Introduction to Robotics

METR 4202: Advanced Control & **Robotics**

Dr Surya Singh -- Lecture # 1

July 29, 2015

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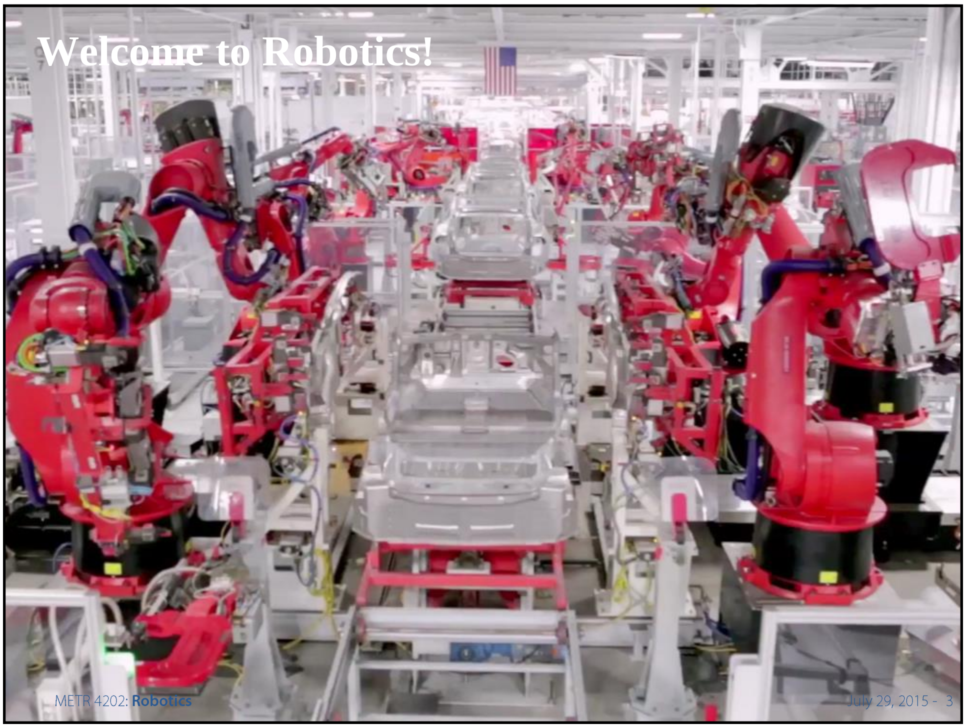
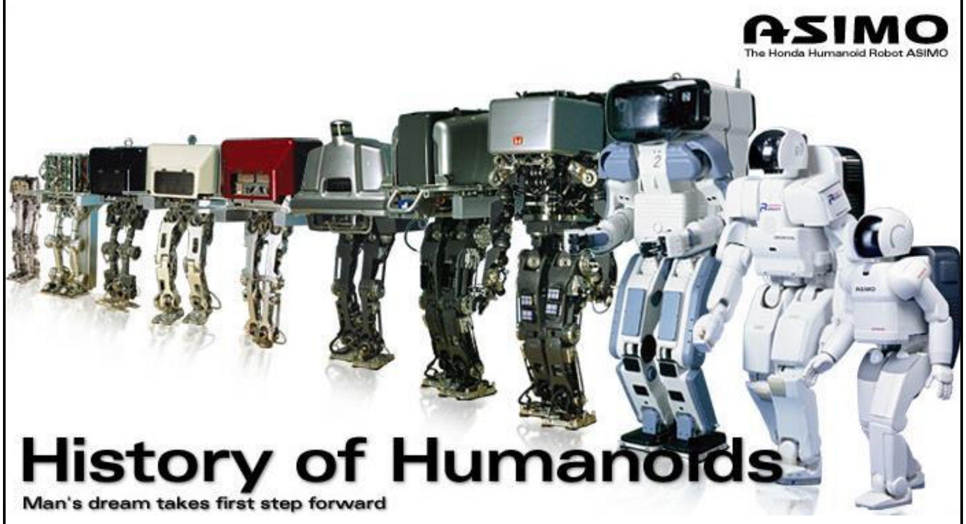
http://robotics.itee.uq.edu.au/~metr4202/

[http://**metr4202.com**]

Welcome to Robotics!

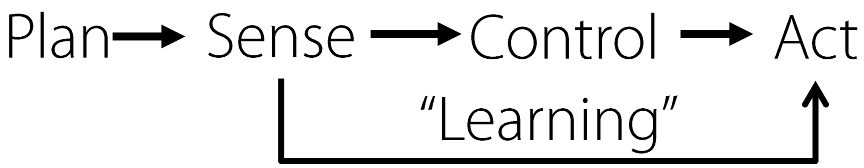



ASIMO
The Honda Humanoid Robot ASIMO
History of Humanoids
Man's dream takes first step forward


Powered by Diesel
Red Bull
MDV

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

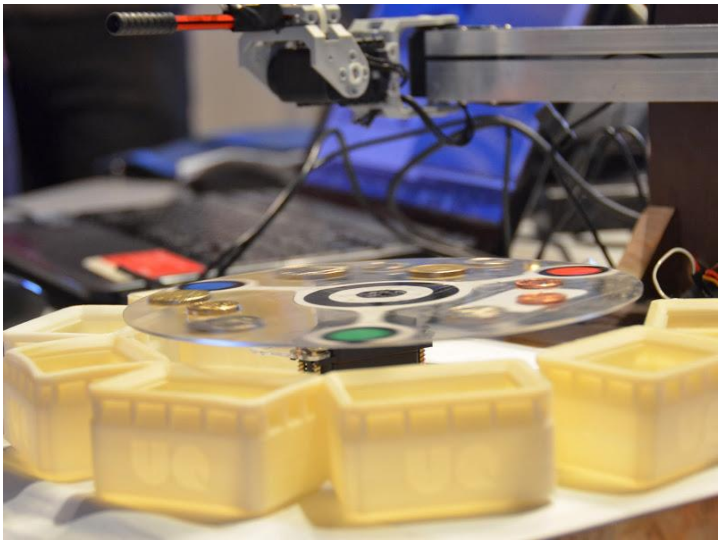
  - Corke
  - Dillman
  - Choset, Thrun, *et al.*
  - [SLAM]

- Adaptive

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

Magicarms

Change. The Future!



Win. The (DARPA Robotics) Challenge!

Schedule of Events

Week	Date	Lecture (W: 12:05-1:50, 50-N201)
1	**29-Jul**	**Introduction**
2	5-Aug	Representing Position & Orientation & State (Frames, Transformation Matrices & Affine Transformations)
3	12-Aug	Robot Kinematics (& Ekka Day)
4	19-Aug	Robot Dynamics & Control
5	26-Aug	Robot Motion
6	2-Sep	Robot Sensing: Perception & Multiple View Geometry
7	9-Sep	Robot Sensing: Features & Detection using Computer Vision
8	16-Sep	Navigation & Localization
9	23-Sep	Localization & **Quiz**
	30-Sep	*Study break*
10	7-Oct	State-Space Modelling
11	14-Oct	Motion Planning + Control
12	21-Oct	Shaping the Dynamic Response
13	28-Oct	Linear Observers & LQR + Course Review

Assessment

- Kinematics Lab (12.5%):
  - Proprioception
  - Arm design and operation (with Lego)
- Sensing & Control Lab (25%):
  - Exteriception
  - Camera operation and calibration (with a Kinect)
- Advanced Controls & Robotics Systems Lab (50%):
  - All together!
- **Quiz** (Open-Notes/closed everything else! -- 12.5%) ☺

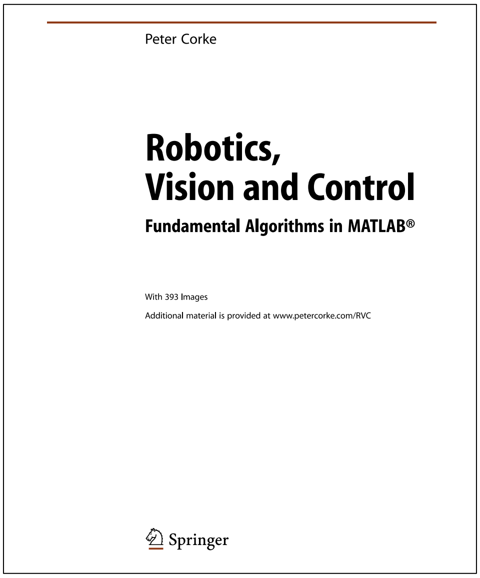
Lectures

- Wednesdays from 12:05 – 1:50 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 11:00 am – 1:00 pm
    in the Axon Learning Lab (47-104)
  - Meeting Weeks 2-9 (**<u>not this week</u>!**)
- Tutorials:
  - Fridays 10:00 – 10:50 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

E-mail & website

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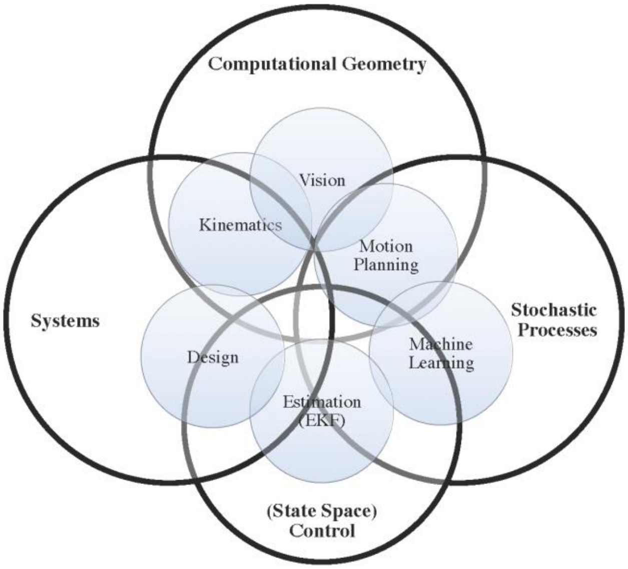
Please use **metr4202** e-mail for class matters!

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)

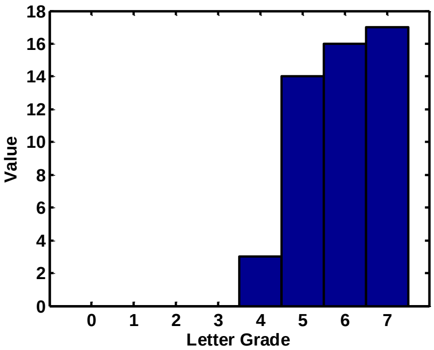
Course Objectives

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.

Last Year's Grade Statistics



- ~ 67 % received D or HD
- Worry about **learning**, not about marks [Seriously!]

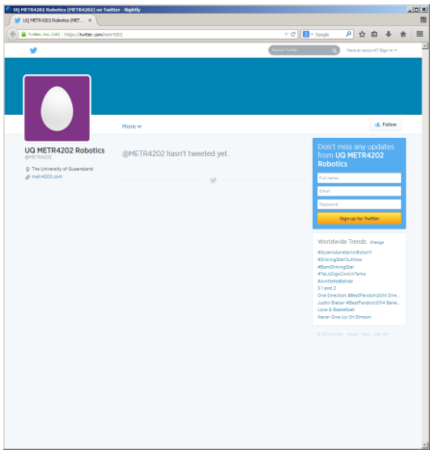
- Though a "7" might be bit more exclusive this year!

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/



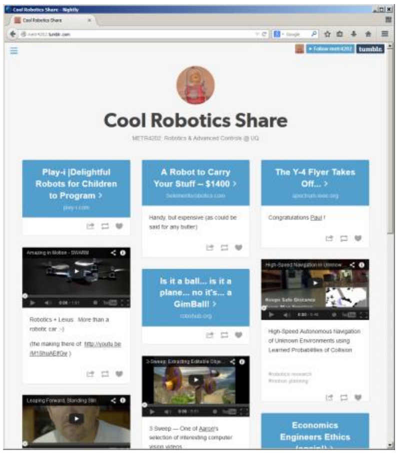
UQ METR4202 Robotics

The University of Queensland

metr4202.com

@METR4202 hasn't tweeted yet.

Don't miss any updates from **UQ METR4202 Robotics**



Cool Robotics Share

METR4202 Robotics & Advanced Controls @ UQ

Play-i |Delightful Robots for Children to Program

A Robot to Carry Your Stuff – $1400

Handy, but expensive (as could be said for any butler)

The Y-4 Flyer Takes Off...

Congratulations Paul !

Robotics + Lexus More than a robotic car :-)

Is it a ball... is it a plane... no it's... a GimBall!

High-Speed Autonomous Navigation of Unknown Environments using Learned Probabilities of Collision

3 Sweep — One of Aaron's selection of interesting computer vision videos

Economics Engineers Ethics

What’s the Magic?

Structure!

(And Some Clever 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:

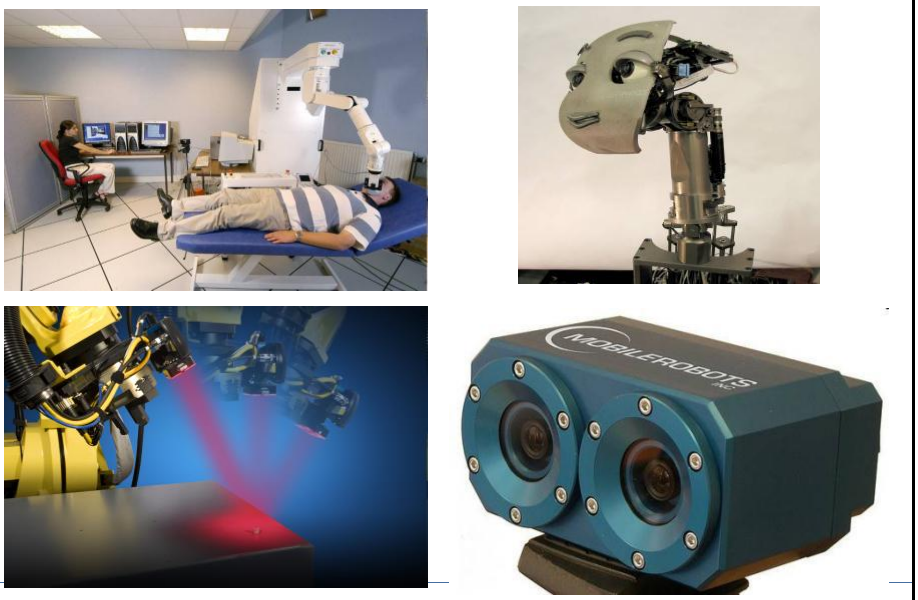
- Putting it in from the design (mechanical structure)
- “Learning” it as the system progresses (structure is the data!)

First Let’s Review the

Sense → Control → Act Loop!

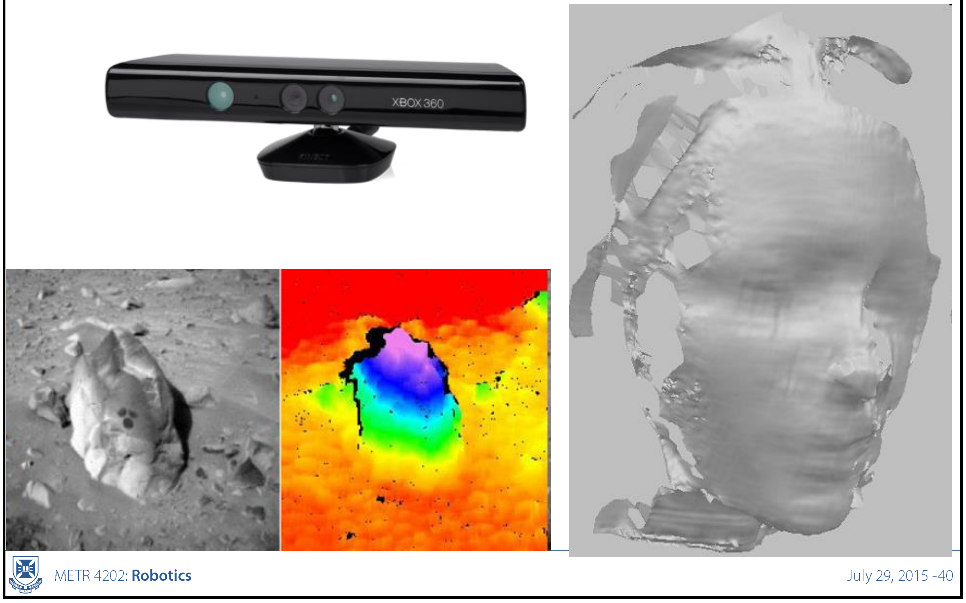
Sensing

Perception: Vision

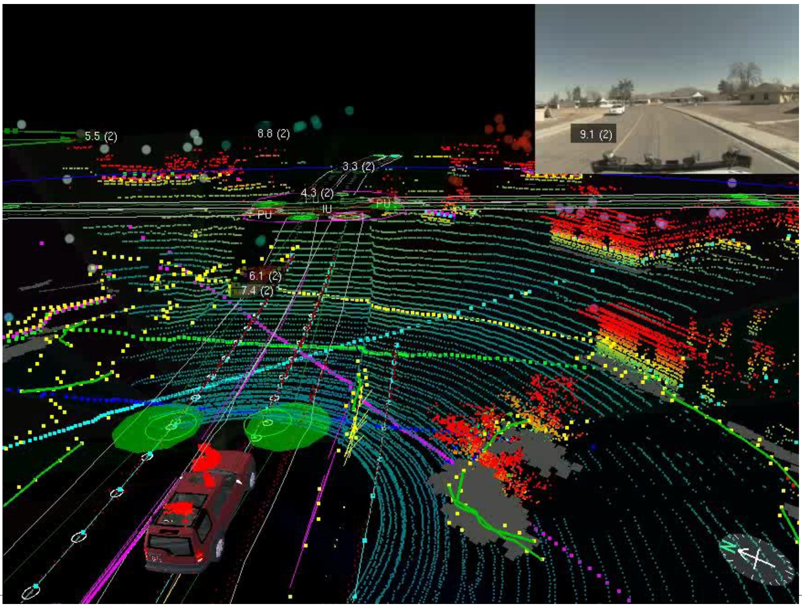


Edges, Segments, Colour, Texture

3D Stereo Vision

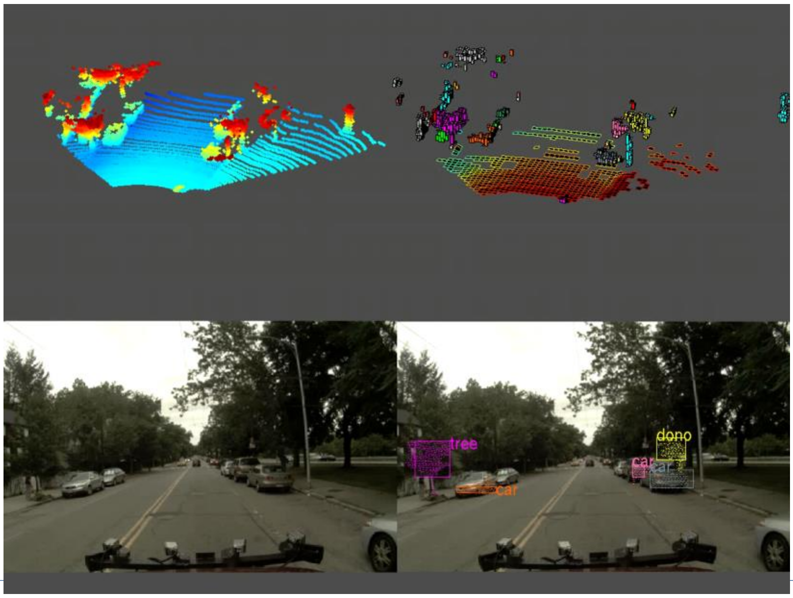


Laser Sensors



Control (Processing) …

Environment Understanding



Honda Asimov Humanoid

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Dynamic Locomotion & Balance …

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Act(ion)

Robot Sniper Training Robots

Extending Our Reach…

(what's hard is not what you expect…)

Throwing and Catching

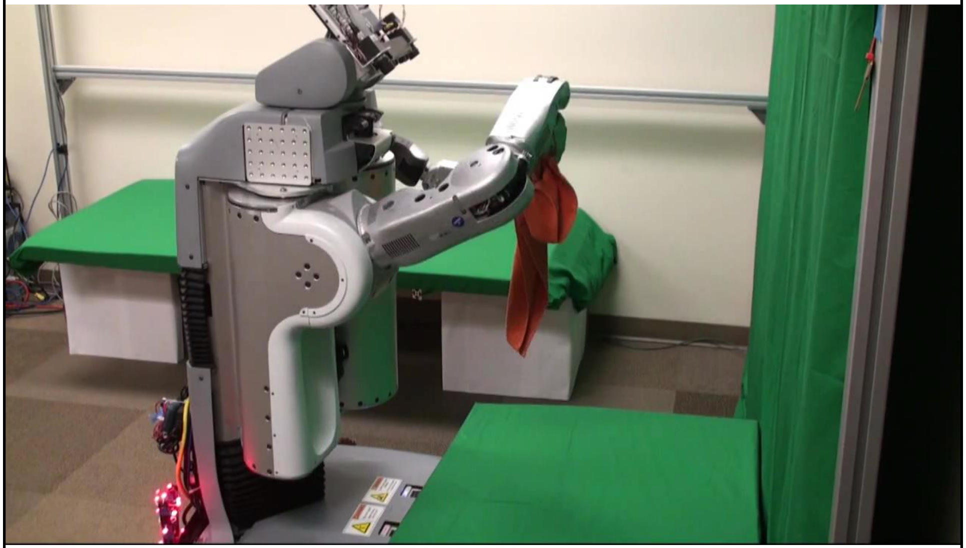
Making Iced Tea

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!)

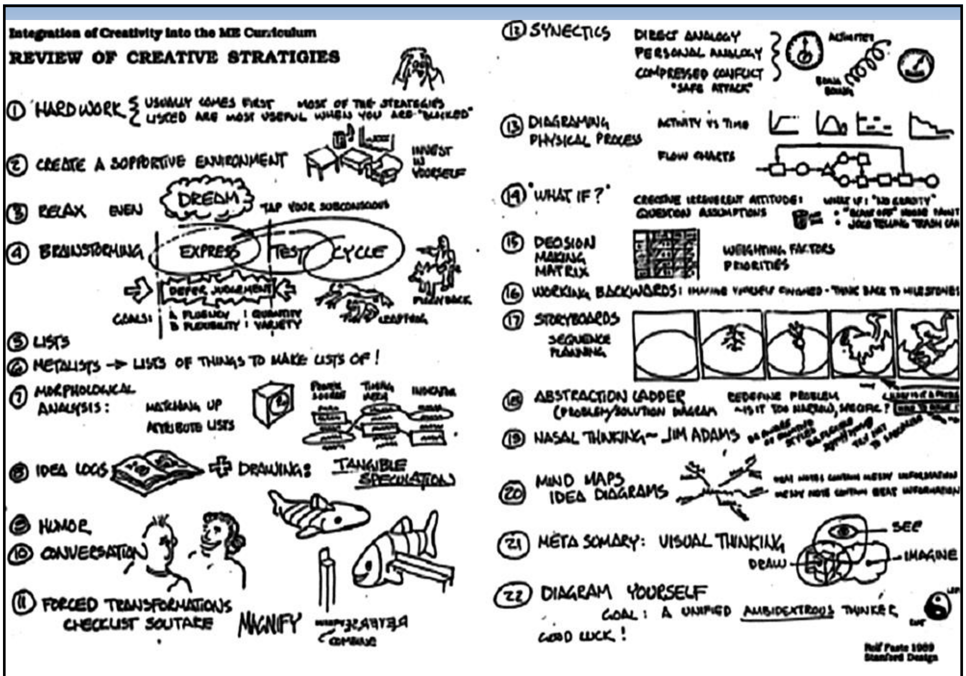
Parallel-Parking…

Parallel Parking…

The Project!

"Handy Robotics"

Next Week ☺



Integration of Creativity into the ME Curriculum

REVIEW OF CREATIVE STRATIGIES

① HARD WORK { USUALLY COMES FIRST MOST OF THE STRATEGIES LISTED ARE MOST USEFUL WHEN YOU ARE "BLOCKED"

② CREATE A SUPPORTIVE ENVIRONMENT INVEST IN YOURSELF

③ RELAX EVEN DREAM TAP YOUR SUBCONSCIOUS

④ BRAINSTORMING EXPRESS TEST CYCLE

DEFER JUDGEMENT PIGGYBACK LEAPFROG

GOALS: A FLUENCY | QUANTITY
B FLEXIBILITY | VARIETY

⑤ LISTS

⑥ METALISTS → LISTS OF THINGS TO MAKE LISTS OF !

⑦ MORPHOLOGICAL ANALYSIS: MATCHING UP ATTRIBUTE LISTS

⑧ IDEA LOGS + DRAWING: TANGIBLE SPECULATION

⑨ HUMOR

⑩ CONVERSATION

⑪ FORCED TRANSFORMATIONS CHECKLIST SOLITAIRE MAGNIFY REVERSE COMBINE

⑫ SYNECTICS DIRECT ANALOGY PERSONAL ANALOGY COMPRESSED CONFLICT "SAFE ATTACK"

⑬ DIAGRAMING PHYSICAL PROCESS ACTIVITY VS TIME FLOW CHARTS

⑭ "WHAT IF ?" CREATIVE IRREVERENT ATTITUDE: QUESTION ASSUMPTIONS

⑮ DECISION MAKING MATRIX WEIGHTING FACTORS PRIORITIES

⑯ WORKING BACKWARDS: IMAGINE YOURSELF FINISHED - THINK BACK TO MILESTONES

⑰ STORYBOARDS SEQUENCE PLANNING

⑱ ABSTRACTION LADDER (PROBLEM/SOLUTION DIAGRAM REDEFINE PROBLEM ~IS IT TOO NARROW, SPECIFIC ?

⑲ NASAL THINKING ~ JIM ADAMS

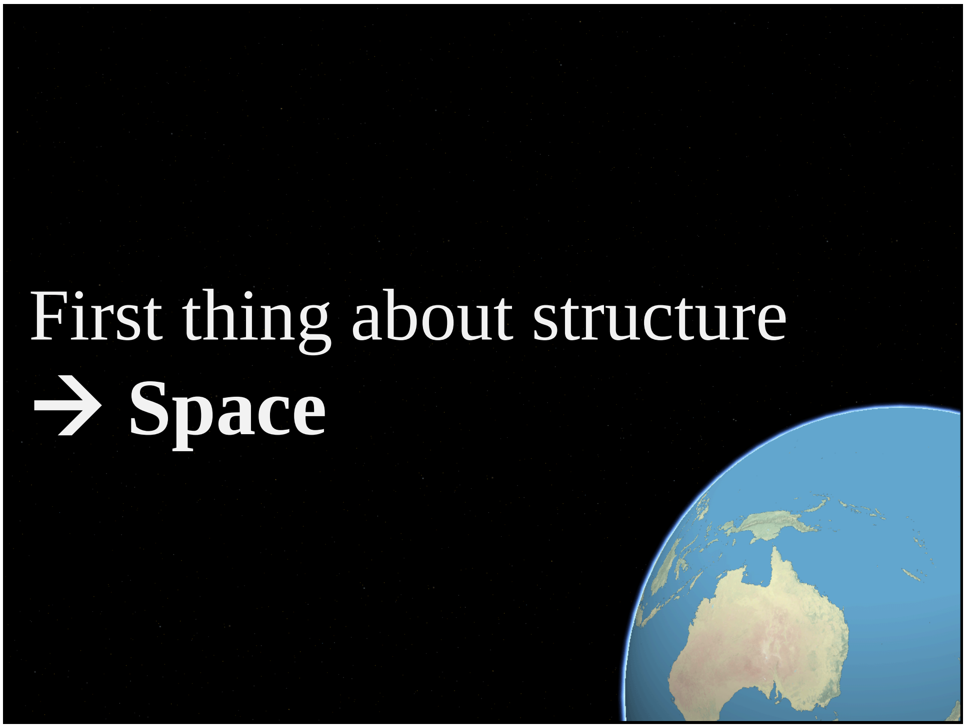
⑳ MIND MAPS IDEA DIAGRAMS NEAT NOTES CONTAIN MESSY INFORMATION MESSY NOTE CONTAIN NEAT INFORMATION

㉑ META SUMMARY: VISUAL THINKING SEE IMAGINE DRAW

㉒ DIAGRAM YOURSELF GOAL: A UNIFIED AMBIDEXTROUS THINKER

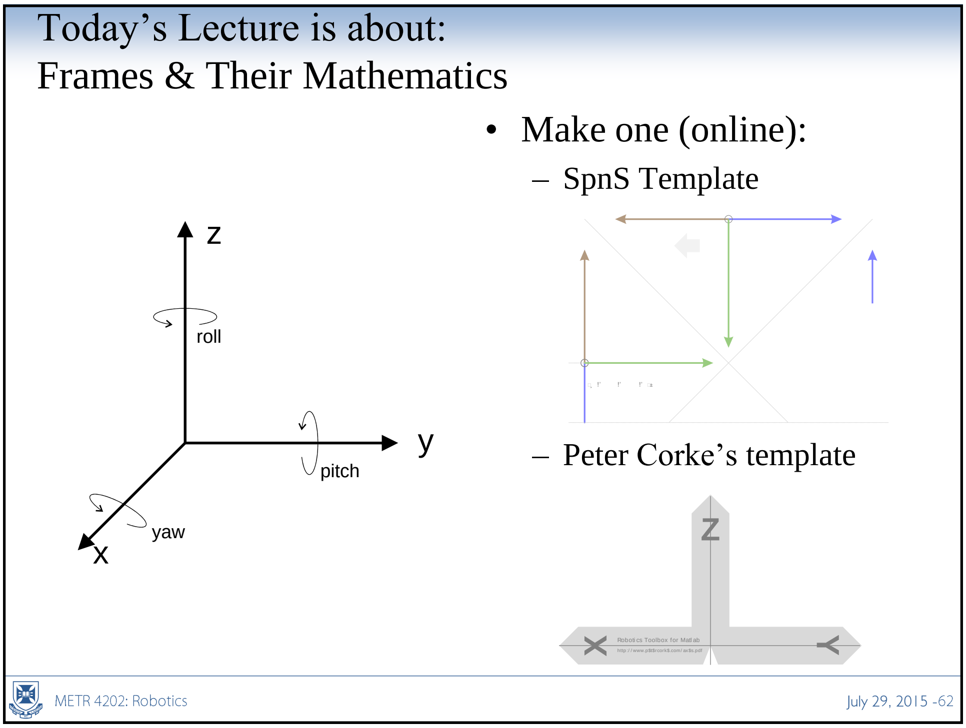
GOOD LUCK !

Rolf Faste 1989 Stanford Design



First thing about structure

→ **Space**



Today’s Lecture is about:
Frames & Their Mathematics

- Make one (online):
  - SpnS Template
  - Peter Corke’s template

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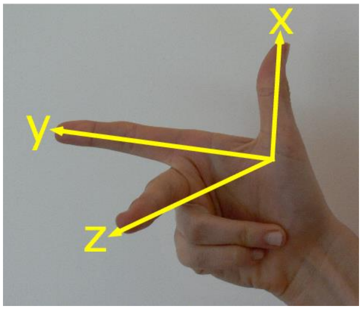
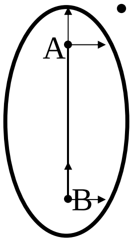
Don’t Confuse a Frame with a Point

- Points
  - Position Only –
    Doesn’t Encode Orientation
- Frame
  - Encodes both position and orientation
  - Has a “handedness”

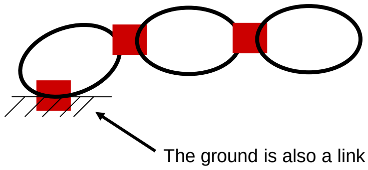


Kinematics Definition

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



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

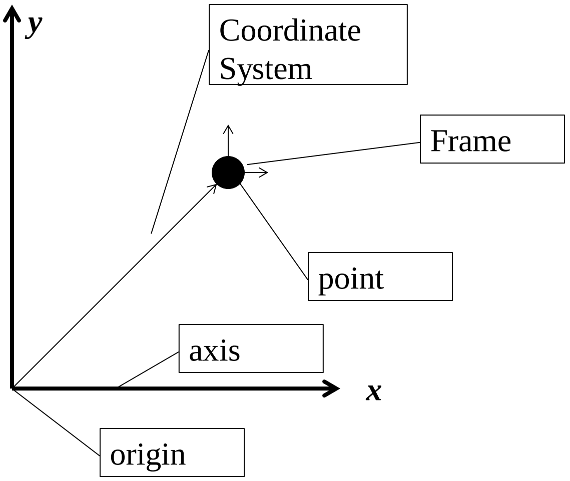


N links
M joints
→DOF = 6N-5M
➔ If N=M, then DOF=N.

Kinematics

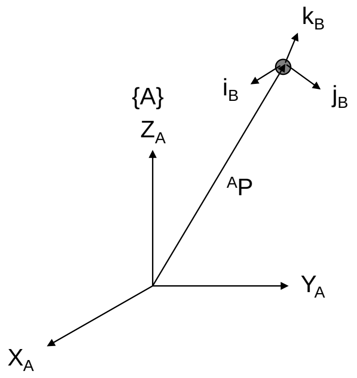
- Kinematic modelling is one of the most important analytical tools of robotics.
- Used for modelling mechanisms, actuators and sensors
- Used for on-line control and off-line programming and simulation
- In mobile robots kinematic models are used for:
  - steering (control, simulation)
  - perception (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



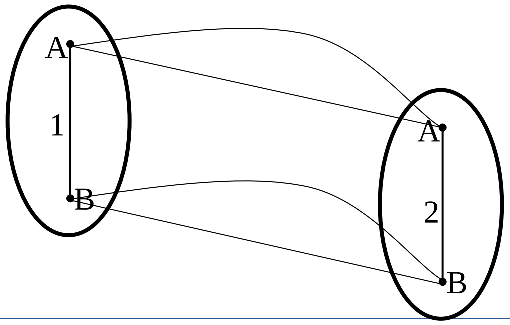
Frames of Reference

- 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

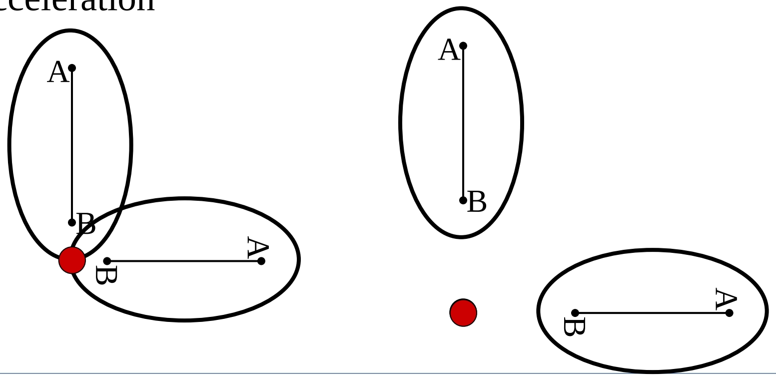
Translation

- 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



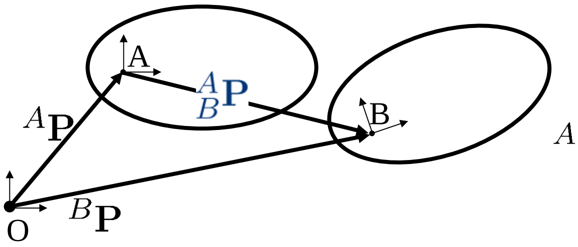
Rotation: Representations

- 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



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

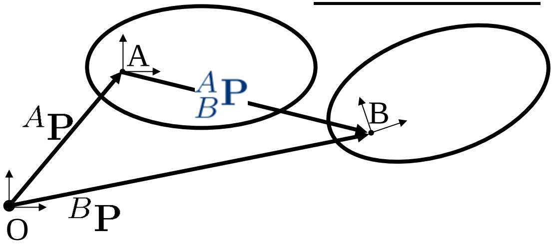
$$ {}^{A}\mathbf{P} + {}^{A}\mathbf{P}^{B} - {}^{B}\mathbf{P} = 0$$

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

- 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

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

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

Position and Orientation [4]

- Rotation is orthonormal

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

- 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:

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

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

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

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