Introduction to Robotics

METR 4202: **Robotics** & Automation

Dr Surya Singh -- Lecture # 1

July 26, 2017

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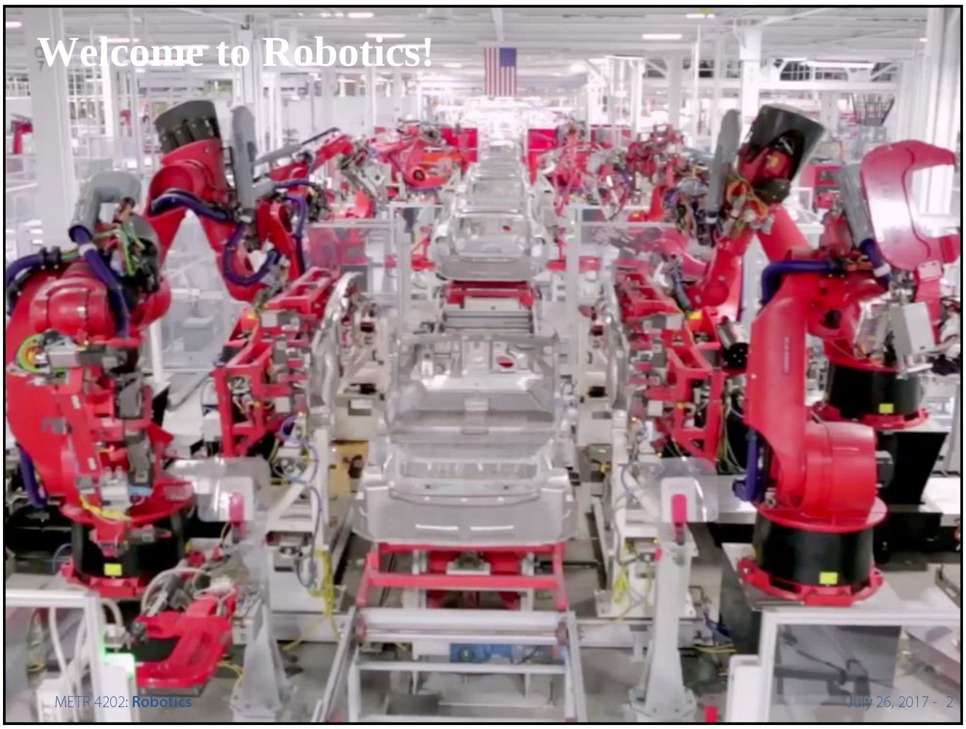
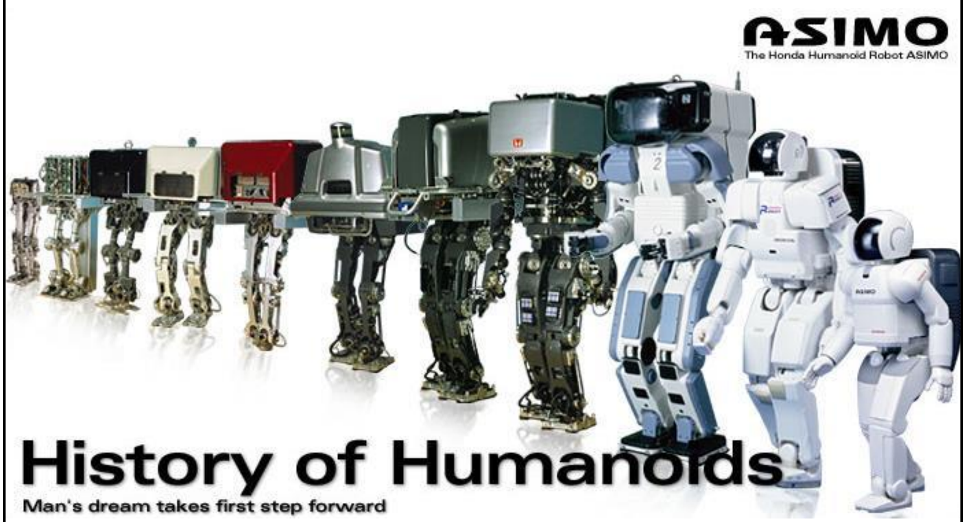
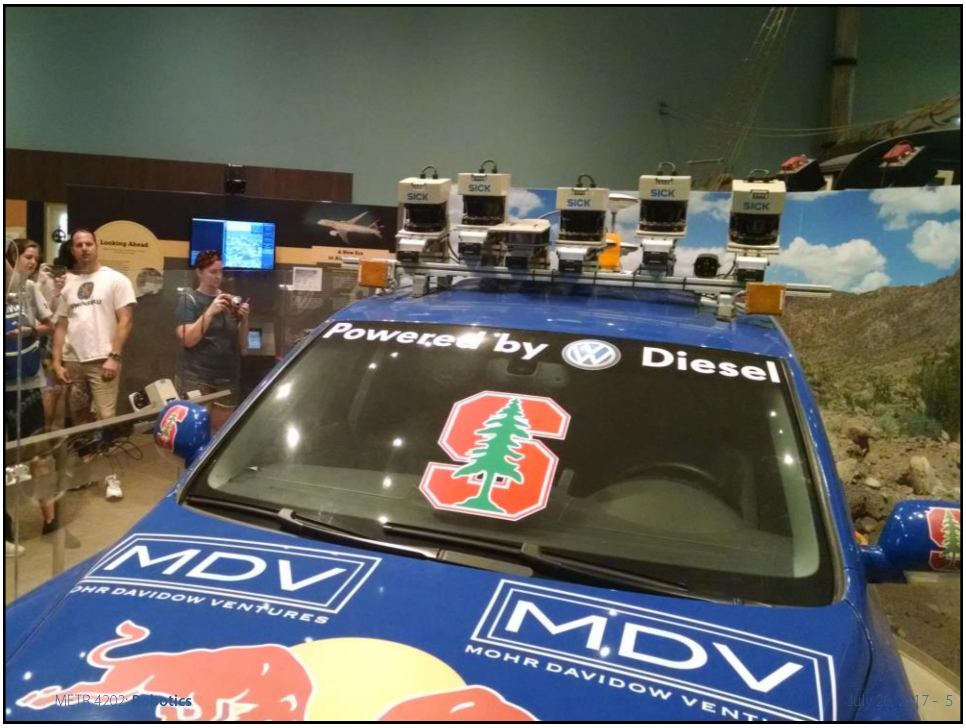
http://robotics.itee.uq.edu.au/~metr4202/ [http://**metr4202.com**]

Welcome to Robotics!




ASIMO
The Honda Humanoid Robot ASIMO
History of Humanoids
Man's dream takes first step forward


Powered by Diesel
Red Bull
MDV


Powered by Diesel
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METR 4202: Robotics
July 26, 2017 - 5


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METR 4202: Robotics
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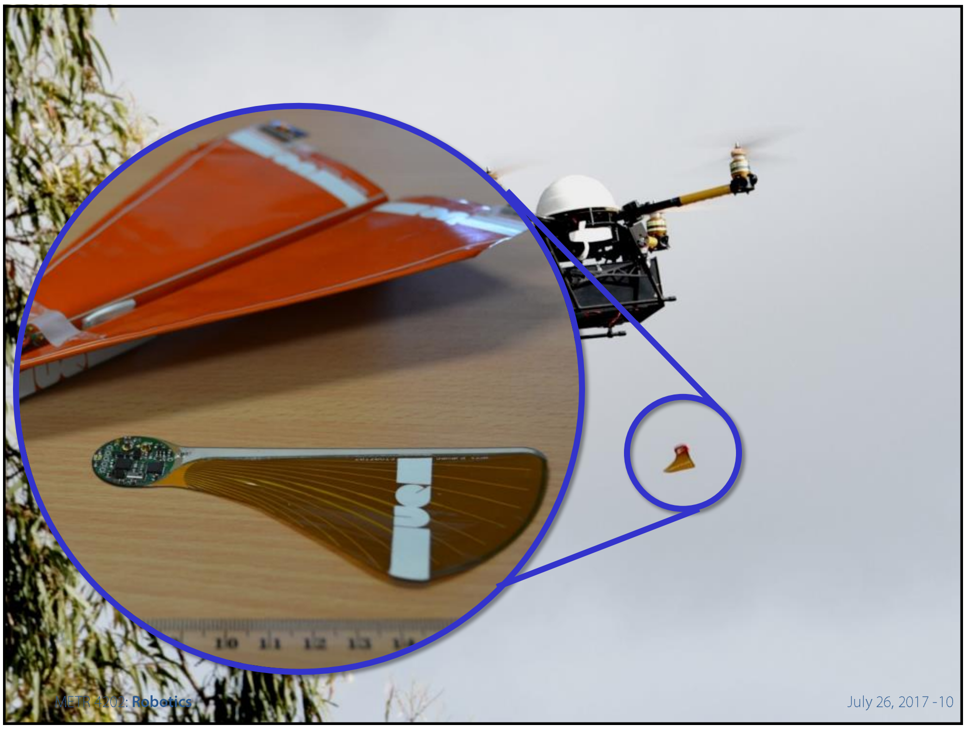
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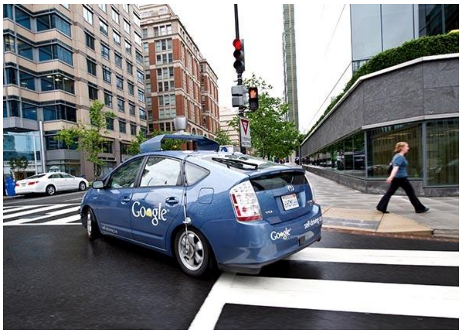
METR 4202: Robotics


Magicarms

The (DARPA Robotics) Challenge!

Cars: Software/Robots With 4 Wheels

Robotics & Automation Has Limits Too



Visual Deformable Object Analysis

So *What is a Robot* ?????

- A "Smart" Machine …
- A "General Purpose" (Adaptive) "Smart" Machine…

Plan → Sense → Control → Act

"Learning"

Robotics Definition

- Many, depends on context…

“A robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.”
(Robotics Institute of America)

It is a machine which has some ability to interact with physical objects and to be given electronic programming to do a specific task or to do a whole range of tasks or actions.
(Wikipedia)

Programmable electro-mechanical systems that adapt to identify and leverage a **structural characteristic** of the environment
(Surya)

Types of Robotics Systems

- Manipulators

- Mobile

- Adaptive

Enabling Mathematics:

- Computational Kinematics
- Operational Space

- Behaviour based “Reflexive” control rules

-Probabilistic methods

Types of Robotics Systems → Textbooks

- Manipulators

- Roth
- Craig
- S&S
- Asada & Slotine
- Tsai

- Mobile

- Corke
- Dillman
- Choset, Thrun, *et al.*
- [SLAM]

- Adaptive

- LaValle
- Thrun
- [[Model] **Predictive** Operations]

Schedule of Events

Week	Date	Lecture (W: 3:05p-4:50, 7-222)
1	26-Jul	Introduction Representing Position & Orientation & State
2	2-Aug	Robot Forward Kinematics (Frames, Transformation Matrices & Affine Transformations)
3	9-Aug	Robot Inverse Kinematics & Dynamics (Jacobeans)
4	16-Aug	*Ekka Day* (Robot Kinematics & Kinetics Review)
5	23-Aug	Robot Sensing: Perception & Linear Observers
6	30-Aug	Robot Sensing: Single View Geometry & Lines
7	6-Sep	Robot Sensing: Multiple View Geometry
8	13-Sep	Robot Sensing: Feature Detection
9	20-Sep	***Mid-Semester Exam***
	27-Sep	*Study break*
10	4-Oct	Motion Planning
11	11-Oct	Probabilistic Robotics: Localization & SLAM
12	18-Oct	Probabilistic Robotics: Planning & Control (State-Space/Shaping the Dynamic Response/LQR)
13	25-Oct	The Future of Robotics/Automation + Challenges + Course Review

Assessment

- Kinematics Problem Set (10%):
  - Proprioception
  - Arm kinematics and kinetics
- Sensing & Control Problem Set (10%):
  - Exterioception
  - Camera operation and calibration
- **Midterm Exam**
  (Individual, Open-Book -- 30%) ☺
- Robotics & Automation Systems Lab (50%):
  - All together!

Lectures

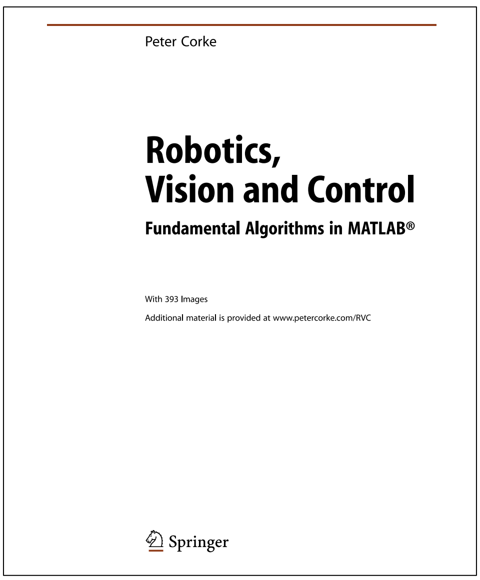
- Wednesdays from 3:05 – 4:50 pm
- Lectures will be posted to the course website **after** the lecture (so please attend)
  - Slides are like dessert – enjoy afterwards!
- Please ask questions
  (preferably about the material ☺)

Tutorials & Labs

- Labs:
  - Thursdays from 12:00 pm – 3:00 pm
    in the Axon Learning Lab (47-104)
  - Meeting Weeks 2-9 (**not this week!**)

- Tutorials:
  - Fridays 11:00 – 11:50 am
    in the Axon Learning Lab (47-104)
  - Meeting: Weeks 1-13 (day after tomorrow!)

Textbook


Peter Corke

Robotics, Vision and Control

Fundamental Algorithms in MATLAB®

With 393 Images

Additional material is provided at www.petercorke.com/RVC

Springer

Robotics, Vision and Control Fundamental Algorithms in MATLAB

By:
Peter Corke

Available online (on campus) via SpingerLink

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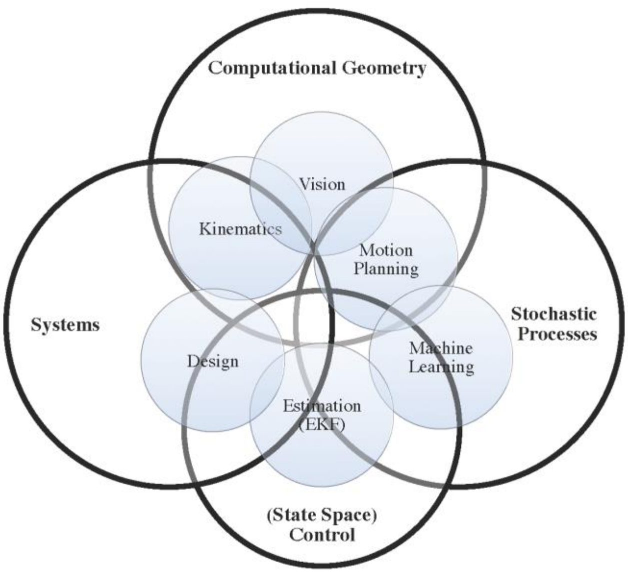
Please use **metr4202-staff** e-mail for ***all*** class matters!

Course Organization



The Point of the Course

- Introduction to terminology/semantics
- An appreciation of how to frame problems in an engineering context
- Modeling and learning to trust the model
- Ability to identify critical details from the problem (separate information from trivia)

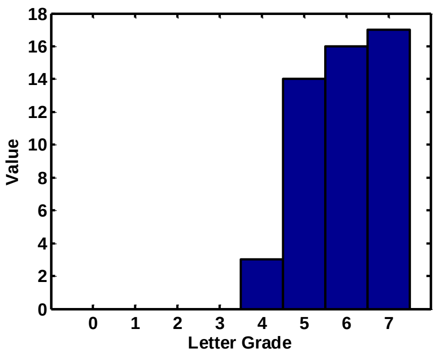
Course Objectives

1. Be familiar with sensor technologies relevant to robotic systems
2. Understand homogeneous transformations and be able to apply them to robotic systems,
3. Understand conventions used in robot kinematics and dynamics
4. Understand the dynamics of mobile robotic systems and how they are modelled
5. Understand state-space and its applications to the control of structured systems (e.g., manipulator arms)
6. Have implemented sensing and control algorithms on a practical robotic system
7. Apply a systematic approach to the design process for robotic system
8. Understand the practical application of robotic systems in to intelligent mechatronics applications (e.g., manufacturing, automobile systems and assembly systems)
9. Develop the capacity to think creatively and independently about new design problems; and,
10. Undertake independent research and analysis and to think creatively about engineering problems.

Grade Descriptors

Grade	Level	Descriptor
Fail	(<50%)	**Work not of acceptable standard**. Work may fail for any or all of the following reasons: unacceptable level of paraphrasing; irrelevance of content; presentation, grammar or structure so sloppy it cannot be understood; submitted very late without extension; not meeting the University's values with regards to academic honesty.
Pass	(50-64%)	**Work of acceptable standard**. Work meets basic requirements in terms of reading and research and demonstrates a reasonable understanding of subject matter. Able to solve relatively simple problems involving direct application of particular components of the unit of study.
Credit	(65-74%)	**Competent work**. Evidence of extensive reading and initiative in research, sound grasp of subject matter and appreciation of key issues and context. Engages critically and creatively with the question and attempts an analytical evaluation of material. Goes beyond solving of simple problems to seeing how material in different parts of the unit of study relate to each other by solving problems drawing on concepts and ideas from other parts of the unit of study.
Distinction	(75-84%)	**Work of superior standard**. Work demonstrates initiative in research, complex understanding and original analysis of subject matter and its context, both empirical and theoretical; shows critical understanding of the principles and values underlying the unit of study.
High Distinction	(85%+)	**Work of exceptional standard**. Work demonstrates initiative and ingenuity in research, pointed and critical analysis of material, thoroughness of design, and innovative interpretation of evidence. Demonstrates a comprehensive understanding of the unit of study material and its relevance in a wider context.

Previous Grade Statistics



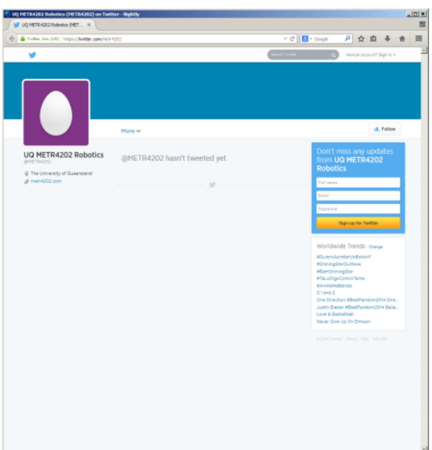
- ~ 67 % received D or HD
- Worry about **learning**, not about marks [Seriously!]
- Though a "7" might be bit more exclusive this year!

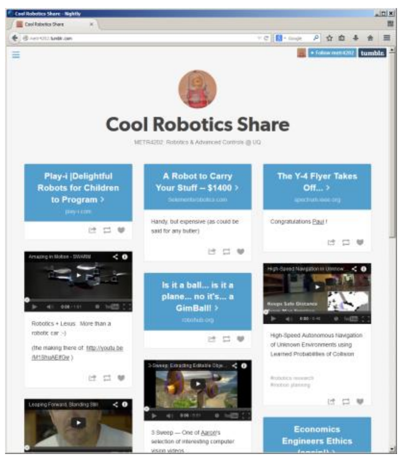
What I expect from you

- Lectures:
  - Participate - ask questions
  - Turn up (hence the attendance marks)
  - Take an interest in the material being presented
- Tutorials:
  - Work on questions before tutorials
  - Use tutorials to clarify and enhance
  - Assignments to be submitted on time

Twitter & Tumblr too!

- https://twitter.com/metr4202
- http://metr4202.tumblr.com/





What's the Magic?

Predictive Action

(i.e., Decision-Making
+ Mechatronics Design)

Robotics: Exploiting the hidden structure…

- Robot working in an "unstructured" environment

➔ Does not have to be dirty to use "field robotics" technology …

➔ Robotics is about exploiting the **structure** …

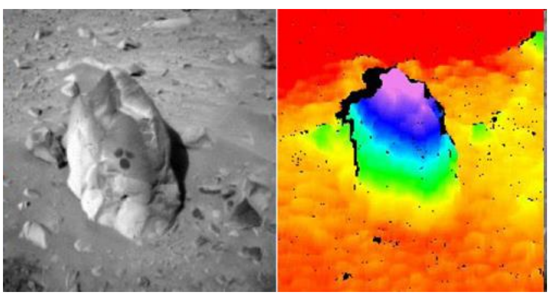
Either by:

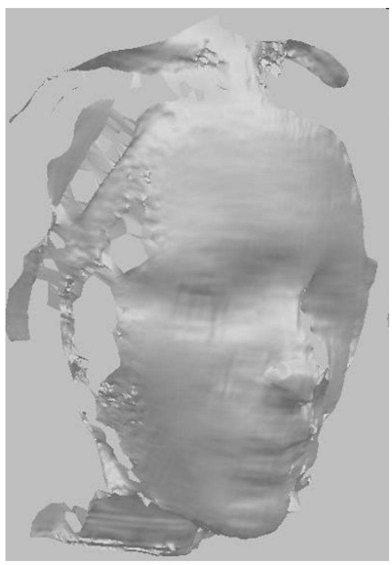
- Putting it in from the design (mechanical structure)
- "Learning" it as the system progresses (structure is the data!)

First Let's Review the Sense → Control → Act Loop!

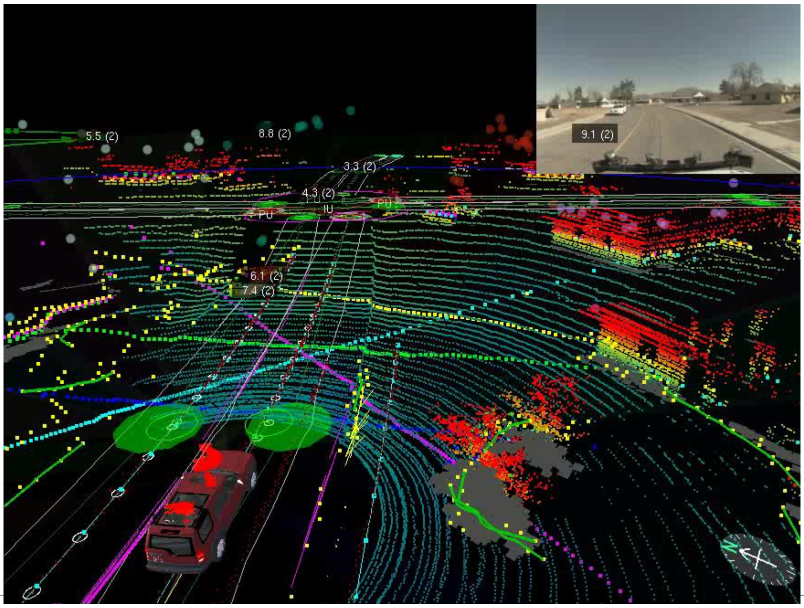
Edges, Segments, Colour, Texture

3D Stereo Vision



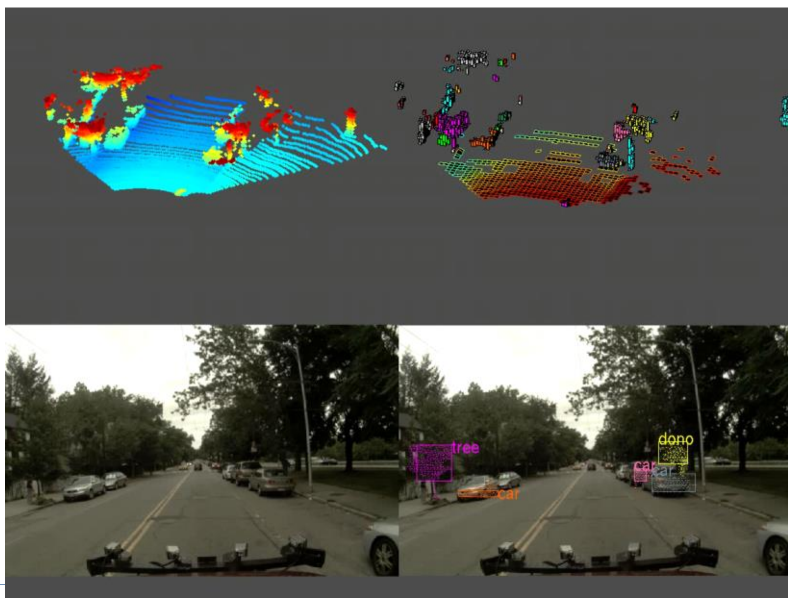


Laser Sensors



Control
(Processing)

Environment Understanding



Act(ion)!

Robot Sniper Training Robots

Extending
Our Reach…

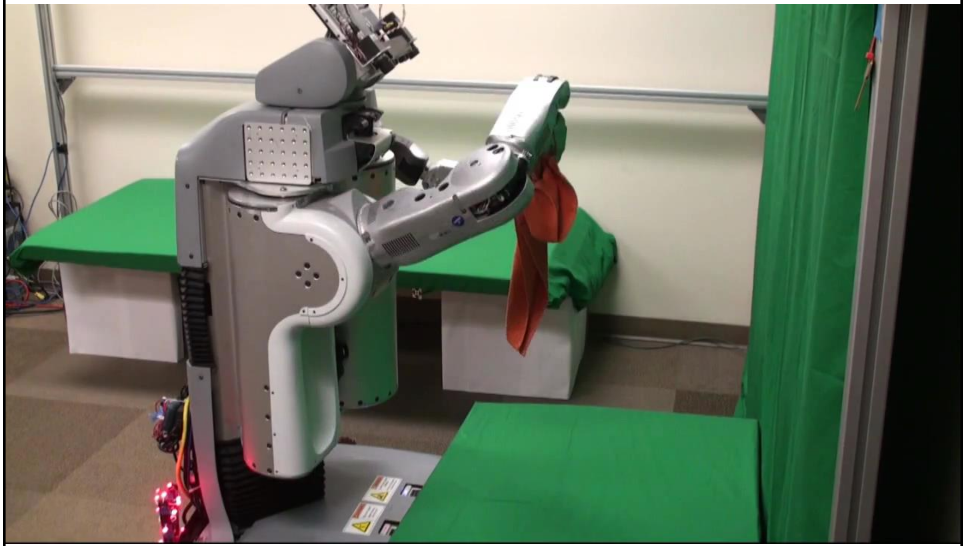
(what's hard is not what you expect…)

People and Robots?

http://www.abc.net.au/radionational/image/4560736-4x3-340x255.jpg

People & Robots: Let Each Do Its Best!

Shirt-Folding (30x speed up)…

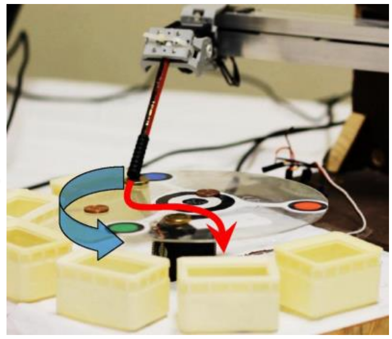


Shirt-Folding (1/3 Speed!)

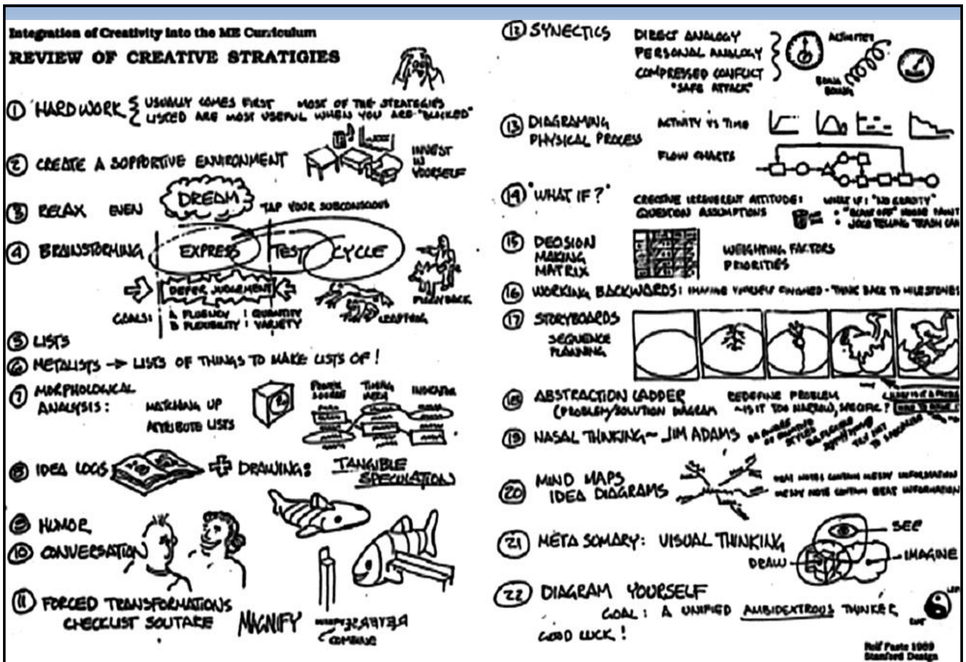
Parallel-Parking…

Parallel Parking…

The Project!
Robotics: Fundamental Building Blocks



Next Week ☺



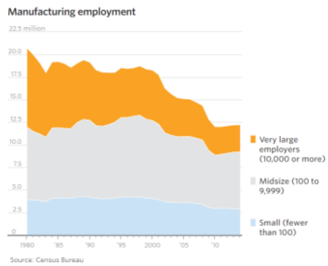
Robotics: Economics & Jobs!

The Automation
Will Take the Job ☹

- US, since 2000:
  Lost 5 million
  Manufacturing Jobs
  – ~2.4 million jobs went to low-wage workers
  – 2.6 million to “gains in efficiency” … making many traditional positions obsolete!

The Robotics
Will Bring It Back ☺

• If the robot can be anywhere, then have it locally* (and small firm)



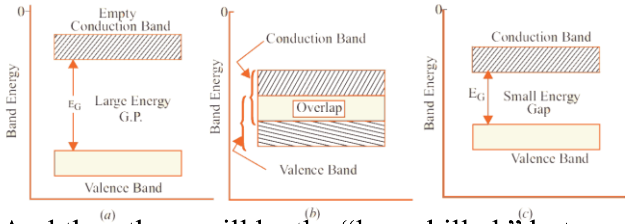
- Ex_2: ATMs help bankers

[1] https://www.bls.gov/iag/tgs/iag31-33.htm#about
[2] http://www.wsj.com/graphics/big-companies-get-bigger/
[3] http://www.economist.com/news/special-report/21707834-truth-and-myth-about-effects-openness-trade-coming-and-going
* As long as there are people “locally” to make it work ☺

Robotics: Economics & Jobs!

Prediction: Job Polarization
Automation Makes Things Glamorous!

- Or… It will make things "Quantum Mechanical"
- There will be the "glamorous" **Conduction Band**



- And then there will be the "low-skilled," but non-routine **Valence Band**

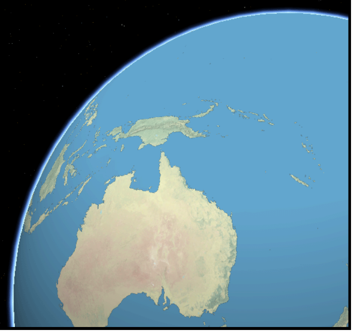
➔ "(Go) Deep or taste not the Pierian spring"

Prediction: Two-Stage Solution
Automation Makes Things Glamorous!

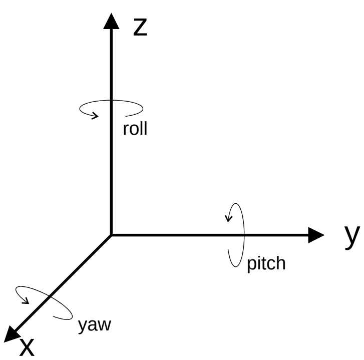
- Glamor professions (actors, sports players, etc.) are a tournament
  - Lots of people competing for a few prizes
-
- If you can get any newspaper, which one do you get?
  - NYT: 1.6M Digital Only, 13% of these are outside US

[1] Freakonomics , P. 94 ("Why Drug Dealers Live With Their Moms")
[2] https://www.nytimes.com/2017/02/02/business/media/new-york-times-q4-earnings.html?_r=1
[3] http://www.niemanlab.org/2016/12/newsonomics-the-new-york-times-is-setting-its-sights-on-10-million-digital-subscribers/

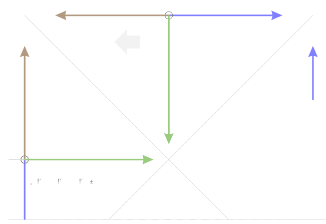
First thing about structure
→ **Space**



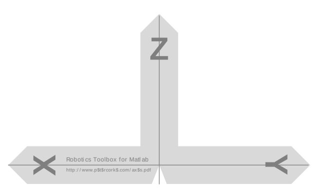
Today’s Lecture is about:
Frames & Their Mathematics



- Make one (online):
  - SpnS Template



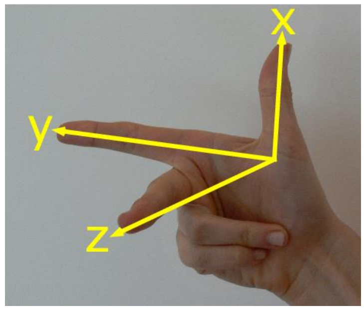
  - Peter Corke’s template



Don’t Confuse a Frame with a Point

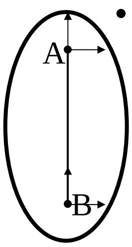
- Points
  - Position Only –
    Doesn’t Encode Orientation

- Frame
  - Encodes both position and orientation
  - Has a “handedness”

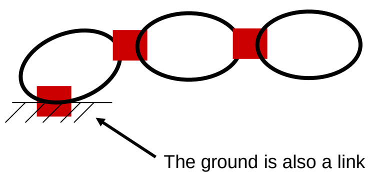


Kinematics Definition

- **<u>Kinematics</u>**: The study of motion in space (without regard to the forces which cause it)



- Assume:
  - Points with ***right-hand <u>Frames</u>***
  - *Rigid-bodies* in 3D-space (6-dof)
  - 1-dof joints: Rotary (R) or Prismatic (P) (5 constraints)

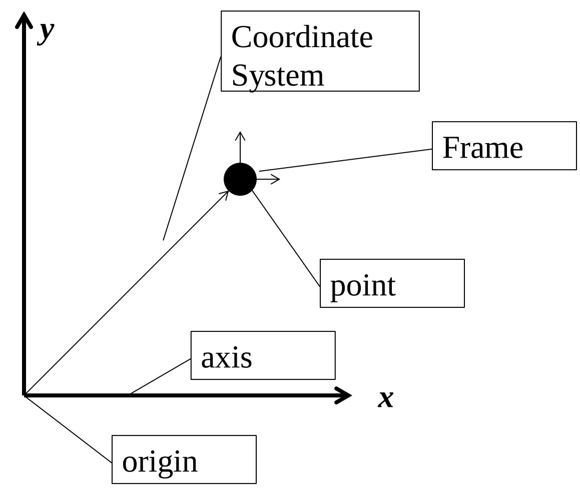


N links
M joints
→DOF = 6N-5M
→ If N=M, then DOF=N.

Kinematics

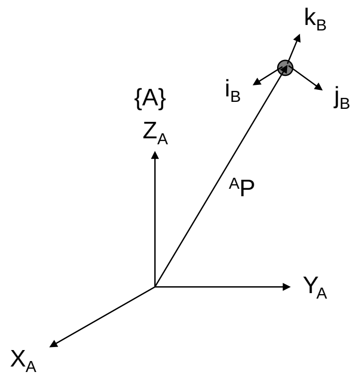
- Kinematic modelling is one of the most important analytical tools of robotics.
- Used for modelling mechanisms, actuators and sensors
- Used for on-line control and off-line programming and simulation
- In mobile robots kinematic models are used for:
  - steering (control, simulation)
  - perception (image formation)
  - sensor head and communication antenna pointing
  - world modelling (maps, object models)
  - terrain following (control feedforward)
  - gait control of legged vehicles

Basic Terminology



Coordinate System

- The position and orientation as specified only make sense with respect to some coordinate system



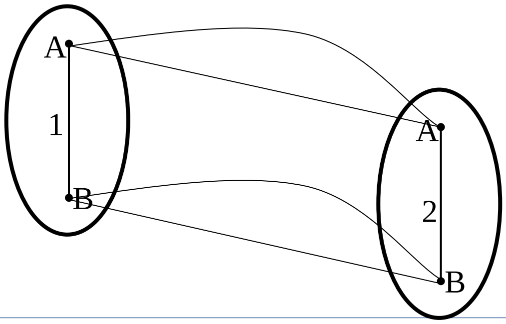
Frames of Reference

- A frame of reference defines a coordinate system relative to some point in space
- It can be specified by a position and orientation relative to other frames
- The *inertial frame* is taken to be a point that is assumed to be fixed in space

- Two types of motion:
  - Translation
  - Rotation

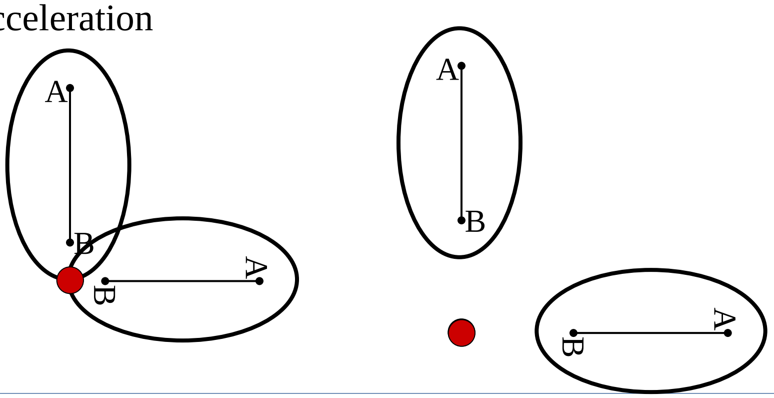
Translation

- A motion in which a straight line with in the body keeps the same direction during the
  - **Rectilinear Translation:** Along straight lines
  - **Curvilinear Translation**: Along curved lines



Rotation

- The particles forming the rigid body move in parallel planes along circles centered around the same fixed axis (called the **axis of rotation**).
- Points on the axis of rotation have zero velocity and acceleration



Rotation: Representations

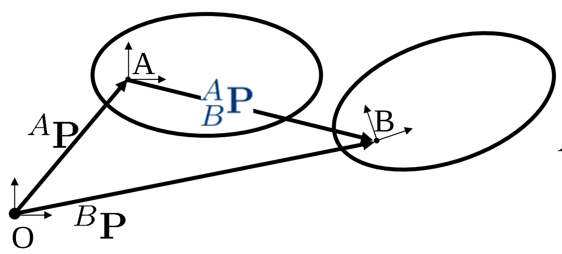
- Orientation are not “Cartesian”
  - Non-commutative
  - Multiple representations

- Some representations:
  - **Rotation Matrices**: Homegenous Coordinates
  - Euler Angles: 3-sets of rotations in sequence
  - Quaternions: a 4-paramameter representation that exploits ½ angle properties
  - Screw-vectors (from Charles Theorem) : a canonical representation, its reciprocal is a “wrench” (forces)

Position and Orientation [1]

- A **position** vectors specifies the location of a **point** in 3D (Cartesian) space

$$\mathbf{P} = \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix}$$



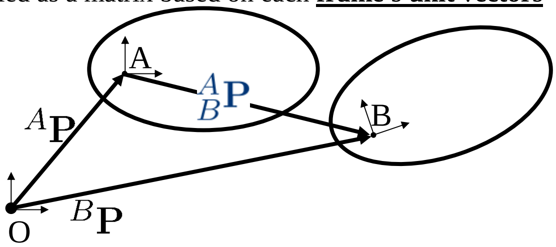
$${}^{A}\mathbf{P} + {}^{A}\mathbf{P}^{B} - {}^{B}\mathbf{P} = 0$$

$${}^{A}\mathbf{P}^{B} = {}^{A}\mathbf{P}_{B} = {}^{A}_{B}\mathbf{P} = \begin{bmatrix} {}^{B}p_x \\ {}^{B}p_y \\ {}^{B}p_z \end{bmatrix} - \begin{bmatrix} {}^{A}p_x \\ {}^{A}p_y \\ {}^{A}p_z \end{bmatrix}$$

- BUT we **also** concerned with its orientation in 3D space.
  This is specified as a matrix based on each **frame’s unit vectors**

Position and Orientation [2]

- Orientation in 3D space:
  This is specified as a matrix based on each **frame's unit vectors**



- Describes {B} relative to {A}
  → The orientation of frame {B} relative to coordinate frame {A}
- Written "from {A} to {B}" or "given {A} getting to {B}"

$$^{A}\mathbf{R}_{B} = {}^{A}_{B}\mathbf{R} = \left[\begin{array}{ccc} ^{A}\hat{\imath}_{B} & ^{A}\hat{\jmath}_{B} & ^{A}\hat{k}_{B} \end{array} \right]$$

- **Columns** are **{B} written in {A}**

Position and Orientation [3]

- The rotations can be analysed based on the unit components …
- That is: the components of the orientation matrix are the unit vectors projected **onto** the unit directions of the reference frame

$$^{A}_{B}\mathbf{R} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}$$

$$\begin{array}{c|c} ^{A}_{B}R & \begin{array}{ccc} (b_x)\,\hat{\imath}_B & (b_y)\,\hat{\jmath}_B & (b_z)\,\hat{k}_B \end{array} \\ \hline \begin{array}{c} (a_x)\,\hat{\imath}_A \\ (a_y)\,\hat{\jmath}_A \\ (a_z)\,\hat{k}_A \end{array} & \begin{bmatrix} \hat{\imath}_B \cdot \hat{\imath}_A & \hat{\jmath}_B \cdot \hat{\imath}_A & \hat{k}_B \cdot \hat{\imath}_A \\ \hat{\imath}_B \cdot \hat{\jmath}_A & \hat{\jmath}_B \cdot \hat{\jmath}_A & \hat{k}_B \cdot \hat{\jmath}_A \\ \hat{\imath}_B \cdot \hat{k}_A & \hat{\jmath}_B \cdot \hat{k}_A & \hat{k}_B \cdot \hat{k}_A \end{bmatrix} \end{array}$$

Position and Orientation [4]

- Rotation is orthonormal

$$\begin{array}{c|c} {}^{A}_{B}R & (b_x)\,\hat{\imath}_B \quad (b_y)\,\hat{\jmath}_B \quad (b_z)\,\hat{k}_B \\ \hline \begin{array}{c}(a_x)\,\hat{\imath}_A\\(a_y)\,\hat{\jmath}_A\\(a_z)\,\hat{k}_A\end{array} & \begin{bmatrix} \hat{\imath}_B\cdot\hat{\imath}_A & \hat{\jmath}_B\cdot\hat{\imath}_A & \hat{k}_B\cdot\hat{\imath}_A \\ \hat{\imath}_B\cdot\hat{\jmath}_A & \hat{\jmath}_B\cdot\hat{\jmath}_A & \hat{k}_B\cdot\hat{\jmath}_A \\ \hat{\imath}_B\cdot\hat{k}_A & \hat{\jmath}_B\cdot\hat{k}_A & \hat{k}_B\cdot\hat{k}_A \end{bmatrix} \end{array}$$

- The of a rotation matrix inverse = the transpose

$$\mathbf{R}\cdot\mathbf{R}^T = 1$$

→ thus, the ***rows*** are **{A} written in {B}**

$${}^{B}_{A}\mathbf{R} = {}^{A}_{B}\mathbf{R}^T = {}^{A}_{B}\mathbf{R}^{-1}$$

Position and Orientation [5]: A note on orientations

- Orientations, as defined earlier, are represented by three orthonormal vectors
- Only three of these values are unique and we often wish to define a particular rotation using three values (it's easier than specifying 9 orthonormal values)
- There isn't a unique method of specifying the angles that define these transformations

Position and Orientation [7]

- Shortcut Notation:

$$\cos(\theta_a) = c\theta_a = \mathbf{c_a}$$
$$\sin(\theta_a) = s\theta_a = \mathbf{s_a}$$

$$\cos(\theta_a + \theta_b) = \mathbf{c_{ab}}$$

$$\therefore \mathbf{s_{ab}} = \boxed{\quad ?}$$

Position and Orientation [8]

- Rotation Formula about the 3 Principal Axes by θ

X: $$\mathbf{R}_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\theta) & -\sin(\theta) \\ 0 & \sin(\theta) & \cos(\theta) \end{bmatrix}$$

Y: $$\mathbf{R}_y = \begin{bmatrix} \cos(\theta) & 0 & \sin(\theta) \\ 0 & 1 & 0 \\ -\sin(\theta) & 0 & \cos(\theta) \end{bmatrix}$$

Z: $$\mathbf{R}_z = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0 \\ \sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Summary

- An outline of the course structure – details are in the Unit of Study Outline
- Considered and presented a basic definition of a mechatronic system
- A look at the courses which will fulfil the requirements for a Mechatronic Engineering Degree
- Some examples of common mechatronic systems

∴ Let's Be "Teleremote Surgeons!"