ECE 370
Introduction to Biomedical Engineering

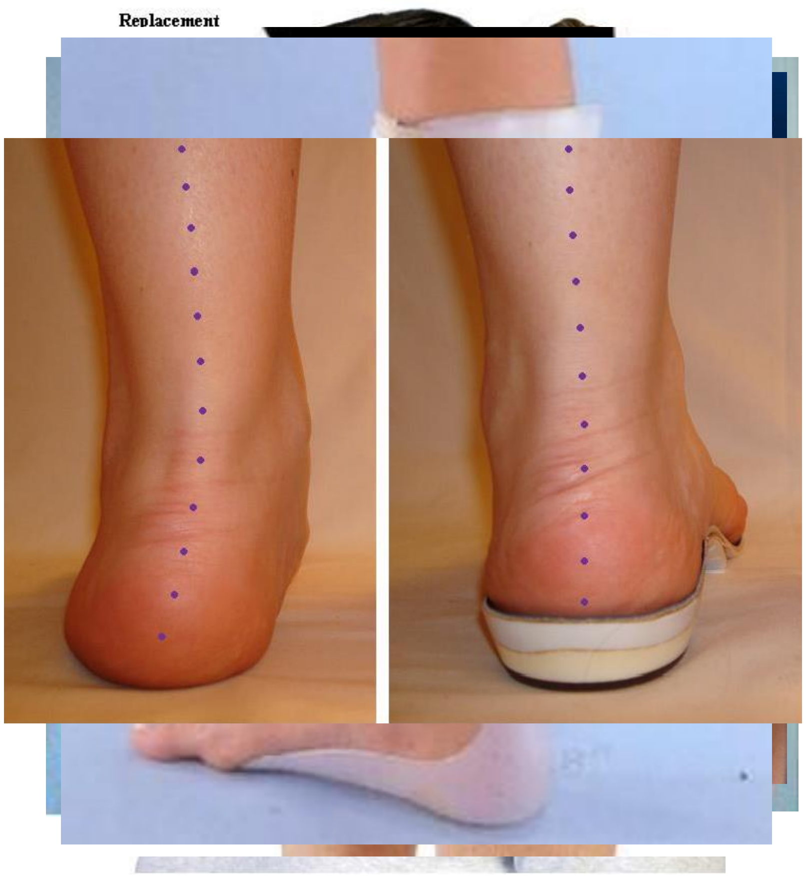
Orthotics, Prosthetics, Bionics

Orthotics

- **What are Orthotics?**
  - An orthopedic appliance/device designed to correct, straighten or support a body part
- **How do they work?**
  - Prevent abnormal motion or movement?
  - Change mechanics?
  - Proprioception?

Orthotics

- **Examples of Applications of Orthotics**
  - Neck → Cervical trauma
    - Prevent motion that may exacerbate the trauma
  - Back → Scoliosis
    - Gradually correct the shape of the spinal column
  - Wrist → Carpal tunnel syndrome
    - Prevent the wrist from moving to allow nerves to heal
  - Knee → Joint or ligament injury
    - Prevent knee trauma
    - Immobilize the knee to allow proper healing after surgery
  - Foot → Drop foot (AFO: Ankle foot orthosis)
    - Keep the foot extended so that walking is easier
  - Foot → Deformities, pressure lesions, or pain
    - Custom support to correct deformities of prevent trauma



Prosthetics

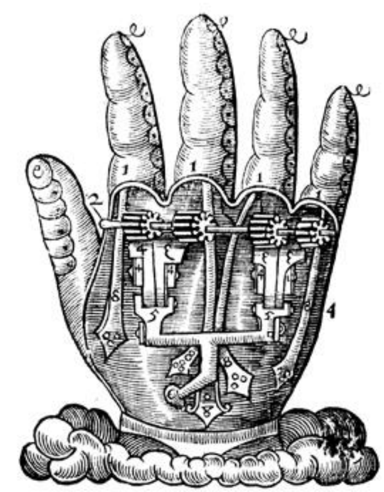
- **What are prosthetics?**
  - An artificial part that replaces a body part.
  - Usually replaces parts lost by injury or missing from birth or to supplement defective body parts.
  - An artificial limb is a *type* of prosthesis
    - Other types include heart valves, hip replacements, etc

Prosthetics

- **Amputations**
  - > 150,000 per year in the US
  - The most common causes of lower-extremity amputation are:
    - Disease (70%)
      - Mostly circulatory complications of diabetes
    - Trauma (22%)
      - Most often limbs and appendages (like the arms, ears, feet, fingers, hands, legs, and nose.)
      - Four out of five are male 15-35 y.o.
    - Congenital or Birth Defects (4%)
    - Tumors (4%)

Prosthetics

- **History**
  - Egyptian Times
    - Mummies found with prosthetic limbs made of fiber
  - The Dark Ages
    - Basic peg legs and hand hooks
    - More cosmetic than functional
    - Meant to hide disgrace and weakness of defeat from other battles.
  - Renaissance
    - Ambroise Pare
    - "Le Petit Lorrain" (a hand operated by springs and catches)
  - 19th and 20th Centuries
    - Many wars → many amputees
    - Government funding for research



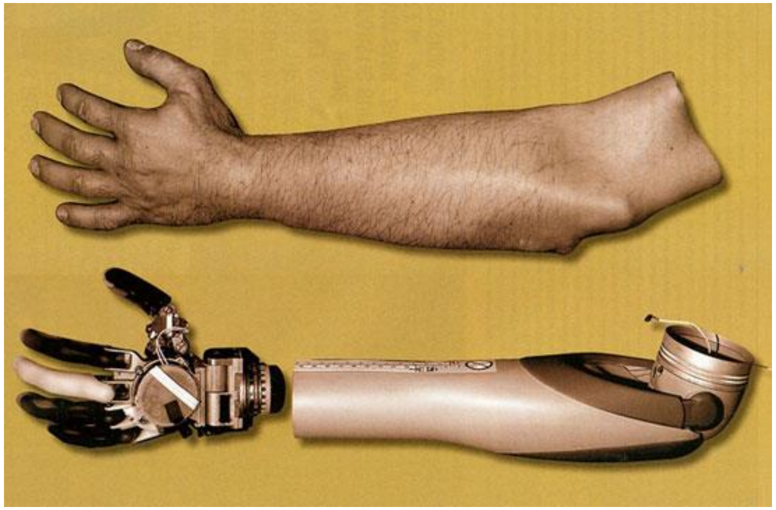
19. "The form of a hand made artificially of iron." From Ambroise Pare, *A Supplement of the Defects in Man's Body*, 1579.

Prosthetics

Modern Prosthetics

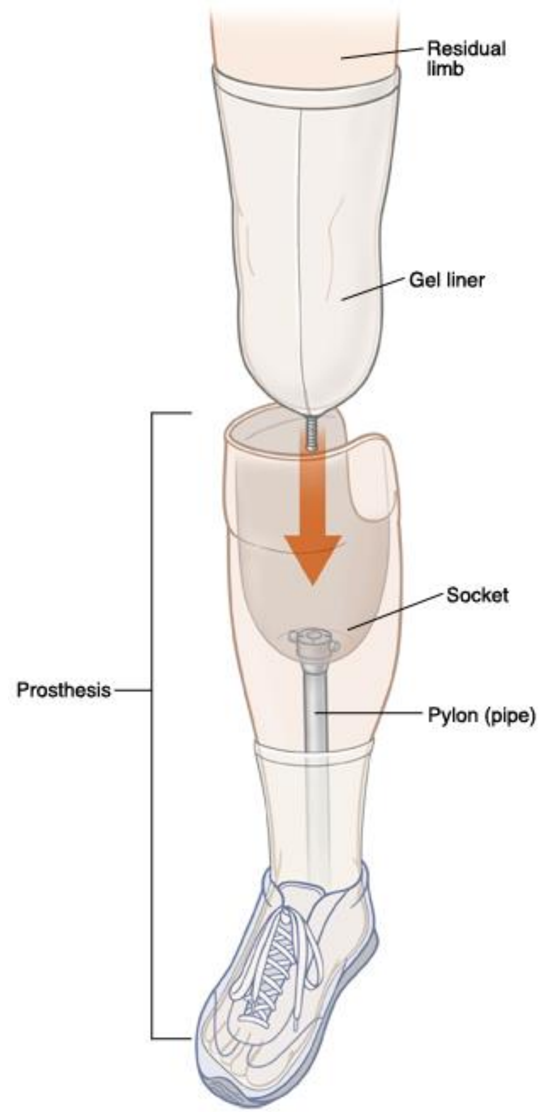
- **Design**
  - Computers used to help fit amputees with prosthetic limbs
  - Computer Aided Design (CAD) and Manufacturing (CAM)
    - Design a model of the patient's arm or leg used to prepare a mold from which the new limb can be shaped.
  - Increased understanding of biomechanics
    - A great deal of emphasis on developing artificial limbs that look and move more like actual human limbs.
- **Materials**
  - Modern materials are stronger and more lightweight.
  - Plastics, titanium, carbon fibers
- **Control**
  - Myoelectric prosthetics

THE CIRCUITRY OF A MYOELECTRIC HAND
Courtesy : Inventors.About.com



Prosthetics

- **Basic Parts**
  - A custom fitted socket
  - An internal structure (also called a pylon)
  - Cuffs and belts that attach it to the body
  - Prosthetic socks that cushion the area of contact,
  - Realistic-looking skin (in some cases)
- **Properties**
  - Lightweight (plastic and titanium or aluminum
    - Newest development: the use of carbon fiber to form a lightweight pylon.
  - Physical appearance improves by foam cover which is in turned covered with a sock or artificial skin that is painted to match the patient's skin color.
  - Prosthetic socks are made from a number of soft yet strong fabrics.



Prosthetics

- **Characteristics of a successful prosthesis:**
  - Be comfortable to wear,
  - Easy to put on and remove,
  - Lightweight,
  - Durable, and cosmetically pleasing.
  - Function well mechanically and require only reasonable maintenance.
  - Depends on the motivation of the individual, as none of the above characteristics matter if the patient will not wear the prosthesis
- **Considerations when choosing a prosthesis:**
  - Amputation level.
  - Contour of the residual limb.
  - Expected function of the prosthesis.
  - Cognitive function of the patient.
  - Vocation of the patient (eg, desk job vs manual labor).
  - A vocational interests of the patient (ie, hobbies).
  - Cosmetic importance of the prosthesis .
  - Financial resources of the patient.

Prosthetics

- **Prostheses (Artificial limbs) are typically manufactured using the following steps:**
  - Measurement of the stump.
  - Measurement of the body to determine the size required for the artificial limb.
  - Creation of a model of the stump.
  - Formation of thermo-plastic sheet around the model of the stump – This is then used to test the fit of the prosthetic.
  - Formation of permanent socket.
  - Formation of plastic parts of the artificial limb –
  - Different methods are used, including vacuum forming and injection molding.
  - Creation of metal parts of the artificial limb using die casting.
  - Assembly of entire limb.

Prosthetics

- **Problems may occur when using prosthesis are:**
  - The poor fitting of the prostheses, causes unequal weight load to lower limbs. This may cause extra stress or pressure on the other (unaffected) leg, or on the stump. The increased pressure may lead to pain and skin problems. Skin breaks that are not treated can become infected. Over time, this may also make another amputation necessary.
  - Walking with prosthesis on takes extra energy.
  - The stump should be checked every day for redness, blisters, soreness, or swelling.
  - Prosthesis need to be adjusted several times before it fits well.

Prosthetics

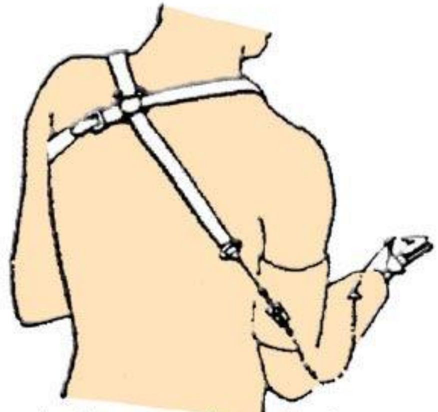
Control of the Prosthetic Device

- **Cosmetic Prosthetics ($)**
  - Generally for upper limb amputation
  - Low to no functionality
  - Made from PVC or silicone

Prosthetics

Control of the Prosthetic Device

- **Body-Powered Prosthetics ($$)**
  - Generally for upper limb amputation
  - Operated by means of a cable and harness system
    - Using the back and shoulder muscles, the cable is pulled to either open or close the hand
  - Some but limited amount of functionality



Prosthetics

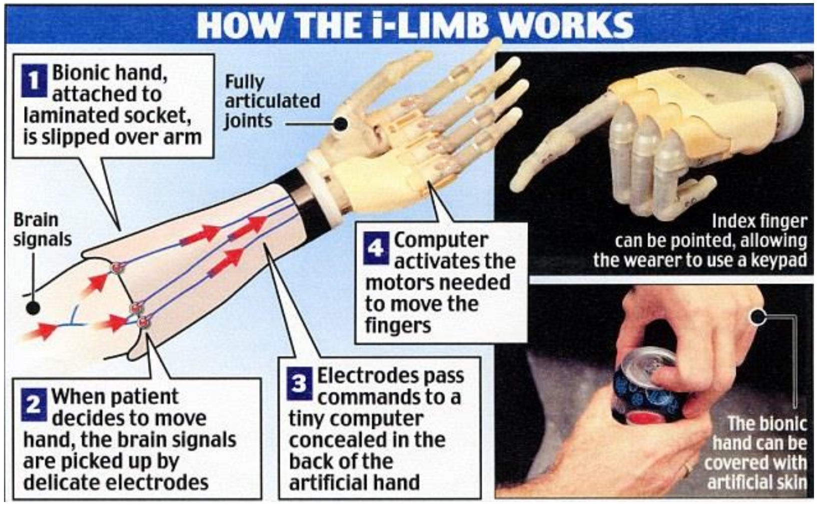
Control of the Prosthetic Device

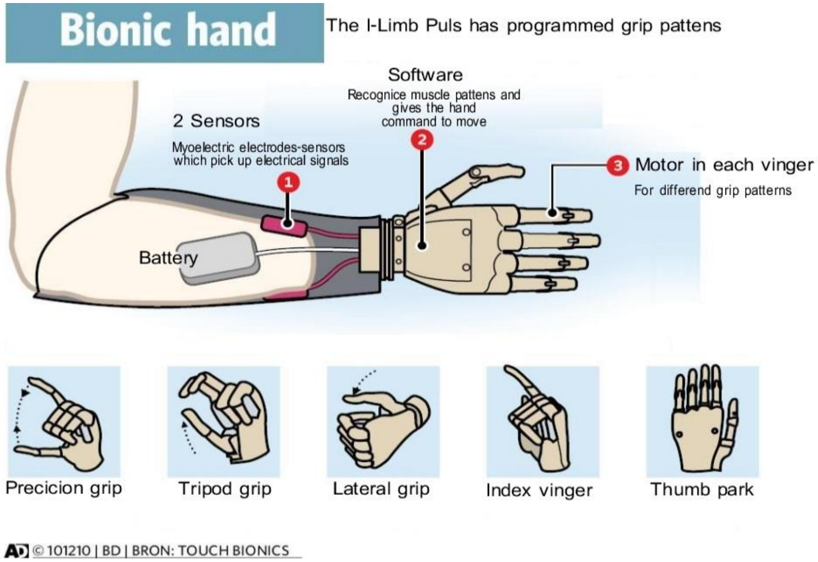
- **Feed-forward control → The C-Leg ($$$)**
  - A built-in microprocessor interprets the user's movements and anticipates their actions → allows motion changes in real time (50 times/sec)
  - The system is actuated through the leg's hydraulic movement
  - Supports up to 10 programmable modes, switchable through a small remote control device
  - It gives users greater flexibility to change speed or direction without sacrificing stability.
    - seamlessly speed up or slow down
    - take on hills or slopes
    - recover from stumbles
    - go down stairs step-over-step

Prosthetics

Control of the Prosthetic Device

- **Myoelectric Prosthetics ($$$$)**
  - The most complex
  - Operated by electrodes (embedded in the socket) which pick up muscle impulses from the contracting muscles of residual limb
    - Electrical signals are sent to the electric hand to open or close it.
  - Enhanced functionality
  - Internal Components: electrodes, battery pack, control unit (processing), motors, and sensors





i-Limb Ultra

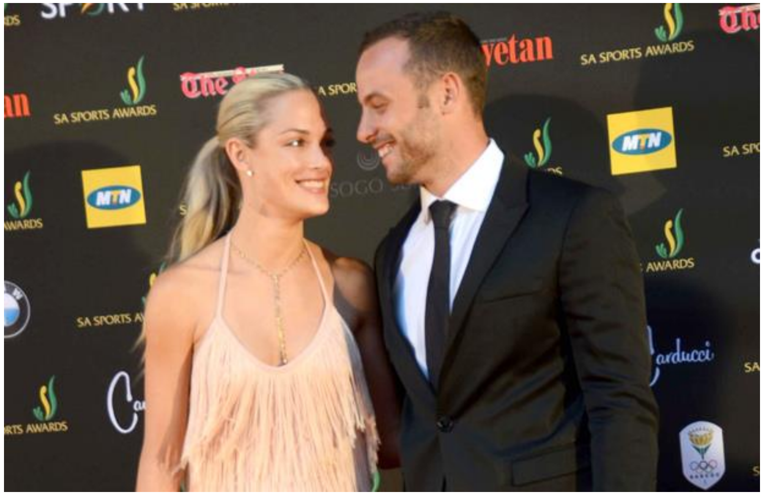
- **i-Limb Ultra Functional Prosthetic Hand**
  - Fingers that move independently and bend at natural joints.
  - Manually rotatable thumb.
  - Multi-flex wrist option or manually rotatable.
  - 4 skin coverings: 2 active and 2 natural.
  - Variety of automated grips along with custom gestures
    - Requires some prepositioning of fingers for some actions.
- **Advantages**
  - Individually moving fingers allow for better grip.
- **Disadvantages**
  - Cost: $18,000 per prosthetic.
  - Although versatile, does require some prepositioning for some actions.
  - Mechanics not perfect yet

Prosthetics in Track

- **Advances in technology → prosthetics being designed for more strenuous tasks.**
  - Lower leg amputees with the ability to run again.
  - Stop mimicking how actual human leg works (1996) → a “j” curve
- **The Flex-Foot Cheetah**
  - Mimicking motions of the hind legs of a cheetah in mid stride, Phillips designed the Flex-Foot Cheetah.
  - Created by carbon fibers
    - High and low stress points vary in amount of fibers
    - Lightweight compared to other prosthetics
  - Allows for compression and also return to normal state
  - Attaches externally to body
  - Hard to maneuver around track with lack of ankles
  - Comfortable for short periods of time
  - Cost per unit is between $15,000-18,000
    - Most often not covered by health insurance

Prosthetics in Track

- **Allowed double leg amputee Oscar Pistorius to compete in 2012 Olympics vs. able bodied people**
- **Controversy**
    - People believe that the spring provided by the Flex-Foot plays an unfair advantage for the runner
        - Provided that the prosthetic does compress and return energy, people assume its more energy than a human leg would provide
    - Glancing back at the numbers from the results section, this is found to be incorrect
        - It takes 25% more energy to move a prosthetic over a human limb
        - 90% energy is returned from the Flex-Foot to the runner while 249% energy is returned by a human limb



Prosthetics in Other Sports

- **Available for a variety of different activities**
  - Gymnastics, basketball, football, baseball, skiing
  - The prosthesis varies depending on the situation
  - Special grips and advanced shock absorption
  - Ultra-light and ultra-strong (titanium)






Prosthetics

Benefit to Society

- **Providing functional prosthetics to those who have lost limbs would**
  - Allow patients to return to work, reducing unemployment and improving productivity
  - Reduce the need for rehabilitation and counseling
  - Reduce patient pain and dependence, lowering medical costs
  - Lower the chance of infection leading to further amputation

Prosthetics

Future Directions

- **Direct bone attachment (osseointegration)**
  - Attaching prosthetic legs to a titanium bolt placed directly in the bone
  - Disadvantages
    - May avoid skin sores, sweating, and pain
    - Amputees have better muscle control of the prosthetic.
    - Amputees can wear the prosthetic for an extended period of time - with the stump and socket method this is not possible.
    - Transfemoral amputees are more able to drive a car.
  - Disadvantages
    - Cannot have large impacts on the limb, such as those experienced during jogging
- **Biohybrid limbs**
  - Insert microchips into muscles to pick up signals from the brain
  - Two-way talk (send and receive)
  - Sensitive to touch and heat

Prosthetics

Future Directions

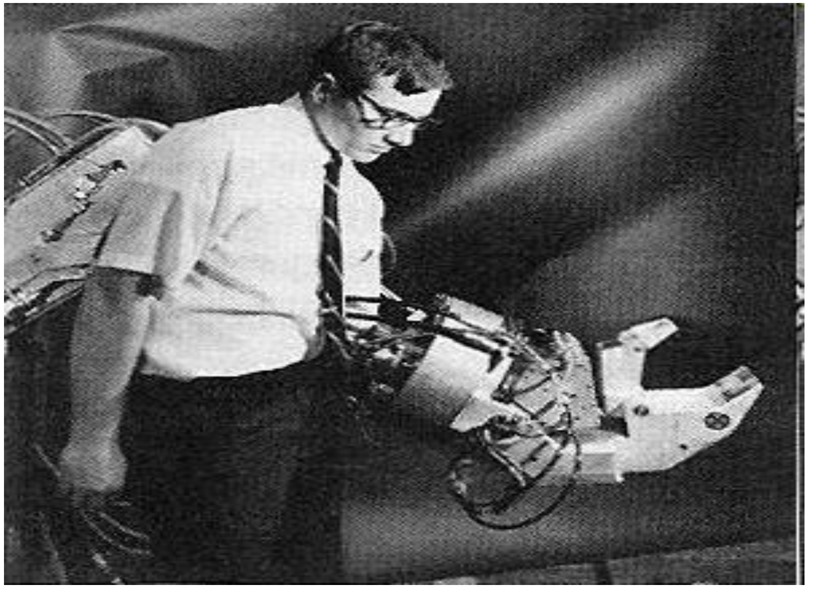
- **Continue to develop limbs whose function is more and more similar to the real thing**
  - As technology advances so does the effectiveness of the prosthetics created
- **Prosthetics may be designed like shoes in the future**
  - An amputee may have a different prosthetic for every activity
- **As springs are implemented into the design, they may act like muscles and return a higher amount of energy to the user**
- **Very possible that having a prosthetic will be more beneficial than a human leg in the future**

Robotic Exoskeletons

- **What are robotic exoskeletons?**
  - An artificial external support structure with automatic controls
  - Wearable robots
    - Designed around the function and shape of the human body
    - Controlled by the human
- **Enhance strength of user**
  - Compensate for muscular degenerative disease
  - Provide superhuman capabilities
  - Can assist in walking, running, jumping higher or even lifting objects one would not normally be able to lift.
- **Types of Exoskeletons**
  - Actuation
    - Passive Exoskeleton
    - Powered Exoskeleton
  - Purposes
    - Rehabilitation
    - Assistance

Robotic Exoskeletons

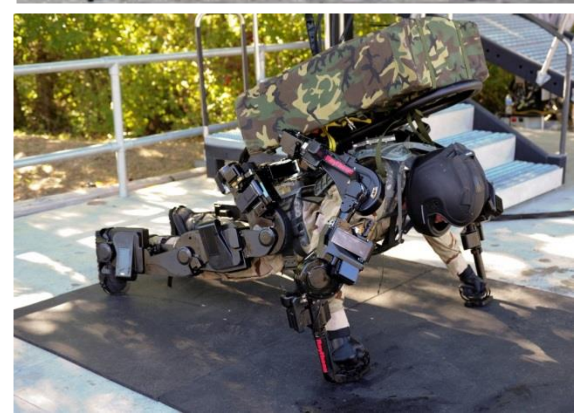
- **Early work**
  - 1965: General Electric Research & Development: Hardiman 1
    - Weighed 1500 lbs
    - Could lift 750 lbs
    - Attempting to operate both legs at once leads to “violent and uncontrollable motion”



Robotic Exoskeletons

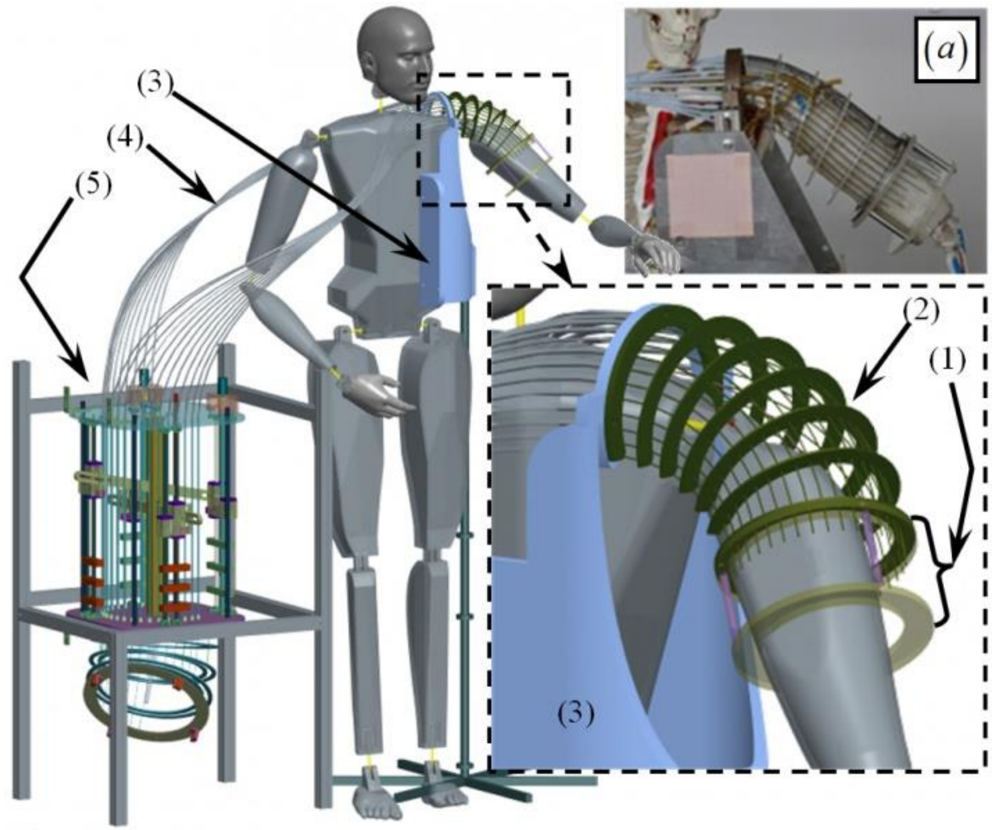
Where could robotic exoskeletons be used?

- **Rehabilitation:**
  - Support muscles and joints during therapy
  - Provide resistance during therapy
  - Teach and correct limb trajectories
- **Disability Treatment**
  - Support and move paralyzed limbs
  - Assist patient to recover to normal level
- **Military:**
  - Increase strength and endurance
  - Act as armor
  - Base for further enhancements:
    - Flight
    - Packaged weapons
    - Computers



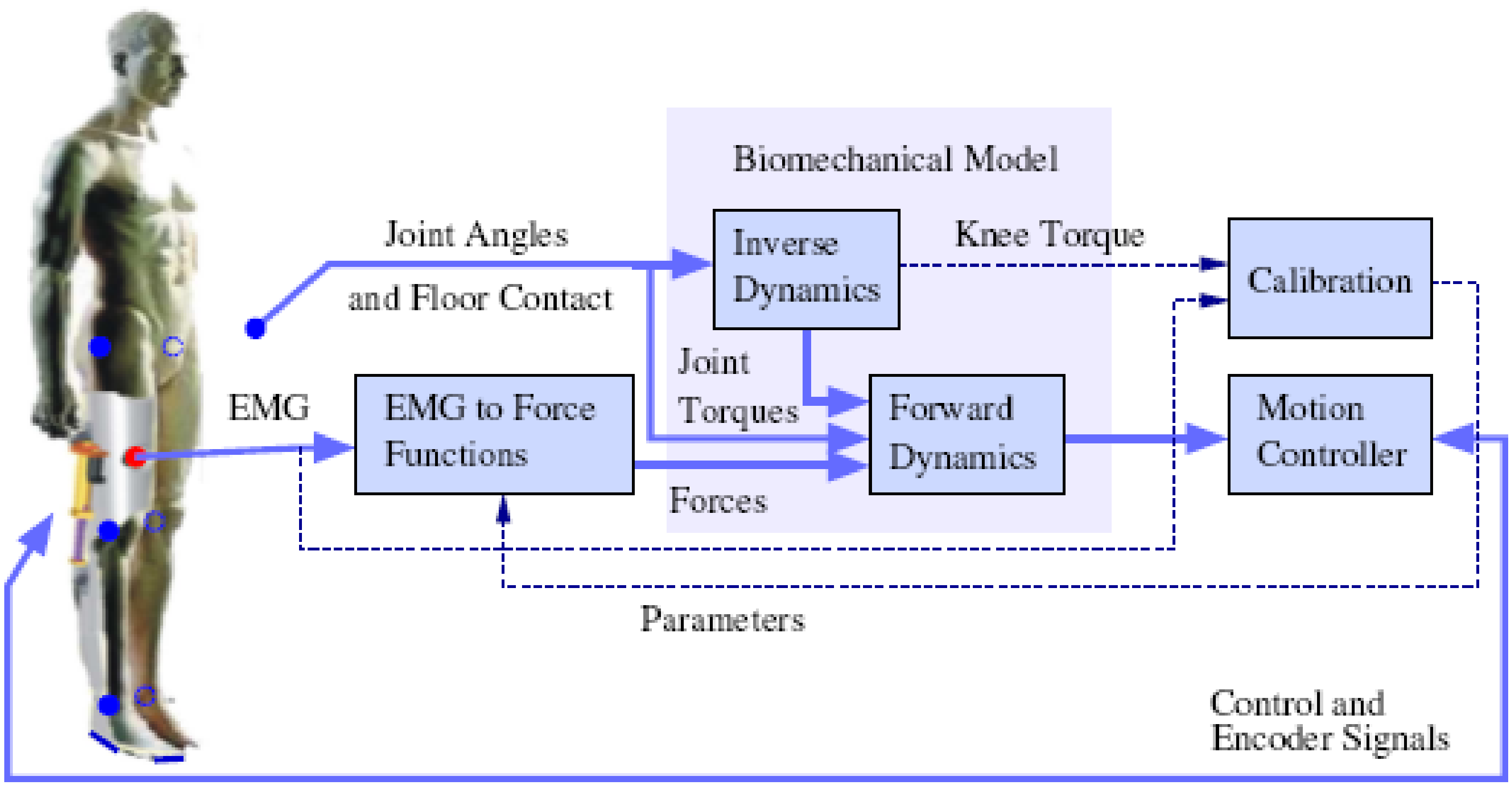
Robotic Exoskeletons

- **What research challenges exist?**
  - Predicting Intended Motion
  - Gravity Balancing
  - Tele-movement
  - Biomechanics
  - Long Lasting Power Supply
  - Lightweight components
  - Human-Robot Interaction
  - Intelligent Autonomous Control



Robotic Exoskeletons

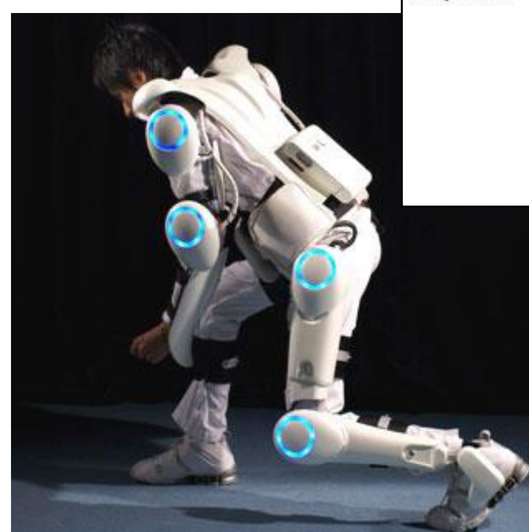
- **System flow chart**



Robotic Exoskeletons

What are current exoskeleton concepts?

- **Hybrid assistive limb (HAL) 5**
  - Cyberdyne and Tsukuba University Japan
  - Power supply: nickel-metal hydride and lithium battery packs
  - Actuation: DC motors
  - Control: EMG and learned motions
  - The HAL5 mimics every move of its user while weighing so little it is unnoticeable.
  - Calibration
    - Input signals from user EMG calibrated against required joint torques.
  - Modeling
    - Operator’s leg regarded as a multilink pendulum system.
  - In clinical trials now



Robotic Exoskeletons

What are current exoskeleton concepts?

- **X1**
  - NASA with the Florida Institute for Human and Machine Cognition (IHMC)
  - Weight: 26 Kg
  - Ten joints
    - Four are motorized
  - Augment the wearer's movements
    - Can also be set to work against them
  - Still in the research and development stage

Robotic Exoskeletons

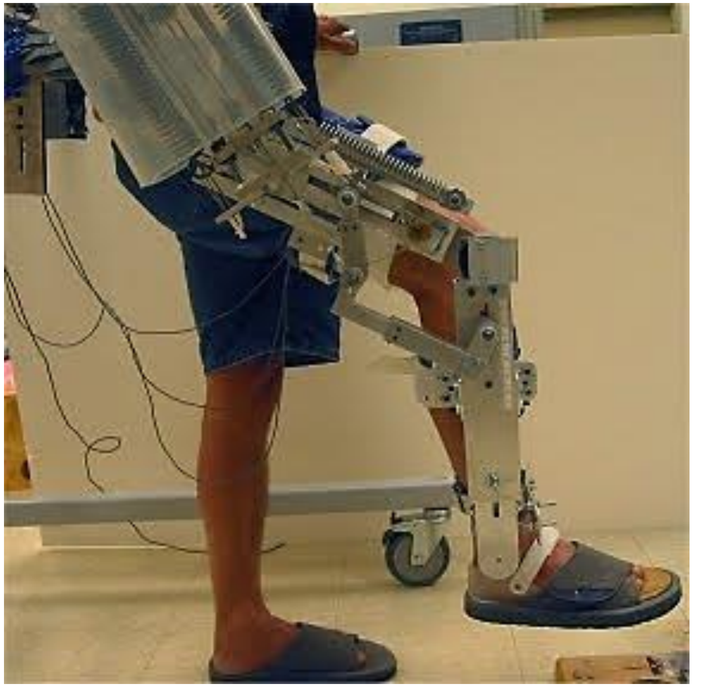
What are current exoskeleton concepts?

- **Ekso (Ekso Bionics)**
  - Weight: 20 kg (supported on the skeletal legs and footrests)
  - Performs the calculations needed for each step
  - In a later model the walking sticks will have motion sensors that communicate with the legs
  - Licensed to Lockheed Martin for military development
- **Rex (Rex Bionics)**
  - Carbon fiber, € 100k
  - Weight: 38 kg
  - Provides movement, including the ability to climb stairs
  - Famous users: British TV presenter Sophie Morgan and BBC correspondent, Frank Gardner.

Robotic Exoskeletons

What are current exoskeleton concepts?

- **Gravity Balancing Orthosis (rehabilitative, passive)**
  - University of Delaware, Newark
  - Target patients: Stroke patients.
  - Use: Reduce effects of gravity on user
  - Composition: Springs and light weight aluminum links



Robotic Exoskeletons

- **What are current exoskeleton concepts?**
- **SARCOS (Raytheon)**
  - Started in 2000 after US Agency DARPA request
  - The XOS Exoskeleton
  - Power: combustion engine and servo motors.
  - Weight: 68 kg
  - Allows its user to lift 90kg payloads “repeatedly with minimal strain”.
    - An exoskeleton for logistics and supply tasks
    - Possible customizations for combat (e.g., transport and use of heavy weaponry) or battlefield operations (e.g., transport of wounded soldiers).
  - XOS 2 – 2010
    - Uses 50 percent less power → increasing fuel efficiency and autonomy.

Robotic Exoskeletons

What are current exoskeleton concepts?

- **The Landwalker Exoskeleton**
  - Created by Japanese Robotics Manufacturer Sakakibara-Kikai.
  - It stands at 3.4 meters tall and weighs an astonishing 1000 kilograms.
  - With guns held at each size, this mammoth of a robot would be intimidating to any soldier on the battlefield.

Advancements and the Future

- **Advancements of the technology have been booming in the past 5 years.**
- **These exoskeletons have the potential to be life-altering.**
- **Applications**
  - Protecting soldiers in the battlefield
  - Robotic surgeons in operating rooms being controlled by surgeons in another room.
  - Exoskeletons helping the disabled as well as people with degenerative diseases.
- **The potential for this technology seems endless and its effects monumental**