



**POLITECNICO
DI MILANO**



Signal Recovery – 2025/2026

Introduction

Ivan Rech

Instructor: **Prof. Ivan Rech**

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*“If you have any questions, please stop me during the lesson
so it will be of help to everyone.
DON'T WAIT TO CLEAR YOUR DOUBTS”*

Course website

- <https://rech.faculty.polimi.it/>

Bibliography

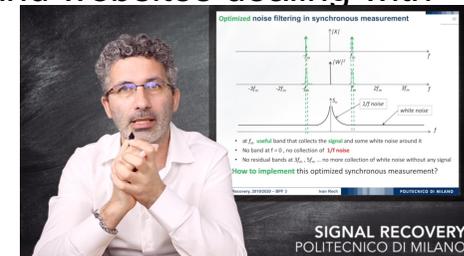
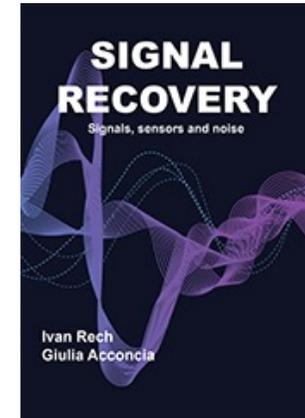
- **Complete set of slides** employed in the lectures
- Ivan Rech, Giulia Acconcia: **"Signal Recovery" book**, (**FREE PDF**)
- Text and explanation of problems given in the written tests carried out in previous years
- **Workbook with examples of exams solved in detail**, preliminary version (**FREE PDF**)
- Papers, presentations, technical documentation, suggested references and websites dealing with signal recovery, sensors and measurement instrumentation

Video

- **Ad hoc videos for each lesson** will be made available on Beep.

Complementary Bibliography

- Sergio Cova, Notes and Bibliography for the course "Signal recovery" Printer: Libreria Cortina, 2014.
- T.H. Wilmshurst, Signal recovery from noise in electronic instrumentation, 2nd edition, Printer: A. Hilger - IOP Publishing Ltd, edition year: 1990, ISBN: 0-7503-0058-2
- Silvano Donati, Photodetectors: Devices, Circuits and Applications, Printer: Prentice Hall, edition year: 2000, ISBN: 0130203378



Teaching activities

Teaching activities will include

- Lectures (2-3 per week). Total lecture hours: 59 (tentative)+Q/A
- Tutorials (1-2 per week). Total tutorial hours: 40 (tentative)

Lectures are intended to introduce students to the concept and methods covered by the course.

Tutorial sessions are intended to present sample problems and solutions and to help students develop problem-solving strategies.

- **Know-how in the foundations of electronic circuits**
- **Basic concepts on semiconductor devices**
- **Foundations of signals**
 - This aspect is very important. We will make one tutorial to recap part of the knowledge. The first chapter of the book has the same goal. ***This could be not enough*** without a previous knowledge, please go back to the previous exams knowledge.
- **Basic knowledge of probability and statistics**
 - We will introduce all the basic concept we will need
- **General background in mathematics and physics**
 - We will have just to solve some integral and use trigonometric expressions

1ST SEMESTER				EXAM SESSION	2ND SEMESTER				EXAM SESSION	SUMMER HOLIDAYS	EXAM SESSION	
SEPTEMBER 2025	OCTOBER 2025	NOVEMBER 2025	DECEMBER 2025	JANUARY 2026	FEBRUARY 2026	MARCH 2026	APRIL 2026	MAY 2026	JUNE 2026	JULY 2026	AUGUST 2026	SEPTEMBER 2026
1 WED <small>JEW. HOLIDAY</small>	1 SAT	1 MON	1 THURS.	1 SUN	1 SUN	1 SUN	1 WED	1 FRI	1 MON	1 WED	1 SAT	1 TUE
2 THURS. <small>JEW. HOLIDAY</small>	2 SUN	2 TUE	2 FRI	2 MON	2 MON	2 MON	2 THURS.	2 SAT	2 TUE	2 THURS.	2 SUN	2 WED
3 FRI	3 MON	3 WED	3 SAT	3 TUE	3 TUE	3 TUE	3 FRI <small>JEW. HOLIDAY</small>	3 SUN	3 WED	3 FRI	3 MON	3 THURS.
4 SAT	4 TUE	4 THURS.	4 SUN	4 WED	4 WED	4 WED <small>MILANO</small>	4 SAT <small>JEW. HOLIDAY</small>	4 MON	4 THURS.	4 SAT	4 TUE	4 FRI
5 SUN	5 WED	5 FRI	5 MON	5 THURS.	5 THURS.	5 THURS. <small>TERRIT</small>	5 SUN <small>EASTER</small>	5 TUE	5 FRI	5 SUN	5 WED	5 SAT
6 MON	6 THURS.	6 SAT	6 TUE	6 FRI	6 FRI	6 FRI	6 MON <small>EASTER MONDAY</small>	6 WED	6 WED	6 MON	6 THURS.	6 SUN
7 TUE <small>JEW. HOLIDAY</small>	7 FRI	7 SUN	7 WED	7 SAT	7 SAT	7 SAT	7 TUE	7 THURS.	7 THURS.	7 TUE	7 FRI	7 MON
8 WED <small>JEW. HOLIDAY</small>	8 SAT	8 MON	8 THURS.	8 SUN	8 SUN	8 SUN	8 WED <small>JEW. HOLIDAY</small>	8 FRI	8 FRI	8 WED	8 SAT	8 TUE
9 THURS.	9 SUN	9 TUE	9 FRI	9 MON	9 MON	9 MON	9 THURS. <small>JEW. HOLIDAY</small>	9 SAT	9 SAT	9 THURS.	9 SUN	9 WED
10 FRI	10 MON	10 WED	10 SAT	10 TUE	10 TUE	10 TUE	10 FRI	10 SUN	10 SUN	10 WED	10 MON	10 THURS.
11 SAT	11 TUE	11 THURS. <small>MILANO</small>	11 SUN	11 WED	11 WED	11 WED	11 SAT	11 MON	11 MON	11 THURS.	11 TUE	11 FRI
12 SUN	12 WED	12 FRI	12 MON	12 THURS.	12 THURS.	12 THURS.	12 SUN	12 TUE	12 TUE	12 FRI	12 WED	12 SAT
13 MON <small>JEW. HOLIDAY</small>	13 THURS.	13 SAT	13 TUE	13 FRI	13 FRI	13 FRI	13 MON	13 WED	13 WED	13 SAT	13 THURS.	
14 TUE <small>JEW. HOLIDAY</small>	14 FRI	14 SUN	14 WED	14 SAT	14 SAT	14 SAT	14 TUE	14 THURS.	14 THURS.	14 SUN	14 FRI	
15 MON <small>BEGIN 1ST SEM</small>	15 SAT	15 MON	15 THURS.	15 SUN	15 SUN	15 SUN	15 WED	15 FRI	15 FRI	15 MON	15 SAT	
16 TUE	16 THURS.	16 TUE	16 FRI	16 MON	16 MON	16 MON	16 THURS.	16 SAT	16 SAT	16 TUE	16 SUN	
17 WED	17 MON	17 WED	17 SAT	17 TUE	17 TUE	17 TUE	17 FRI	17 SUN	17 SUN	17 WED	17 MON	
18 THURS.	18 TUE	18 THURS.	18 SUN	18 WED	18 WED	18 WED	18 SAT	18 MON	18 MON	18 THURS.	18 TUE	
19 FRI	19 SUN	19 WED	19 MON	19 THURS.	19 THURS.	19 THURS.	19 SUN	19 TUE	19 TUE	19 FRI	19 WED	
20 SAT	20 MON	20 THURS.	20 SAT	20 TUE	20 FRI	20 FRI	20 MON	20 WED	20 WED	20 SAT	20 THURS.	
21 SUN	21 TUE <small>TERRIT</small>	21 FRI	21 SUN	21 WED	21 SAT	21 SAT	21 TUE	21 THURS.	21 THURS.	21 SUN	21 FRI	
22 MON	22 WED	22 SAT	22 MON	22 THURS.	22 SUN	22 SUN	22 WED	22 WED	22 FRI <small>JEW. HOLIDAY</small>	22 MON	22 SAT	
23 TUE <small>FEST. EBR</small>	23 THURS. <small>MI</small>	23 SUN	23 TUE	23 FRI	23 MON <small>BEGIN 2ND SEM</small>	23 MON	23 THURS.	23 SAT	23 SAT	23 TUE	23 SUN	
24 WED <small>FEST. EBR</small>	24 FRI	24 MON	24 WED	24 SAT	24 TUE	24 TUE	24 FRI	24 SUN	24 SUN	24 WED	24 MON	
25 THURS.	25 SAT	25 TUE	25 THURS. <small>MMAS</small>	25 SUN	25 WED	25 WED	25 SAT	25 MON	25 MON	25 THURS.	25 TUE	
26 FRI <small>TERRIT</small>	26 SUN	26 WED	26 FRI	26 MON	26 THURS.	26 THURS.	26 SUN	26 TUE	26 TUE	26 FRI	26 WED	
27 SAT	27 MON	27 THURS.	27 SAT	27 TUE	27 FRI	27 FRI	27 MON	27 WED	27 WED	27 SAT	27 THURS.	
28 SUN	28 TUE	28 FRI	28 SUN	28 WED	28 SAT	28 SAT	28 TUE	28 THURS.	28 THURS.	28 SUN	28 FRI	
29 MON	29 WED	29 SAT	29 MON	29 THURS.			29 WED	29 FRI	29 FRI	29 MON	29 SAT	
30 TUE <small>MILANO</small>	30 THURS.	30 SUN	30 TUE	30 FRI			30 MON	30 THURS.	30 SAT	30 TUE	30 SUN	
31 FRI	31 FRI	31 WED	31 SAT				31 TUE	31 SUN		31 FRI	31 MON	

□ LECTURE
 □ EXAMS
 □ INTERMEDIATE TESTS
 □ OTHER ACTIVITIES
 □ LAUREE MAGISTRALI (EQUIVALENT TO MASTER OF SCIENCE)
 □ 1ST LEVEL LAUREA PROGRAMMES
 □ SATURDAY
 □ BANK HOLIDAYS
 □ HOLIDAYS

15 weeks
107 hours

Tools

- 2h Introduction 23/2 (2h)
- 3h Signals description 25/2 (2h)+26/2(1h)
- 2h Noise description: part 1 26/2 (1h)+27/2(1h)
- 1,5h Noise description: part 2 27/2(1h) +2/3 (0.5h)
- 1,5h Filtering signals 2/3 (1,5h)
- 2h Tutorial 5/3**
- 1h Filtering noise 6/3(1h)

First Part – filtering

- 2h Low pass filter: part 1 6/3(1h) +9/3 (1h)
- 1,5h Low pass filter: part 2 9/3 (1h) + 11/3 (0,5)
- 2,5h Low pass filter: part 3 11/3 (1,5h)+16/3(1h)
- 2h Tutorial 12/3**
- 2h Tutorial 13/3**
- 1,5h Optimum filter: part 1 16/3 (1h)+18/3 (1h) +Q/A
- 1,5h Optimum filter: part 2 18/3 (1h)+23/3(1h) +Q/A
- 2h Tutorial 19/3**
- 2h Tutorial 20/3**
- 4h High pass filter: part 1 23/3(1h)+27/3(2h)+2/4(1h+1h Q/A)
- 2h Tutorial 25/3**
- 2h Tutorial 30/3**
- 2h Tutorial 1/4**
- 4h High pass filter: part 2 8/4(2h)+10/4(2h)
- 2h Tutorial 9/4**
- 2h Tutorial 13/4**

----- MID TERM (14/4 17:15) -----

- 3h Band pass filter: part 1 15/4 (2h)+16/4 (1h)
- 2,5h Band pass filter: part 2 (IN VIDEO + Q&A 16/4 (1h))
- 3h Band pass filter: part 3 17/4 (2h)+ 22/4(1h)

- 2h Tutorial 20/4**
- 3h Band pass filter: part 3 22/4 (1h)+ 23/4(2h)
- 2h Tutorial 24/4**
- 2h Band pass filter: part 4 27/4 (2h)

Second Part - sensors

- 2,5h Photodetector: part 1 29/4 (2h)+ 30/4(0,5h)
- 2h Photodetector: part 2 30/4 (1,5h)+7/4 (0,5h)
- 2h Tutorial 4/5**
- 2h Tutorial 6/5**
- 2h Photodetector: part 3 7/5 (1,5h)+8/5 (0,5h)
- 3h Photodetector: part 4 8/5 (1,5h)+ 11/5 (1,5h +Q/A)
- 2h Tutorial 13/5**
- 2h Photodetector: part 5 14/5 (2h)
- 2h Tutorial 15/5**
- 2h Photodetector: part 6 18/5 (2h)

SEMINAR ON A REAL APPLICATION 20/5 2h

- 1,5h Temperature sensor 21/5 (1,5h+Q/A)
- 2h Tutorial 22/5**
- 2h Strain Gauges 25/5 (2h)
- 2h Tutorial 27/5**
- 2h Tutorial 28/5**
- 2h Tutorial 29/5**

2h SEMINAR ON STATE OF THE ART AND PERSPECTIVE 4/6

This is only an indicative schedule, any important changes will be communicated via WEBEEP

- 2024 Exam duration: **2h 45min**. (pre-covid the duration was 3h but with 8 questions, in the 2020-2023 it was shortened to 2h 15min but with six questions).
- weighing: six questions with same weight
- pass boundary set at 60% (**18/30**). Pass boundary is equated to adjust for varying difficulty levels across different exams
- 5 exam dates set by the School of Industrial and Information Engineering
- A midterm with just 1 problem (3 questions). To be defined if online or in classroom depending on the classroom availability. If you pass the midterm exam you can just make only the second problem at one of the exams in the June-July session.
- Students who pass the written exam with a score ≥ 27 may take an *optional* oral exam. The oral exam could be request, in any case, from the professor
- Oral exam can increase or decrease the final grade

PLEASE: download and read the complete notice for the exam

ATTENTION

The exam is based on open questions. There is therefore no unique way to respond to the request.

With the same question it is possible to answer correctly with **different degrees of detail**. Responses will be evaluated accordingly.

Trivial example: Given a signal with a certain shape and a 10Hz band immersed in a noise with a 1GHz band, you are asked to improve the signal to noise ratio:

- You decide to reduce the noise band from 1GHz to 999MHz. The filter improves the S/N and it is correct but it is definitely not what is expected
- You decide to reduce the noise band to 1MHz. The filter improves the S/N, it is correct and better than the previous one but still it is not what we will learn to be the best we can do
- You Optimize the filter according to the shape and band of the signal.

These three answers are ALL correct but of course, as with your future job, they will have three different ratings. During the course and in the exercises we will practice on real exam topics to understand how to take the exam correctly.

Signal Recovery deals with electronic techniques for recovering sensor signals from noise

main goal

not just to know and properly describe techniques and instruments

but rather

to gain a good insight in the problems and in the approaches developed.

We wish to **evaluate the solutions and understand the reasons of choices and decisions**, critically highlighted by

- a) the physics of phenomena involved
- b) the principles of signal and noise processing
- c) the actual performance of the available devices.

- We have to clearly distinguish intrinsic limitations and contingent limitations:
intrinsic limitations are set by laws of nature and **cannot be overcome**
contingent limitations are due to the state of the art and **can be overcome** by the technological progress.
- Be aware that **different technological implementations** may rely on the **same idea** and that the **evolution in technology** unceasingly stimulates **new ideas**
- To gain insight means to move at the pace of progress in science and technology and be able to contribute to it.

“To obtain this result we have to understand the physics of phenomena involved and to go insight the formalism and the mathematical approach”

ATTENTION:

- Within this course we will use a lot of math.
- We need math to create a MODEL that allows us to understand/describe the physical phenomenon.
- **We are interested** in an *intuitive understanding* of the individual formulae to better understand the connections with the different aspects of **a complex problem** and find the better solution
-
- **We are NOT interested** (*and therefore will not be asked for the exam*) in the single mathematical steps that lead us from the model to the final finite formula (the exam is based **ONLY** on the material illustrated in the slides during the lessons).

At the exam you will be asked ONLY the degree of detail seen and explained in the classroom.

In a Math class, the Professor showed that:

$$\lim_{x \rightarrow 8} \frac{1}{x - 8} \rightarrow \infty$$

Then he picked a student that followed with attention and asked

$$\lim_{x \rightarrow 5} \frac{1}{x - 5} \rightarrow ?$$

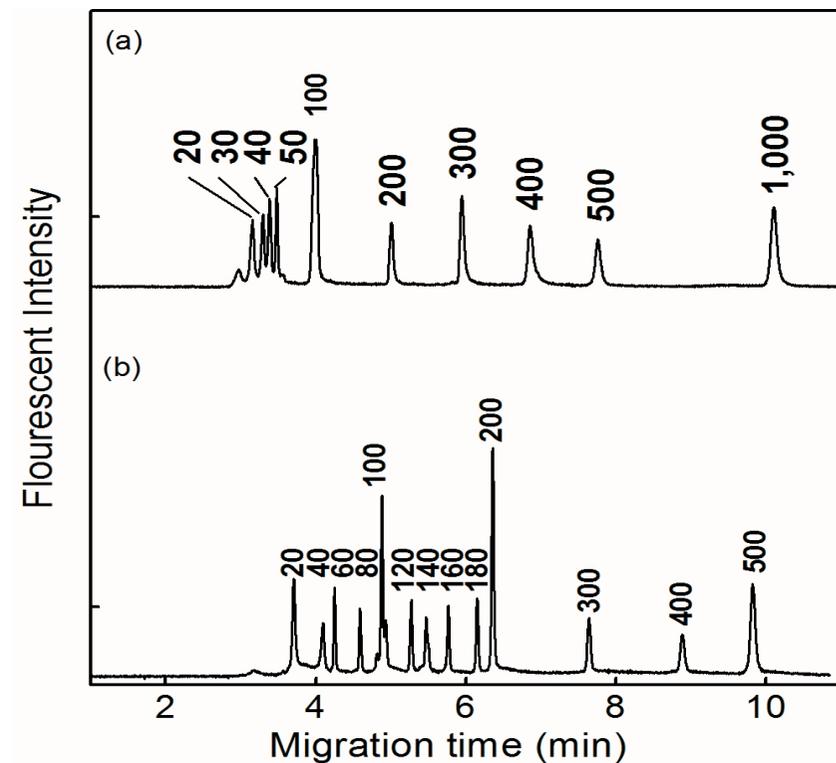
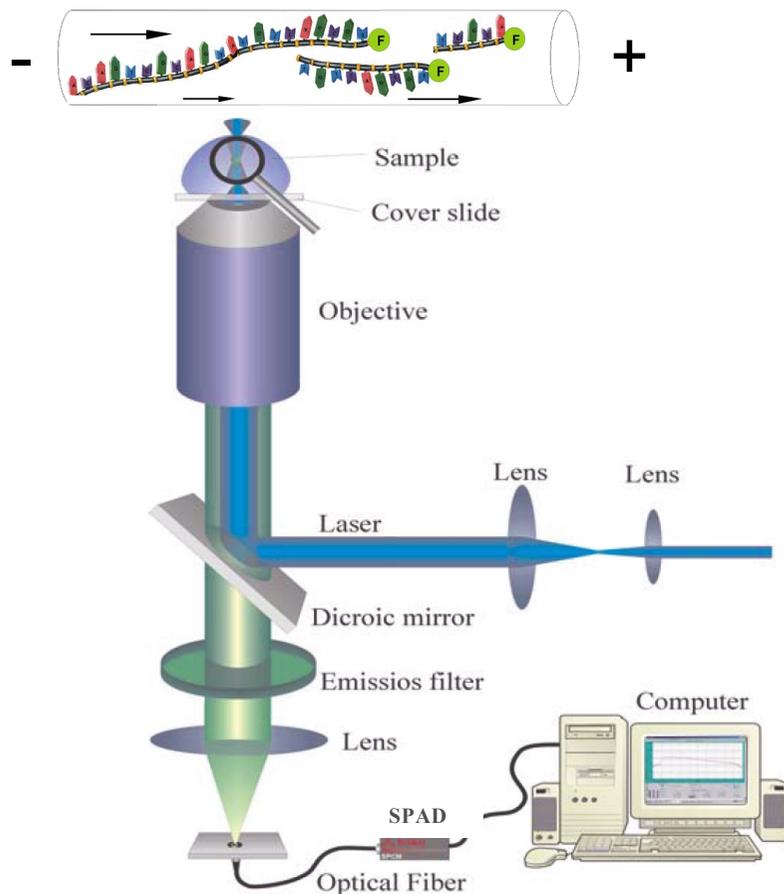
and the answer was

$$\lim_{x \rightarrow 5} \frac{1}{x - 5} \rightarrow \infty$$

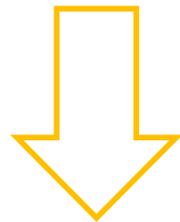
Well, this is just a joke, not observed in reality ...
... but examples similar to this occur in real courses !

GOAL: DNA separation of fragments of different lengths

- Excited molecules in the focal volume give rise to a fluorescent signal
- Fragments with different length move with different speed
- Fragments reach the focal point with different delays



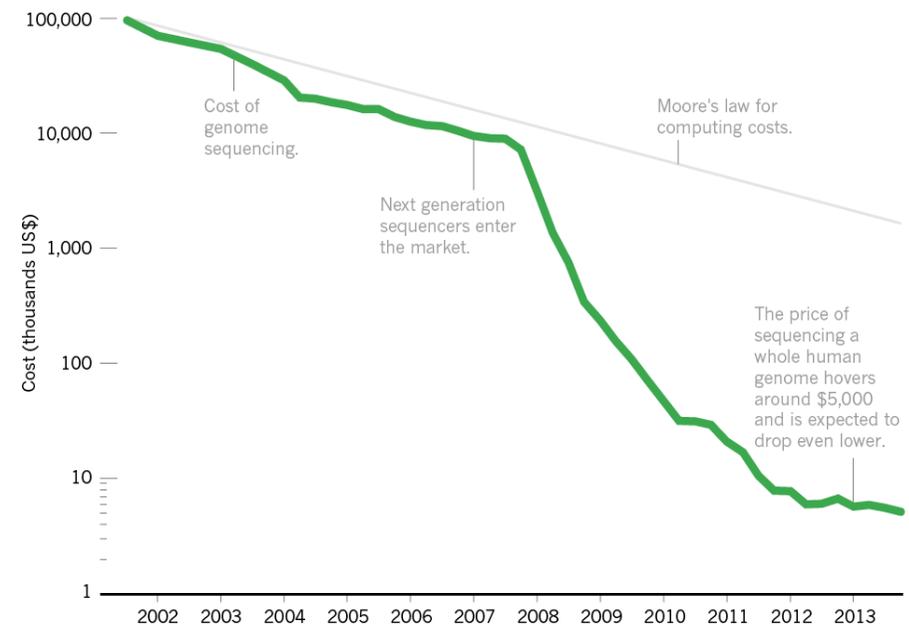
In the first few years at the end of the **Human Genome Project**, the cost of genome sequencing roughly followed Moore's law, which predicts exponential declines in computing costs. After 2007, sequencing costs **dropped precipitously**.



Next generation sequencer enter the market



Higher sensitivity



Signals and noise. Introduction to measurements, errors and statistical distributions. Mathematical treatment of signals and noise in the time and in the frequency domain. Signal-to-Noise ratio (S/N). Autocorrelation functions, energy and power spectra. Noise sources in electronic circuits and sensors. Main types of noise spectra. Noise interpretation

Extracting signals from noise. Linear filters with constant parameters and with time-variant parameters, action on signals and noise and resultant S/N. Pulse-signals and constant-parameter low-pass filters; Gated Integrator (GI); Boxcar Integrator (BI); Sample-and-Hold (S&H) and fast samplers; discrete filtering by sampling and weighted average of samples. Optimum filtering for pulse-amplitude measurements, significance and practical usefulness. Noise with $1/f$ spectrum: characteristic features and ensuing problems, filtering approach. Constant-parameter high-pass filters; correlated double sampling (CDS) and further developments; Baseline Restorer (BLR). Periodic signals and constant-parameter resonant filters; modulation of signals and noise; Lock-in Amplifier (LIA), analog and digital implementations of LIAs.

Sensors are treated by discussing the physical principles of their operation; the device structure and technology; characteristic features and electrical parameters; output signals and information content; equivalent electric circuit; internal noise. Photodetectors: vacuum tube and semiconductor photodiodes; photoconductors; Photomultiplier tubes (PMT), avalanche photodiodes (APD) and single-photon avalanche diodes (SPAD); analog and digital detection, single-photon counting (SPC) and ***time-correlated single-photon counting (TCSPC) (not included in the exam)***. Temperature Sensors: thermo resistances. Strain and Force Sensors: strain gauges sensors.