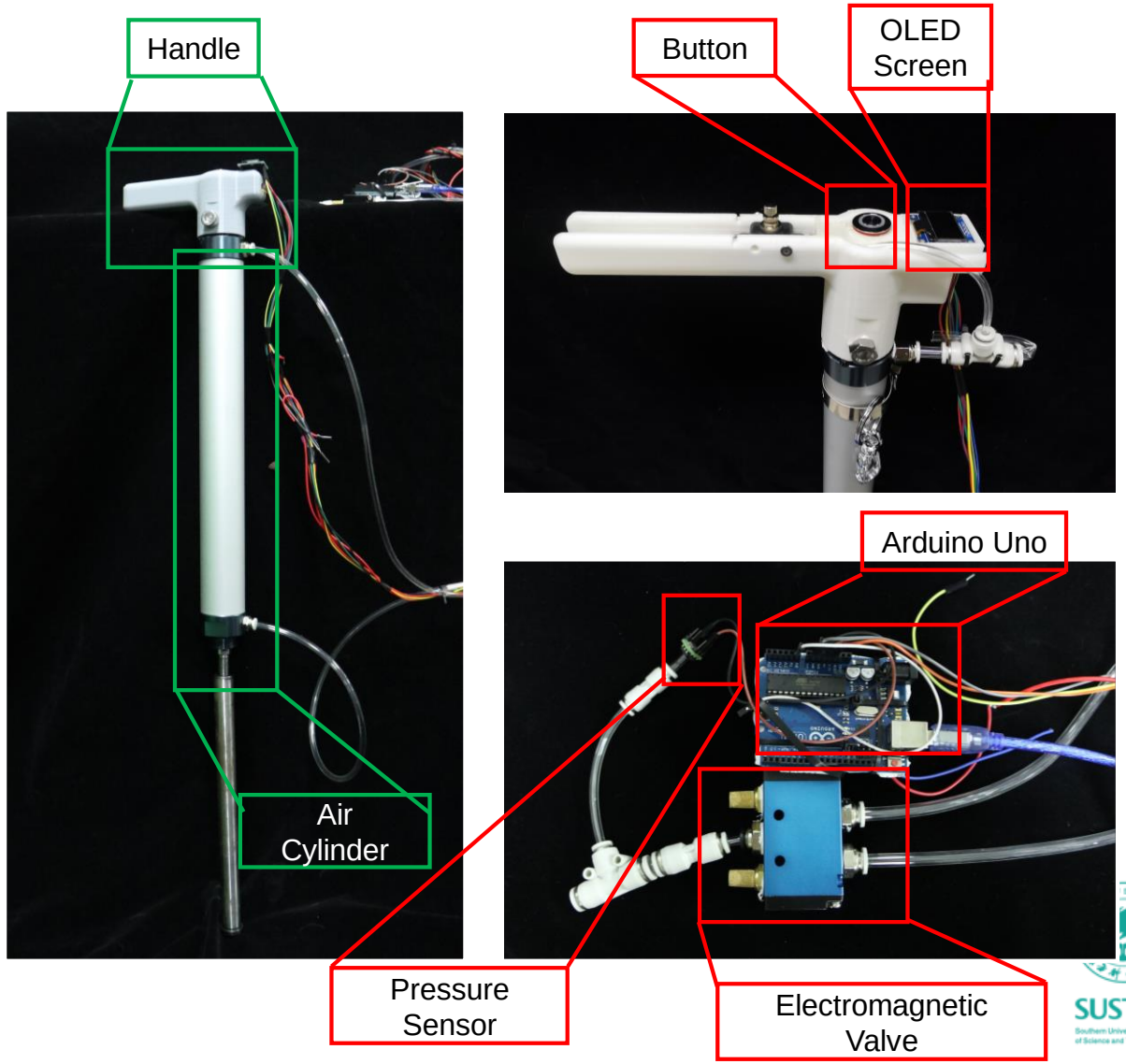




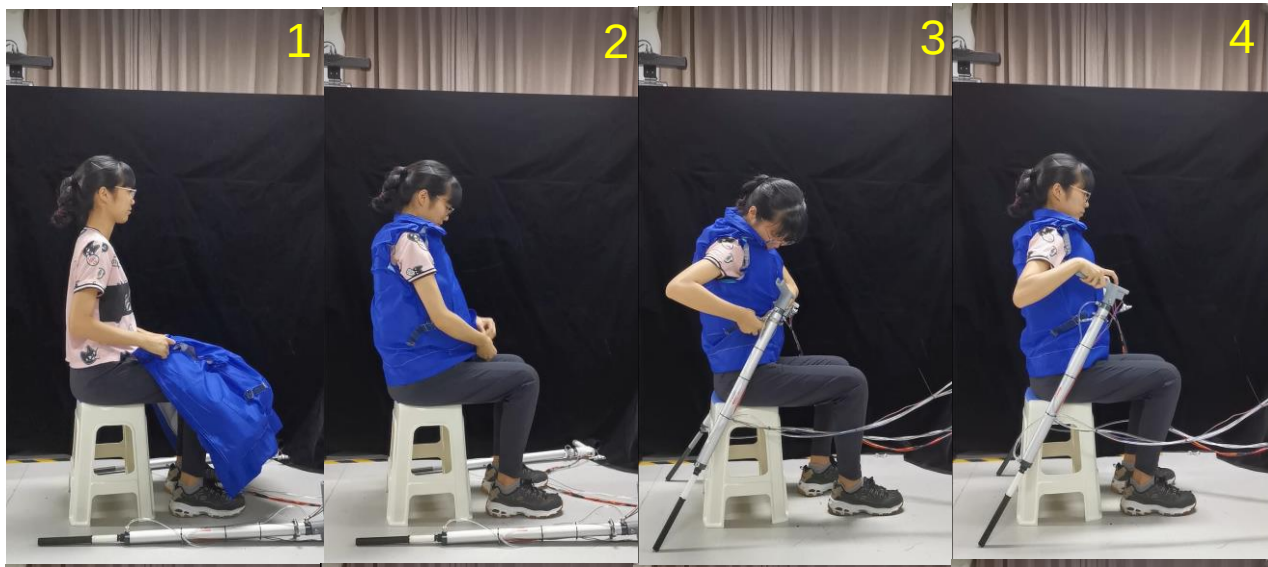
Prototyping: Air Cylinder for Robotic Cane

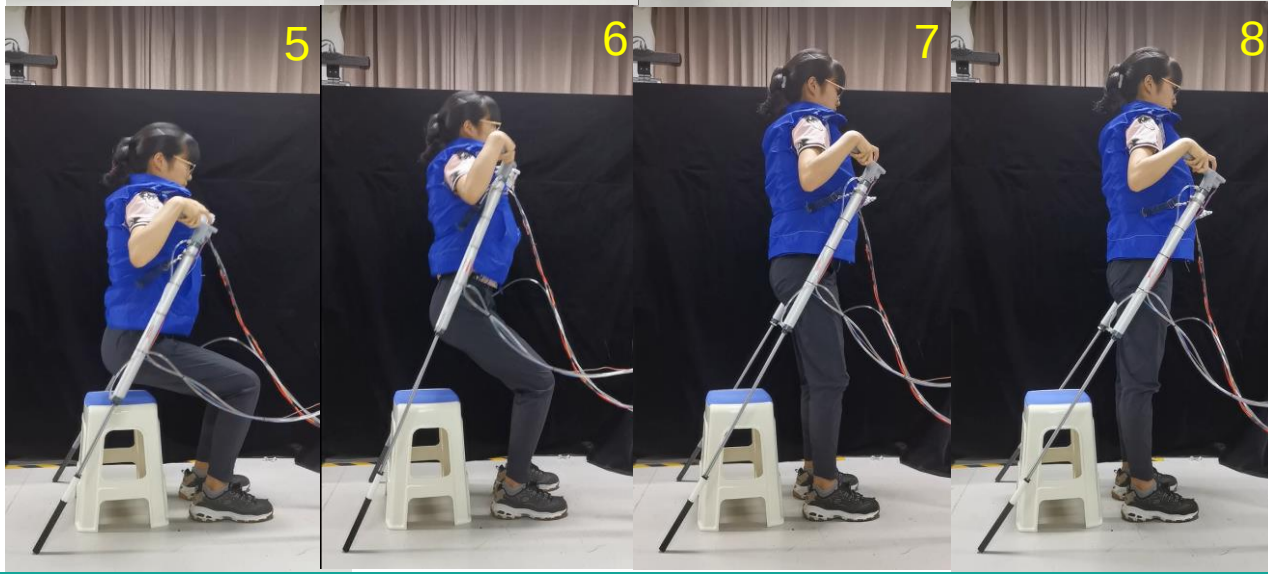
Working Principle





Prototyping: Air Cylinder for Robotic Cane





Review and Discussion

Elderly Friendly Design

To be improved

- Intention Detection
  - By studying related paper, we think that changes in trunk angle during motion transition can be used for intention detection.
  - And Matlab Mobile, an app in the cell phone, can use the phone's sensor to record angles (100Hz at maximum). In this case, cell phone may replace extra sensors for intention detection.
- Power Source
  - At this stage, we don't the add power source on SRL now. Instead, currently we just connect the tube to the outside pneumatic system for power supply.
- Sizing Optimization
  - To make it light-weight and easy to carry are important. We'll try to addressed it later.

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Conclusions

1. We propose a robotic cane as a Supernumerary Robot Limb, which can assist the elderly during motion transition in the chosen location, bed, chair and toilet for at home usage.
2. By experiments, sit-to-stand motion transition is analyzed. Normal cane's role and the effectiveness of air cylinder during this process are addressed.
3. A prototype, including a pneumatic vest and an extendable cane as a system, is made to demonstrate the concept of robotic cane.

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