Introduction to Dynamic System Modelling

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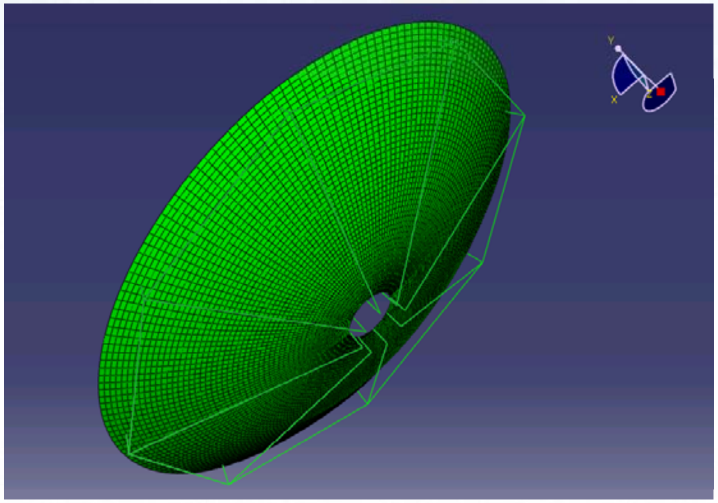
The Lecture Contains

- Introduces a few Controlled Dynamical Systems
- Modelling of a Dynamical System
- Presents two Dynamic Systems for Mathematical Modeling namely:
  - A Cruise Control System
  - A Disk Reading System

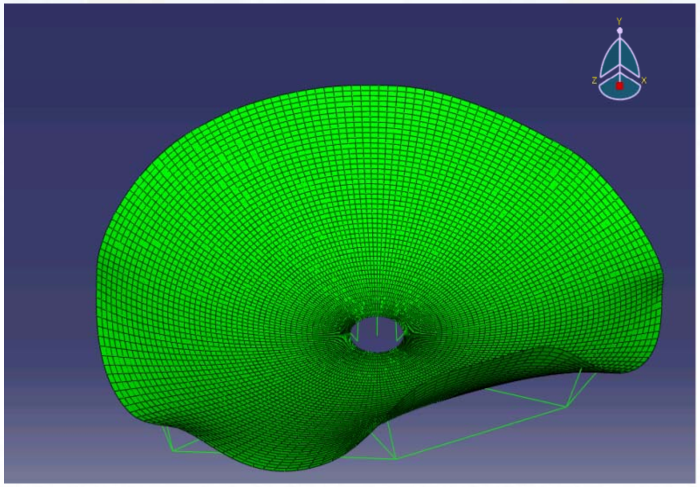
Course Introduction

- **Electro-mechanical systems are ubiquitous today. Starting from an Intelligent Washing Machine that determines washing span of garments on it's own to Rockets and Un-manned Vehicles that determines it's course of flight autonomously – our world is full of such autonomous dynamic systems today.**
- **Due to the mind boggling variety of such examples that we come across – a systems approach is highly needed to understand the nature of such systems and predict dynamic response.**
- **In order to design and develop an autonomous system, you need to have knowledge of two fundamental subjects – dynamical systems and feedback control. While, the first helps you in terms of understanding the response of the system under various mechanical and electrical inputs; the knowledge of feedback control helps you to develop autonomous systems that can follow a set of desired commands or generate a desired response or output.**
- **In this lecture, I will give you the glimpses of an array of applications in which we have applied this concept. This will help you to understand where you can possibly apply the knowledge that you will acquire in this field**

EXAMPLE 1: Next Generation: Controllable Antenna



Antenna with Muscle Wire

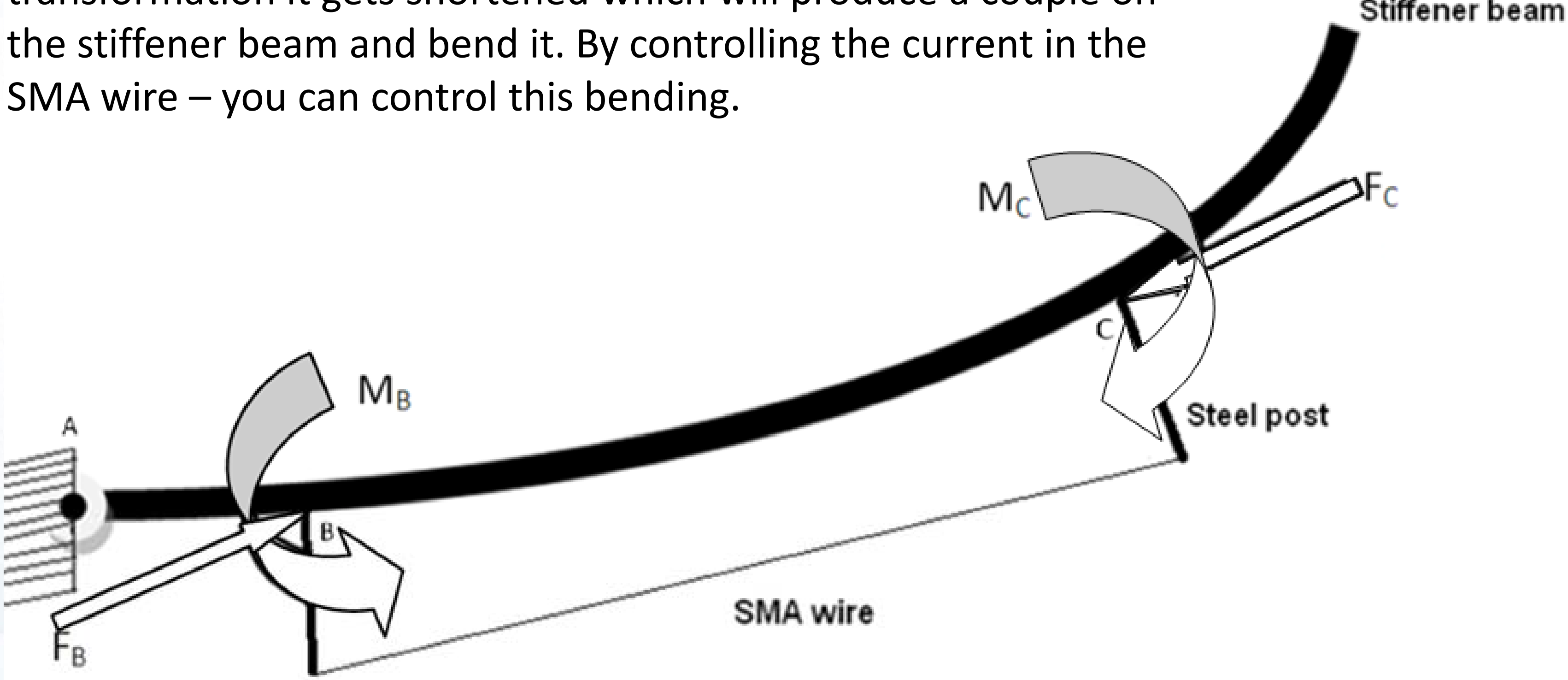


Deformed Antenna after triggering the Muscle Wires

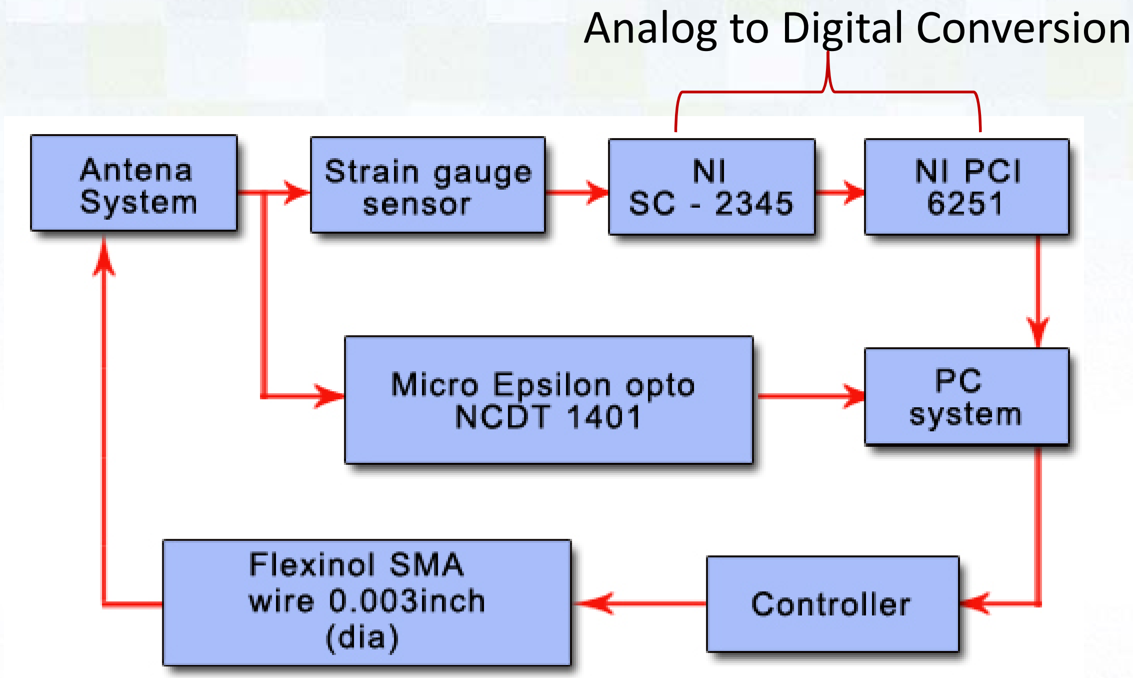
Shape of an antenna could be controlled by controlling the tension in the "muscle wires". Muscle wires made of Shape Memory Alloy (SMA) gets shortened if heated by electricity. In this process, an wire of diameter 350 micro-meter could generate force up to 10N. Using this technology, one can control the transmission pattern from an antenna

A Beam Deformation by SMA Wire

Note: As we pass current into the SMA wire, due to phase transformation it gets shortened which will produce a couple on the stiffener beam and bend it. By controlling the current in the SMA wire – you can control this bending.

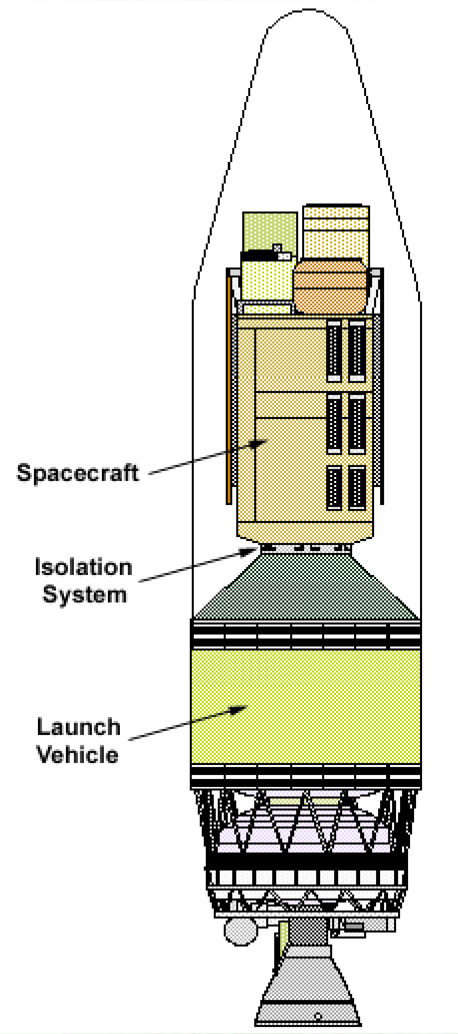


Schematic of the Controllable Antenna System

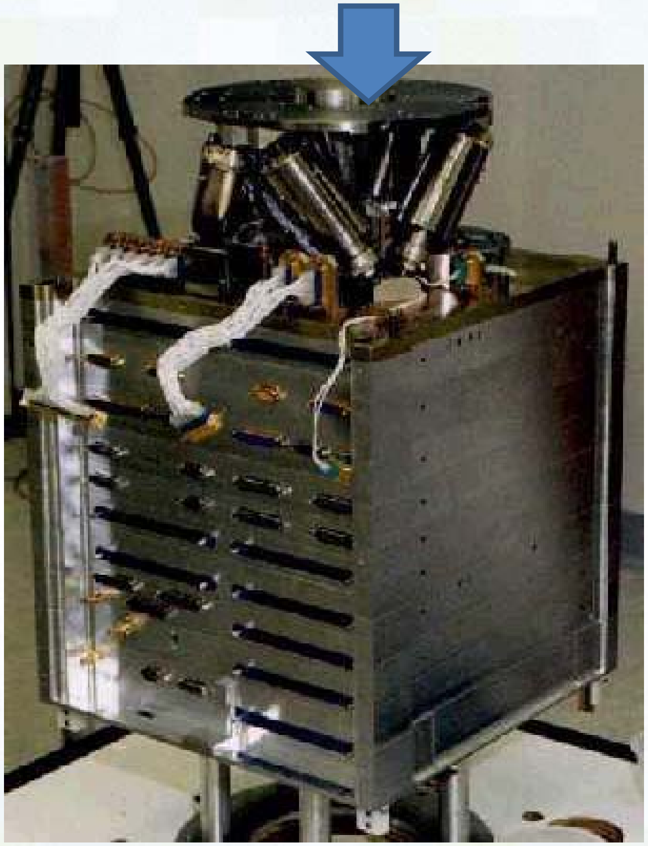


Note: In this system there are two sensors: (a) Strain Gauge Sensor (used for sensing the strain which can be converted to deflection and (b) Laser Displacement Sensor (Opto NCDT); the muscle wires are Flexinol SMA, which can be classified as actuators.

EXAMPLE 2: Satellite Ultra quiet Isolation Technology Experiment (SUITE)

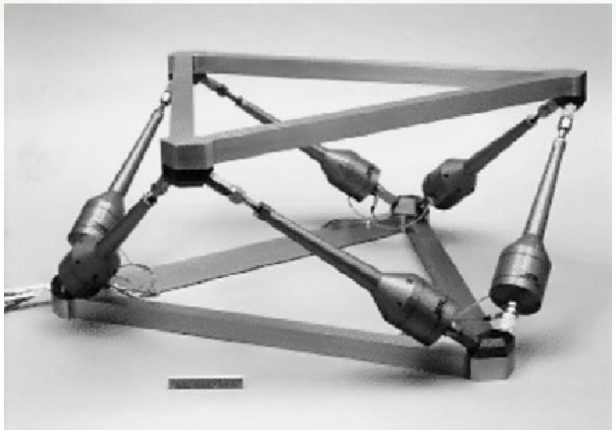


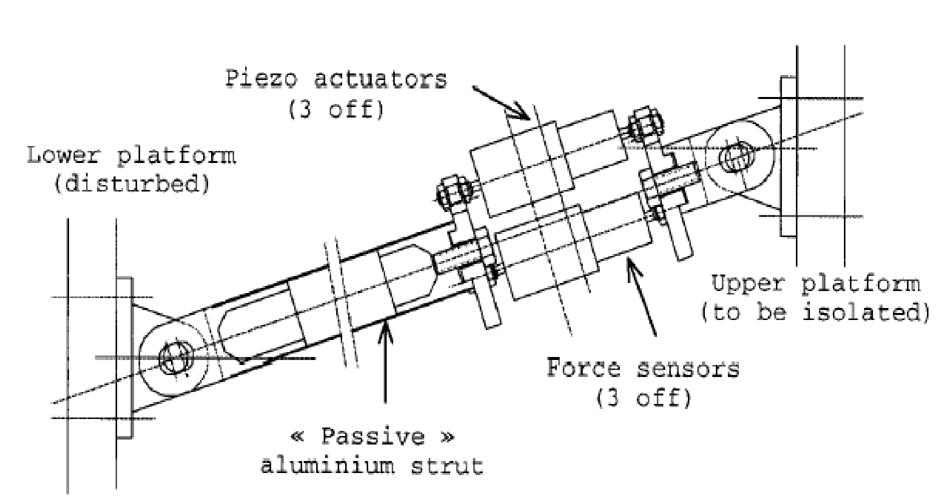
Consider the top-part designed for vibration isolation



Satellite has a highly sensitive payload, which must be saved from tremendous vibration that gets generated in a satellite launching vehicle. Vibration isolators are used for this purpose.

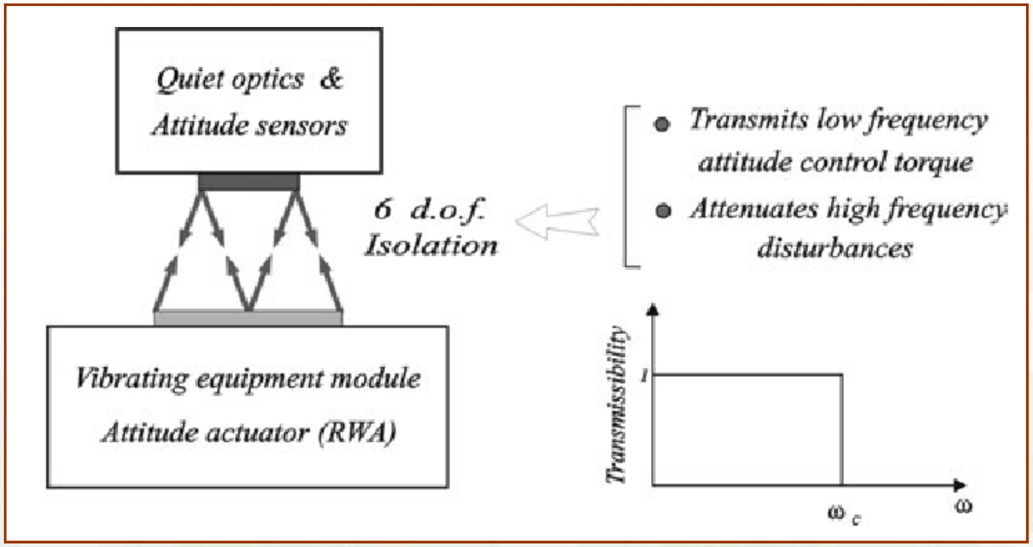
Detailed Description of the Vibration Isolator



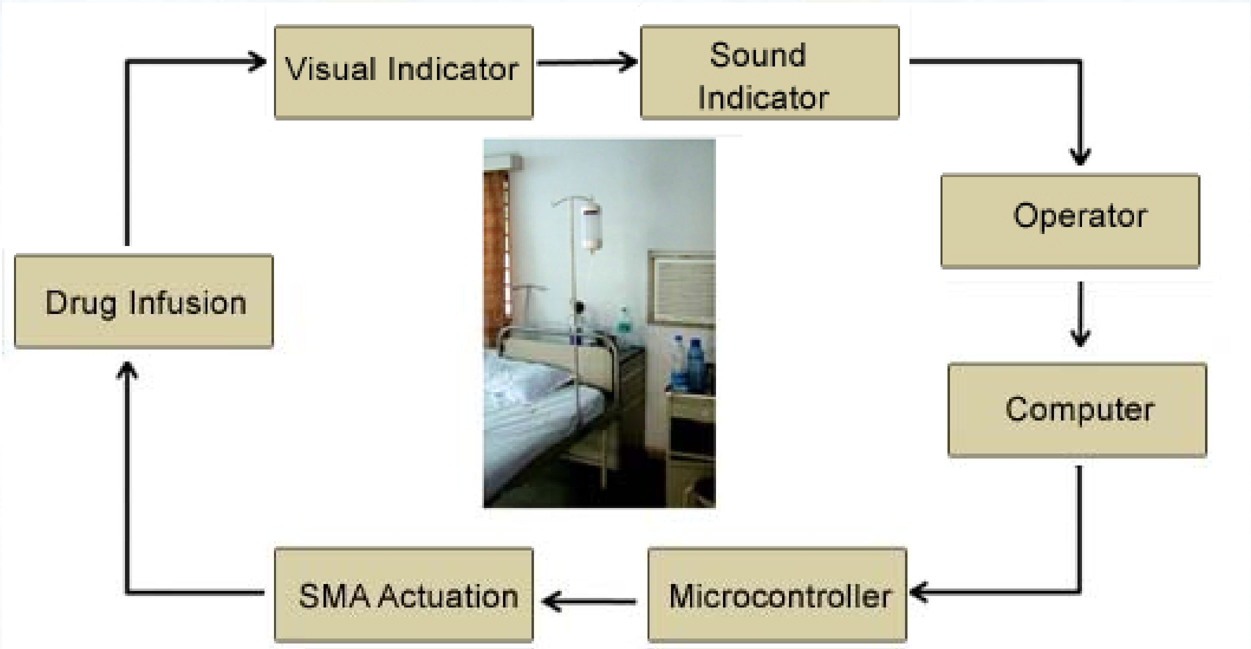


One such isolator is known as Active Stewart Platform

Here, the isolation is achieved by controlling the leg-lengths of six-links with the help of piezoelectric actuators

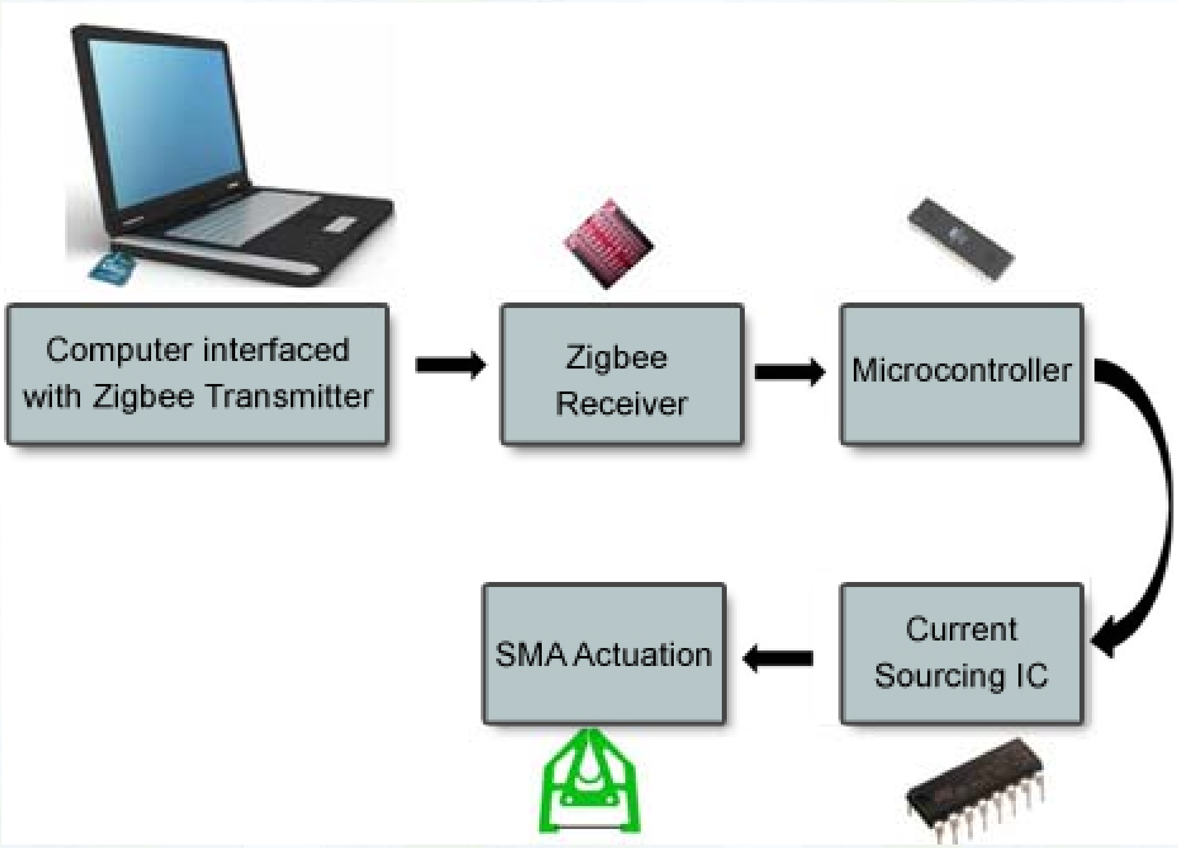


EXAMPLE 3: A Drug Infusion Control System



An autonomous drug infusion control system could solve a very challenging problem of hospitals of our country where the number of nurses are too few in comparison to the number of patients. This system is envisaged to control the flow of various drugs and nutrients to patient's body autonomously and send an warning to the nurse when the supply gets over..

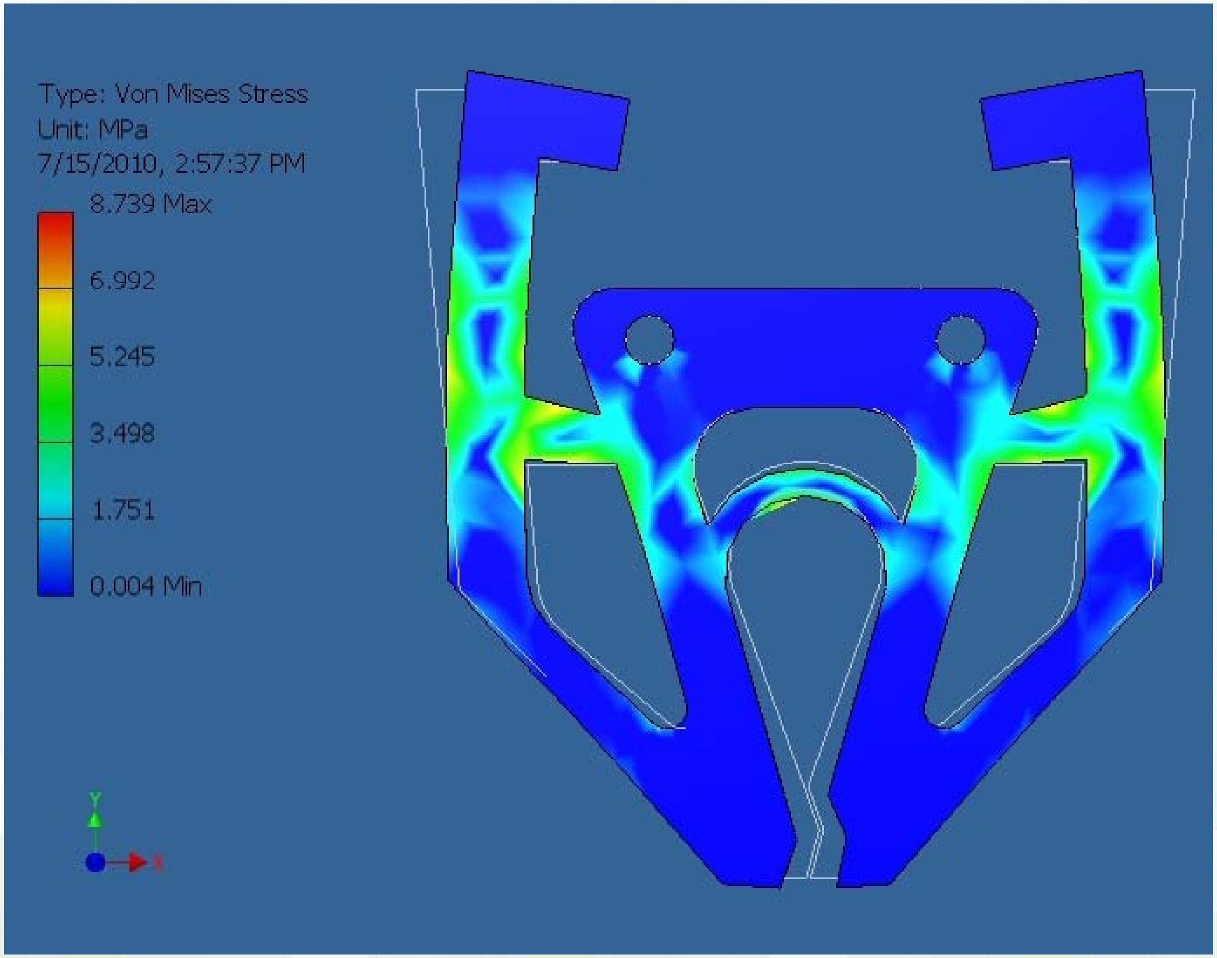
Concept Detailing of a Smart Drug Infusion System



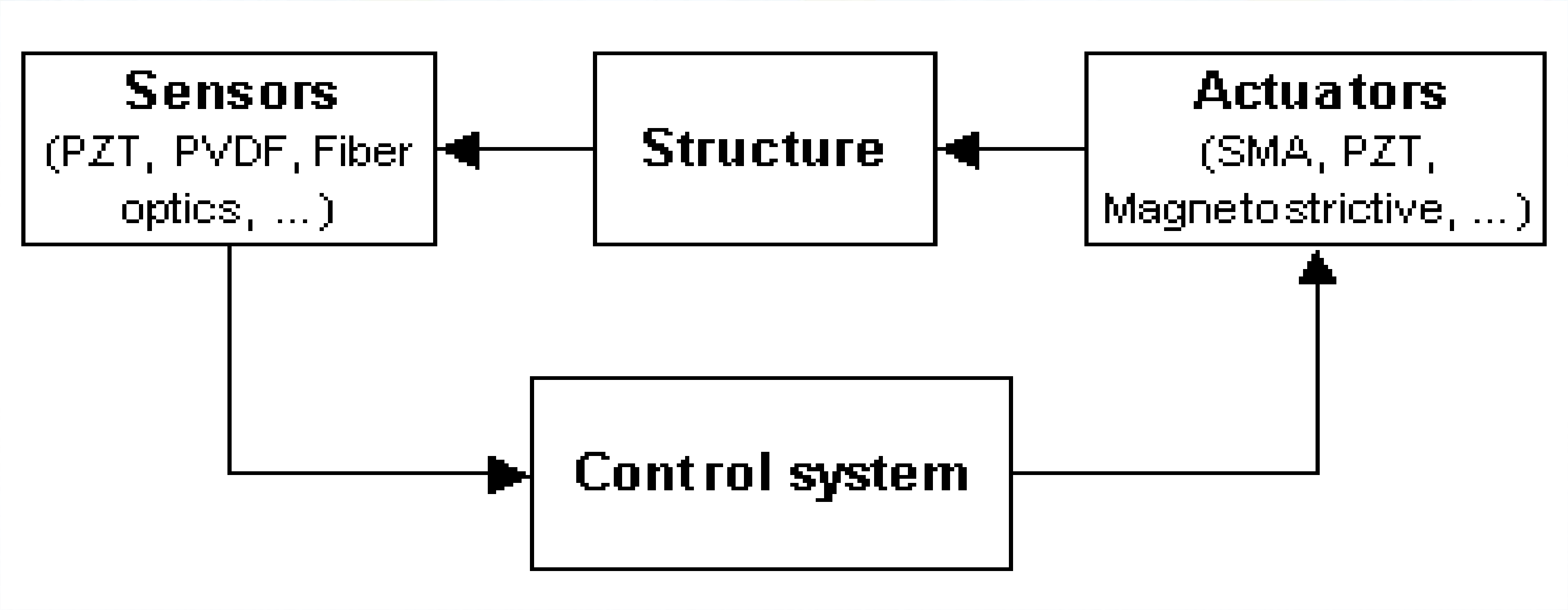
The challenge of this project is to design a smart intravenous drug infusion system free from roller clamp with high visibility medicine level indicators and sound indicators which can be easily operated with remote control

This is a novel concept in which essentially flow from a tube is controlled with the help of an micro-actuator (shown as a green compliant system). The system is controlled using wire-less communication.

A Closer look of the Compliant Mechanism



Did you notice a Common Pattern?



In all these examples, the structures – Dynamical Systems like Antenna, Isolator and Drug Infusion System are controlled by the Actuators based upon commands from the Control System which has taken decisions based on an array of Sensors.

Modelling a Dynamical System

Models are mathematical ***representations*** of system dynamics

Models allow the dynamics to be simulated and analyzed, without ***physically building*** the system.

Models are simplified form of the system and hence are ***never 'exact'!***

Models can be used in describing the ways in which a system can perform.

Certain types of analysis (e.g., parametric variations) can't easily be done on the actual system but can be simulated through system models

Models can be run much more quickly & thus saves developmental time

A single system may have many models

Choice of inputs and outputs depends on point of view

Inputs:
These are the parameters that are *external* to the model that you are building

Inputs in one model might be outputs of another model (e.g., output of an antenna controller provides input to the antenna model)

Outputs: Physical variables (often states) that one can m*easure*

Choice of outputs depends on what we intend to sense and what parts of the component model interact with other component models

States: Chosen such that their values at a reference time and the corresponding inputs are known. May or may not include Outputs.

Assumptions in a Model

- **There are two types of assumptions – implicit and explicit assumption**
- **Implicit assumptions are generally universally known and hence rarely stated – for example, use of continuum model , earth as inertial reference frame etc.**
- **Explicit assumptions are stated in the beginning of establishing a mathematical relationship.**
- **In this course we will explicitly assume that the dynamic systems to be modelled are Linear and Time Invariant (LTIV) in nature. In simple terms, this would imply that the dynamic systems will be modelled as a set of ordinary differential equations (neglecting the non-linear effects) and also the coefficients in such governing equations are constant.**

A system is modeled either

- by defining the input-output characteristics or
- by selecting a set of state variables

Inputs describe the *external excitation* of the dynamics . Inputs are *extrinsic* to the system dynamics (externally specified) . Constant inputs are often considered to be *parameters*

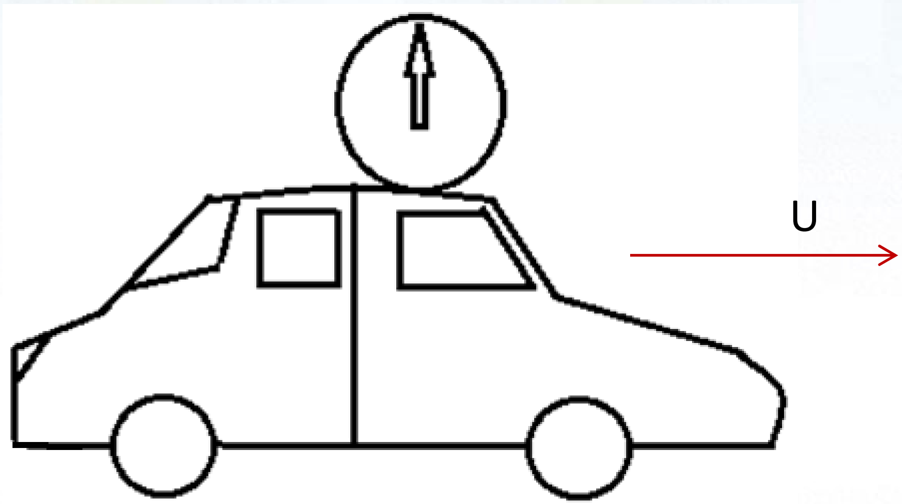
Outputs are variables that are *to be calculated or measured*

Input-output relation is often governed by a generalized ODE of the form

$$a_n y^{(n)} + \ldots.. + a_2 y^{(2)} + a_1 y^{(1)} + a_o y = b_m u^{(m)} + \ldots. + b_1 u^{(1)} + b_o u(t)$$

Where $y^{(n)} = d^n y/dt^n$, $u^{(m)} = d^{(m)} u/dt^m$

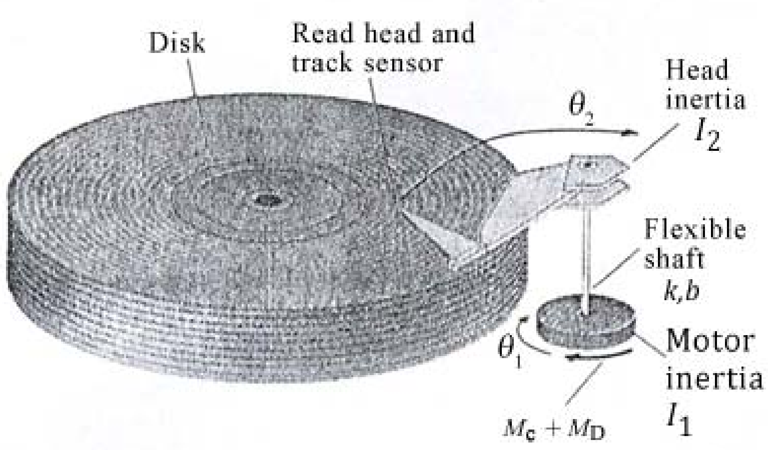
Consider a Cruise Control Model:



The car above is travelling at a speed u. Neglecting excitations due to road undulations etc. can you find out the governing Equation of Motion (EOM)?

Can you find out the input-output relationship from the EOM?

Consider the Disk Reading System



Input M_c
Output θ_2

Non-collocated sensing

Can you find out the Governing Equation of Motion?
Can you find out the relationship between the Torque and Angular Displacement?

General Reference Books

- *Feedback Control of Dynamic Systems* – Franklin, Powell and Naeini, Pearson Education Asia
- Advanced Control Systems – Dorf and Bishop, Pearson Education Asia
- *Control Systems Engineering* – Norman S Nise, John Wiley & Sons
- *Modern Control Engineering* – K. Ogata, Prentice Hall
- *Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering* – W. Bolton, Prentice Hall
- *Handbook of Sensors and Actuators* - Elsevier, series editor: P. P. Regtien