CS 499-002: Virtual Reality

Dr. Zoran Duric

Department of Computer Science
George Mason University

Office: Nguyen Engineering Building 4443
Office Hours: Monday & Tuesday 3:00-4:00 pm or by appt.
Email: zduric@cs.gmu.edu

URL: http://cs.gmu.edu/∼zduric/
Lab URL: http://cs.gmu.edu/∼vislab/
Course URL: http://cs.gmu.edu/∼zduric/cs499.html
Piazza URL: https://piazza.com/class#fall2012/cs499002

Course Information

Meets: Monday 4:30 pm - 7:10 pm in Innovation Hall 129

Prereqs: CS 310 and CS 367, MATH 203 (Linear Algebra) recommended

Textbook: G. C. Burdea and P. Coiffet. *Virtual Reality Technology, 2nd Ed.*, John Wiley & Sons, Inc., 2003. I strongly recommend that you buy the book. Additionally, articles and other supplementary materials will be assigned as readings for the class.

Attendance: I expect you to attend every class. You will be expected to participate and this participation will be a part of your grade.

Piazza: This term we will be using Piazza for class discussion. The system is highly catered to getting you help fast and efficiently from classmates and myself. Rather than emailing questions to me, I encourage you to post your questions on Piazza.

Topics & Grading

Topics

- VR Input Devices
- VR Output Devices
- Computing Architectures for VR
- Modeling
- Programming in VR
- Human Factors
- Applications

Grading

Homeworks:	20%
Class participation:	15%
Exam:	25%
Project:	40%

Project

- There will be semester long team projects using *Microsoft Kinect* devices.
- You will present project proposals early and those will be critiqued.
- The entire class is expected to participate in discussion during project proposal presentations and final project presentations.
- The project will include writing your own code.
- You may negotiate during a *different project with haptics* or some other VR device or environment.
- However, you will have to be very convincing and make very good and detailed arguments why you should be allowed to do it.

Assignments & Class Participation

- There will be homework assignments that may include reading articles on VR.
- Other assignments will include writing code that will move you ahead with the project.
- I will occasionally ask you to find some data or code and share it with the class.
- You will need to present at least once in front of the class. It could be a paper, VR system, VR environment, or even some coding hints that may help with data processing.
- All assignments should be submitted on time unless you have a *really* good excuse.
- I expect you to be in class which means no computers or tablets or phones, no texting, no games, no social networks. If you are using a device you must share with the class whatever you are doing.

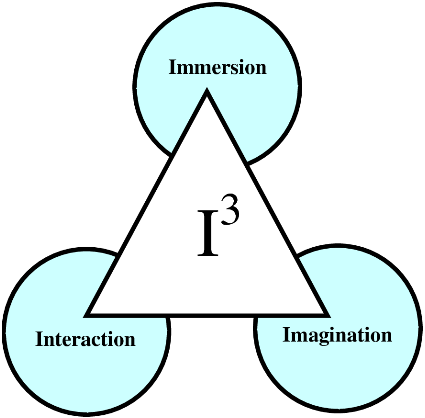
Virtual Reality: Definition

From Burdea and Coiffet book:

"A high-end user-computer interface that involves real-time simulation and interaction through multiple sensorial channels." (vision, sound, touch, smell, taste)

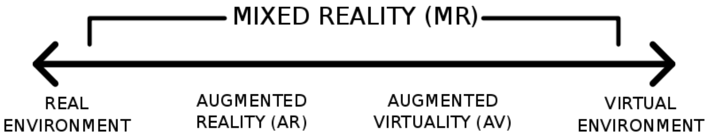
Example: Los Alamos National Laboratory

Virtual Reality Triangle



What is Mixed Reality

Reality-Virtuality Continuum



P. Milgram and F. Kishino. “A Taxonomy of Mixed Reality Visual Displays”, *IEICE Transactions on Information Systems*, Vol. E77-D, pp. 1321–1329, 1994.

Assignment for the next class: Find and read the article!

Sensorama Simulator

- Sensorama Simulator
- US Patent #3,050,870,1962
- By Morton Heilig
- 3D video, motion, color, stereo sound, aromas, wind effects, and a vibrating seat.

Brief History of Virtual Reality Timeline

Ultimate Display

Ivan E. Sutherland

- Early pioneer of GUI and VR
- Sketchpad (Ph.D. Thesis, 1963)
- Recipient of Turing Award in 1988

Ultimate Display (1965)

> "The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such room would be fatal. With appropriate programming such a display could literally be the Wonderland into which Alice walked."

- I. E. Sutherland, "Ultimate Display," In Proceedings of the IFIP Congress, pp. 506-508, 1965.

The Sword of Damocles

- I.E. Sutherland's early head mounted display
- 1966-68
- First at MIT Lincoln Labs and then at University of Utah
- Primitive early system
  - heavy
  - stereo vision
  - tracking

Brief History of Virtual Reality Timeline

Project GROPE

Frederick Brooks, Jr.

- Recipient of Turning Award in 1999

GROPE Project

- 1971 – 1990
- Simulation of molecular docking
- Haptic feedback

F. P. Brooks, Jr., M. Ouh-Young, J. J. Batter, P. J. Kilpatrick. “Project GROPE - Haptic Displays for Scientific Visualization,” In *Proceedings of the ACM SIGGRAPH Conference*, pp. 177–185, 1990.

NASA — A Pioneer in VR

- The first complete system was developed by NASA "Virtual Visual Environmental Display" (VIVED early 80s.
- They prototyped the LCD HMD.
- Became "Virtual Interface Environment Workstation" (VIEW) in 1989.
- Motivated by large simulation and training needs.

Commercialization

VPL Inc.

- The first company to sell VR products
- VPL Products
  - DataGlove (1987): Hand-sensing glove
  - DataSuit: A full-body, motion-tracking system
  - EyePhone: the first commercial HMD
  - RB2 (Reality Build for Two): A shared VR system for two people
  - Jaron Lanier (chief executive officer) declared "Virtual Reality Day" on June 7, 1989.
  - Brought the hype of VR.

Data Glove

Laboratory for the Study and Simulation of Human Movement

Faculty and Staff

Dr. Lynn Gerber, CHHS

Dr. Zoran Duric, VSE

Sidney Johnson

Karen Thompson

Students

Nalini Vishnoi

Cody Narber

David Bagheri

Robert Noteboom

Mike O'Malley

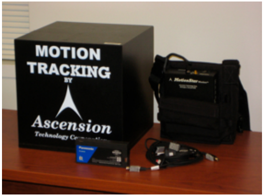
Gene Shuman

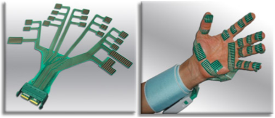
Sam Gelman

Former Students

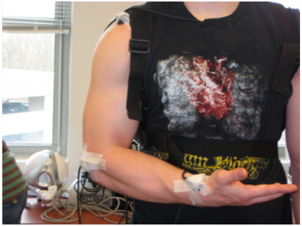
Dr. Younhee Kim, Dr. Wallace Lawson, Matt Revelle, Michael Sullivan, Ivan Avramovic, Nina Garcia, Jake Scott

Laboratory for the Study and Simulation of Human Movement





Laboratory for the Study and Simulation of Human Movement



Laboratory for the Study and Simulation of Human Movement

Phantom, EMG, Optotrak simulated movement data capture

Representative Research Projects

Applying Computer Vision to Analyze Human Functional Movements

Design a computer vision system with a goal of obtaining reliable segmental motion data, which can distinguish one individual from another and identify abnormal motion patterns.

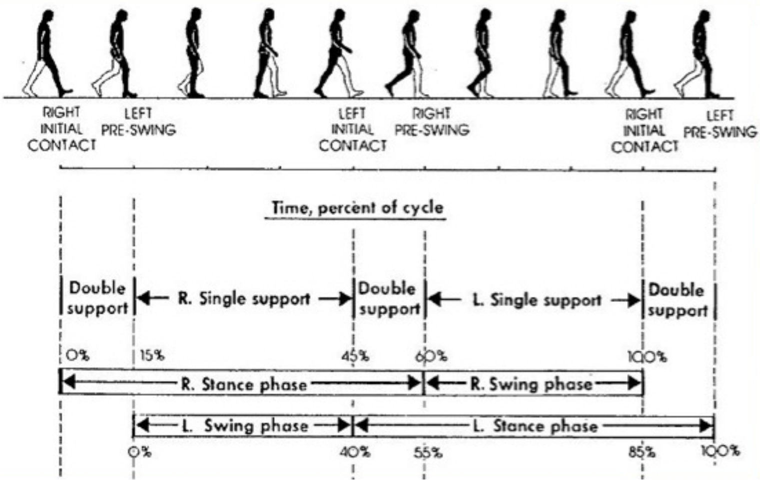
- Identify phases of gait reliably
- Compare gait patterns of individuals
- Analyzing upper extremity movements

Using Haptic Technologies to Capture Objective Information About Persons with and without Disabilities

- Implemented several simulated functional activities to assess normal subjects' cognitive and motor performance.
- Simulations were tested in 21 college-age students

Biomechanics of Human Gait

What information about the subject ca be obtained from gait?



Source: http://www.laboratorium.dist.unige.it/∼piero/Teaching/Gait/

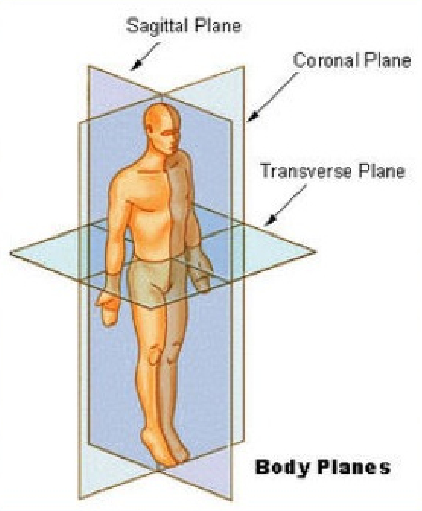
Biomechanics of Human Gait

- Local minima of vertical displacement correspond to double support
- Local maxima of vertical displacement correspond to mid-swing

Marker Based Motion Capture

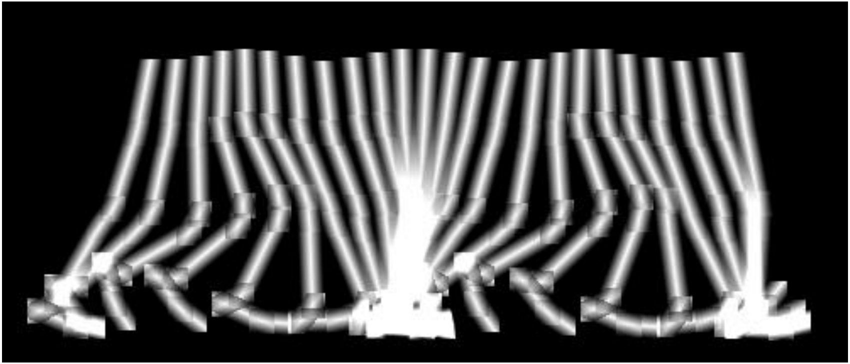
- Marker-based imaging of gait creates a skeletal reconstruction using reflective markers affixed to anatomical landmarks
- Reflective markers are tracked using high speed cameras
- High level of accuracy, but takes time

Anatomical Body Planes



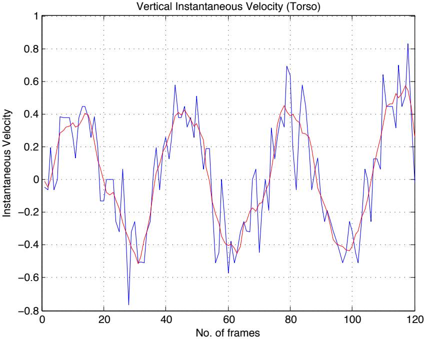
Source: http://www.wikidoc.org/index.php/Anatomical_terms_of_location

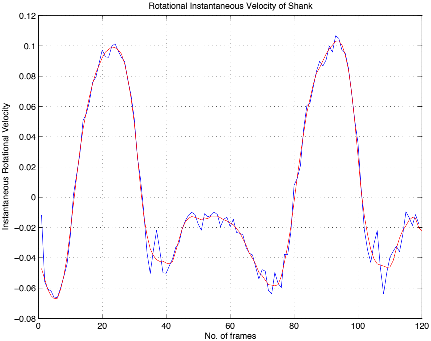
Visualized Gait Sequence from Winter



Data source: D.A. Winter, *Biomechanics and Motor Control of Human Movement*, Wiley, 2009.

Phases of Gait from Data





Left: Velocity of the Base of Rib Cage. Right: Rotational velocity of the Shank.

Using Computer Vision to Analyze Human Gait (Lawson, Vishnoi)

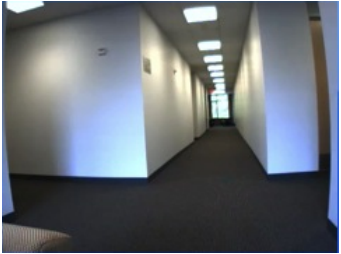
Background

- Loss in mobility can effect quality of life and have adverse effects on the independence of older population
- People suffering from disabilities develop compensatory techniques to overcome the limitations they face
- Comparison with normal gait enables physiatrists to find the targets for rehabilitation

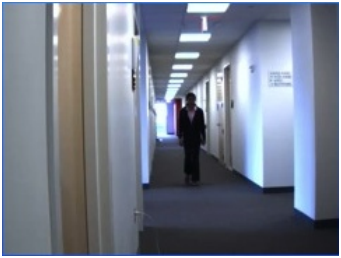
Objectives

- Analyze human movement using a data capture method that is inexpensive, quantitative, sensitive and non-intrusive
- Develop techniques to identify phases of gait using principles of biomechanics and use them to compare gait patterns of different people

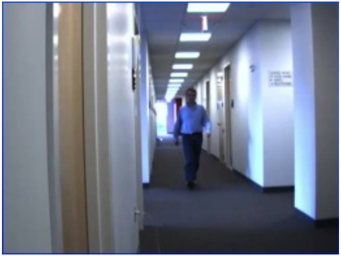
Identifying Phases of Gait Cycle (Lawson, Vishnoi)



Nalini sagittal plane movement



Nalini frontal plane movement

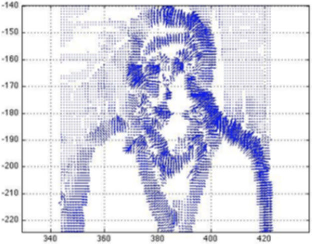


Ed frontal plane movement

Videos collected at 60 fps.
Approved by GMU HSRB.

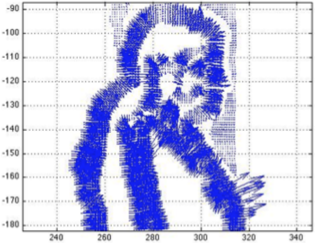
Identifying Phases of Gait Cycle (Lawson, Vishnoi)

frames, foreground, convex hull



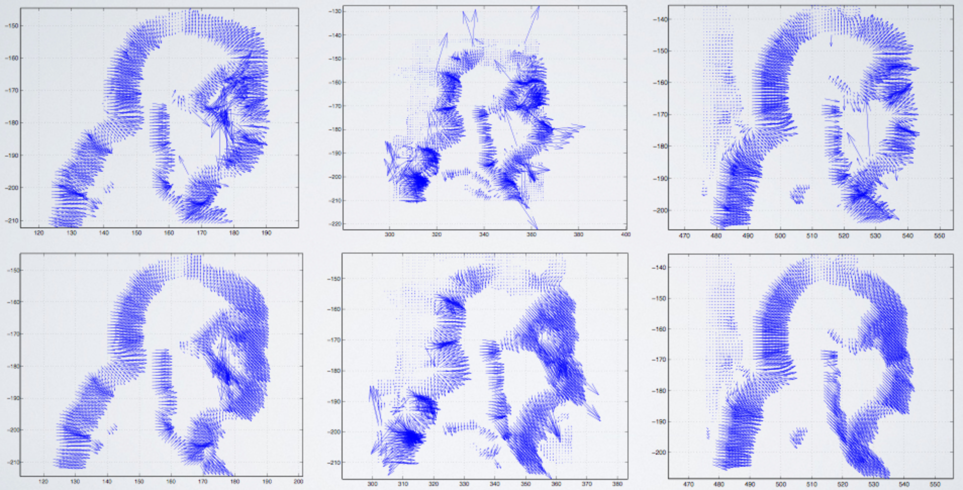
normal flow

frames, foreground, convex hull



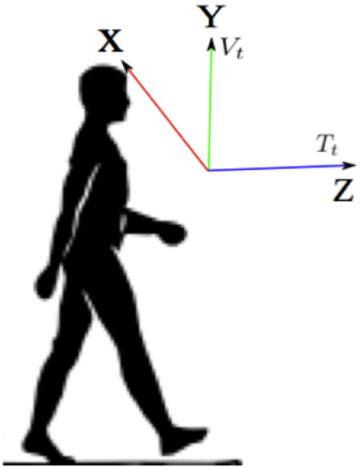
normal flow

Identifying Phases of Gait Cycle (Lawson, Vishnoi)



Top row: normal flow from the head region. Bottom row: median filtered flow

Human Motion Model

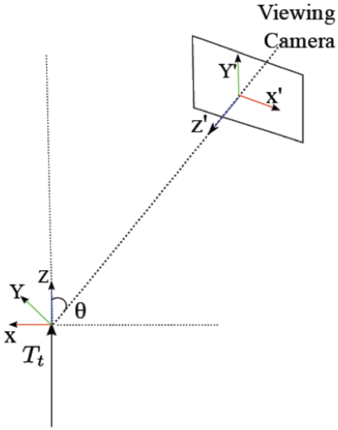


- Motion of limb segments can be described as translation plus rotation, but motion of the head and torso can be approximated by translation only
- Body motion model:

$$T_x = 0, \quad T_y = V_t, \quad T_z = T_t$$

T_t: forward translation
V_t: up and down movement of head

Image Motion Models



- Motion parameters:
  - $U = T_t \sin\theta$ (parallel translation)
  - $V = V_t$ (upward motion)
  - $W = T_t \cos\theta$ (expansion)
- Image motion for translational movement is given by

$$\dot{x} = f\frac{U - xW}{Z}, \quad \dot{y} = f\frac{V - xW}{Z}$$

- Focus of expansion: $\left(\frac{U}{W}, \frac{V}{W}\right)$
- Extremal cases:
  - Frontal view — FOE in the image
  - Sagittal view — FOE in infinity

Frontal Plane Motion Model

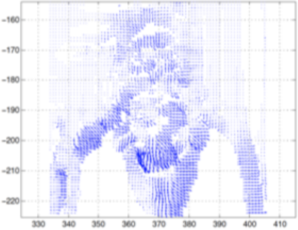
- Depth, Z, approximately constant in each frame
- Person is moving towards the camera

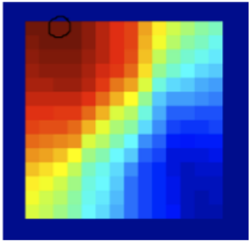
$$U = 0, \quad V = V_t, \quad W = T_t$$

- FOE is given by $(0, V_t/T_t)$
- Variation in FOE is due to head excursion
- Zero crossings of the vertical component correspond to minima and maxima of head excursion

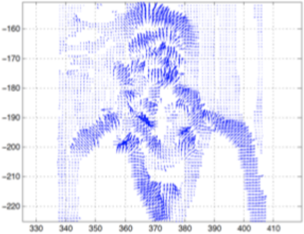
Computing the FOE

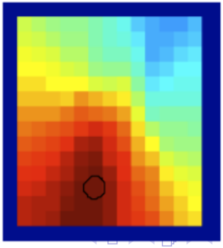
As the head moves down, the FOE moves up





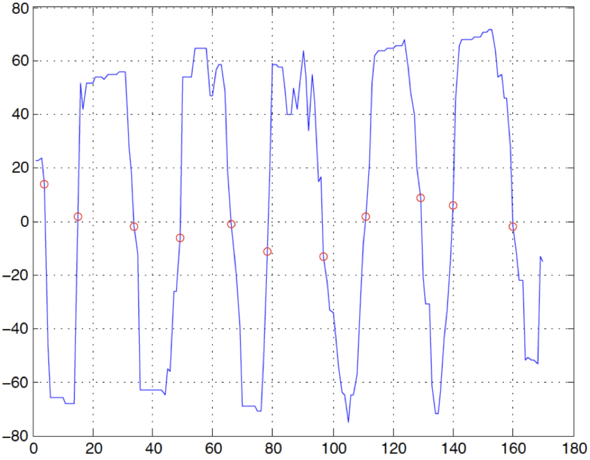
As the head moves up the FOE moves down



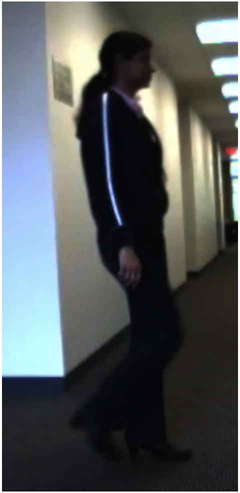


Detect Zero-crossings in Vertical Component of the FOE

Frontal FOE



Sagittal Plane Motion Model

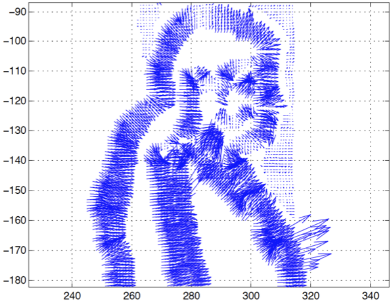


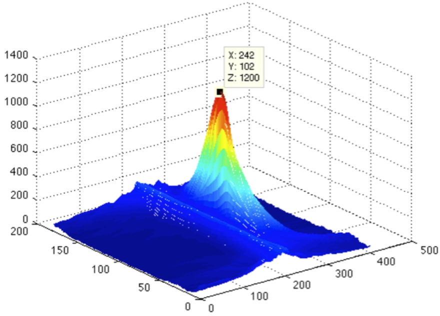
- Person is moving parallel to the camera:

$$\theta = \pi/2, \quad U = T_t, \quad V = V_t, \quad W = 0$$

- FOE is outside the image
- Detect reversals in the direction of head velocity
- Zero crossings of the vertical image velocity correspond to minima and maxima of head excursion

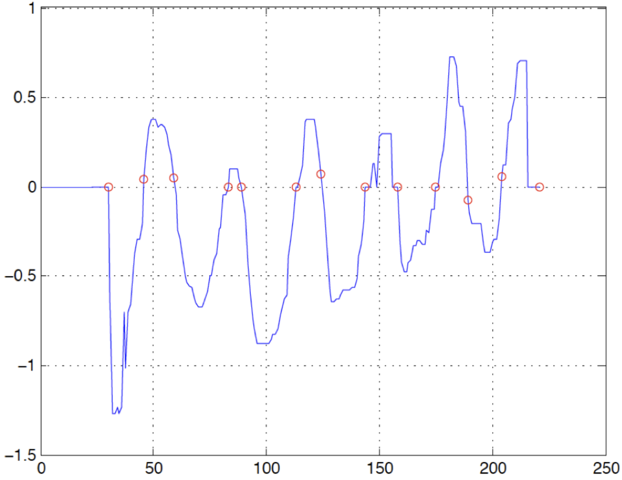
Computing Head Motion





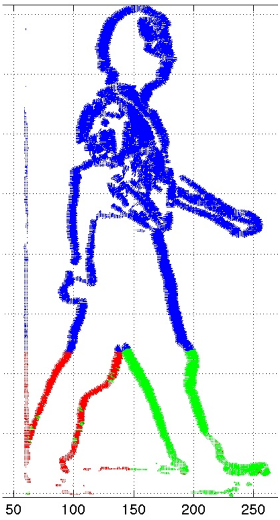
- Two parameter image translation model is fitted to the flow
- Each flow value votes for motion directions on a grid
- Maximal number of votes corresponds to translation

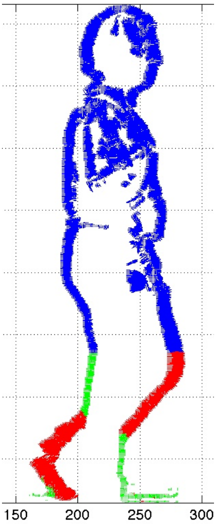
Detect Zero-crossings in Vertical Component of Motion



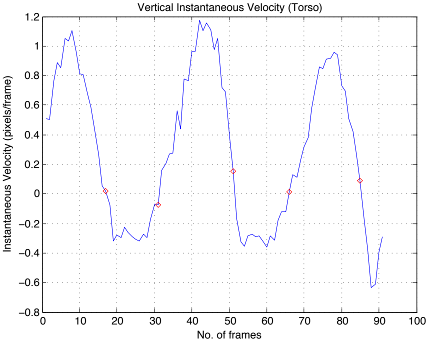
Zero crossing of vertical velocity component correspond to the minima and maxima of head excursion

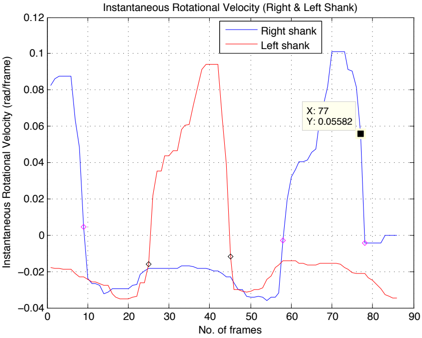
Other Phases of Gait: Lower Leg Tracking





Other Phases of Gait: Velocity Computation





Other Phases of Gait

Frames corresponding to zero-crossings of vertical excursion and lower-leg rotational velocity; heel-strike right (frame 48), double support (frame 56), toe-off left (frame 64), mid-swing (frame 70), heel-strike left (frame 84), double support (frame 90), toe-off right (frame 97), and mid-swing (frame 105).

Synchronizing Key Frames for Frontal and Sagittal Motions

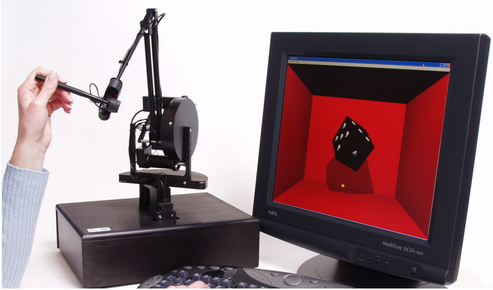
Synchronizing Key Frames for Frontal and Sagittal Motions

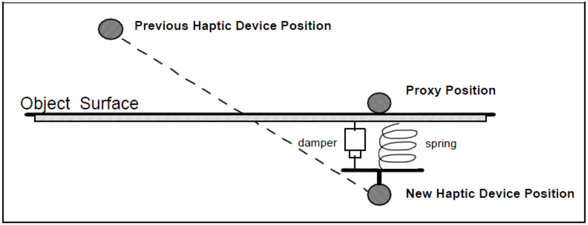
Synchronizing Videos

1. Synchronize key frames first
2. Synchronize short videos between the frames — drop frames if needed

Frontal and sagittal views of the same person
Frontal views of two people

Haptics




Previous Haptic Device Position
Proxy Position
Object Surface
damper
spring
New Haptic Device Position

Using Haptic Technologies to Capture Objective Information About Persons with and without Disabilities (Narber)

Background

- Virtual reality has been applied to both the evaluation and treatment of persons with Traumatic Brain Injury (TBI)
- Stimuli that are physical and repetitive, are thought to be bottom up and those that are cognitive and interactive are considered top down
- Haptics can be used to manipulate virtual objects
- We have used haptics to simulate functional movements (e.g. writing)

Objective

Determine whether normal individuals can improve their performance on two basic tasks: a fine motor manipulation and a word assembly task testing cognitive skill

Cognitive and Motor Skills

Cognitive Skills

Associativity: Defined as both recall and object/shape association. Allows subjects to make connections to what they have done in the past, and to recognize when steps need to be performed.

Planning: The ability to examine the situation and set up a sequence of steps on your own in order to successfully accomplish the task.

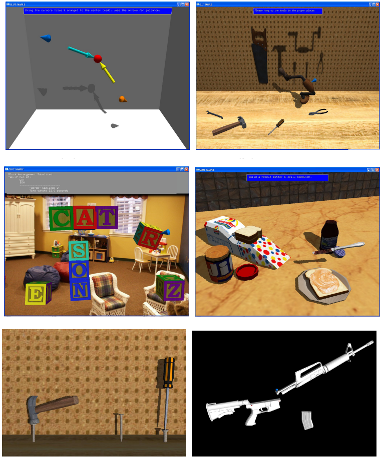
Sequence: Defined as knowing what order one must follow to correctly complete a task in a specific way.

Motor Skills

Movement: Defined as the persons ability to navigate the simulations cursor through the scene. Jerky, non-smooth movements constitute problems with their movement skill.

Interaction: The ability to grab and manipulate objects within the scene.

Haptic Templates (Narber)



Haptic training task

Trajectories in the Workbench task

Making a sandwich task

	Cognitive			Motor	
	Associativity	Planning	Sequence	Move	Interact
WorkB	M	L	L	H	H
LetterB	H	H	M	M	M
Sand	M	H	H	M	L
Tool	H	M	M	L	M
M4	M	M	H	M	M