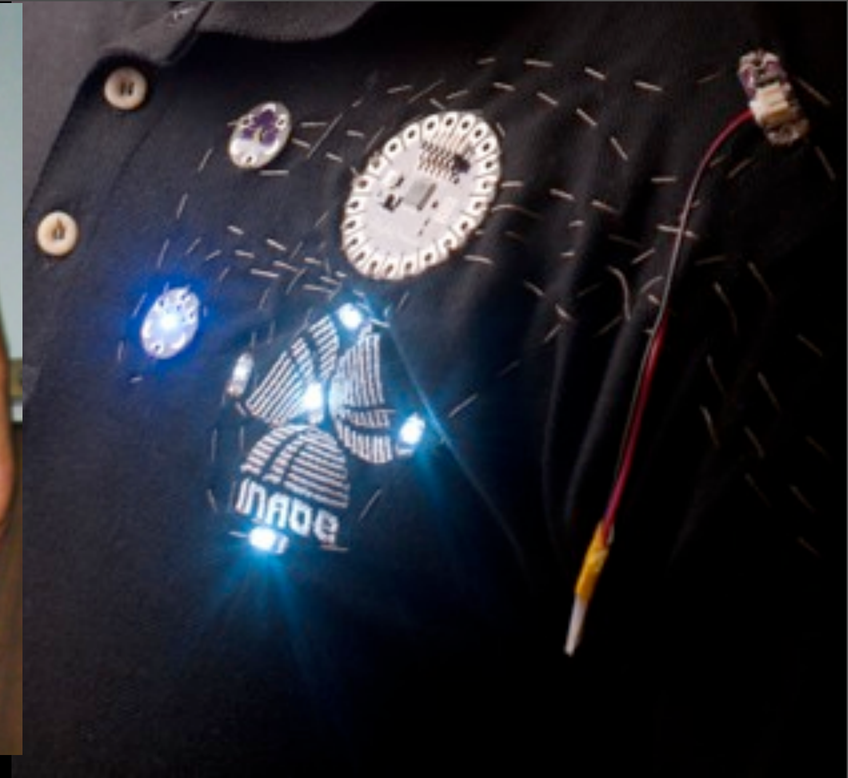

Hard Sensors for Soft Phenomena

Winter School on Ubiquitous Computing

Ubi-Health Project

Tonantzintla, Pue. Mexico, 6-17

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About this talk

The goal is to give an introduction to sensors and the difficulties to measure phenomena related to human activity from the perspective of a researcher working with multiple physical devices, such as robot teams.

Overview

1. Concepts about sensors
2. Finding patterns
3. Designing sensors
4. Final remarks

Concepts

Concepts (1)

transducer: device that converts variations of a signal in one form of energy into another form of energy.

In Robotics and Electronics, a transducer is commonly a device that coverts a physical non-electrical signal into an electrical signal, i.e., a microphone converts “sound”, air pressure, into an electrical signal.

Signals converted from transducers can be recorded, amplified, processed, and so on.

sensor: a transducer that converts a physical stimuli into electrical signal that a microprocessor can read.

Concepts (2)

Strictly speaking, a sensor is a kind of transducer. However both terms are commonly interchanged.

Sensors enable a machine, e.g. a robot, a smartphone, to perceive both its internal state and its surrounding.

Concepts (3)

Most sensors fall into two categories according to their output:

Digital sensors return discrete values, e.g. contact with an object.

Analog sensors return continuous values, e.g. lightning intensity.

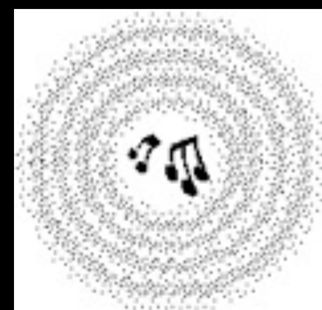
However to be processed for a microprocessor or PC, most signals are converted into a format suitable for digital systems, using for instance an Analog to Digital converter (A/D converter).

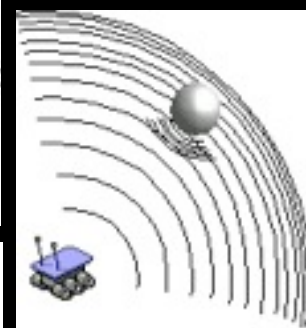
Concepts (4)

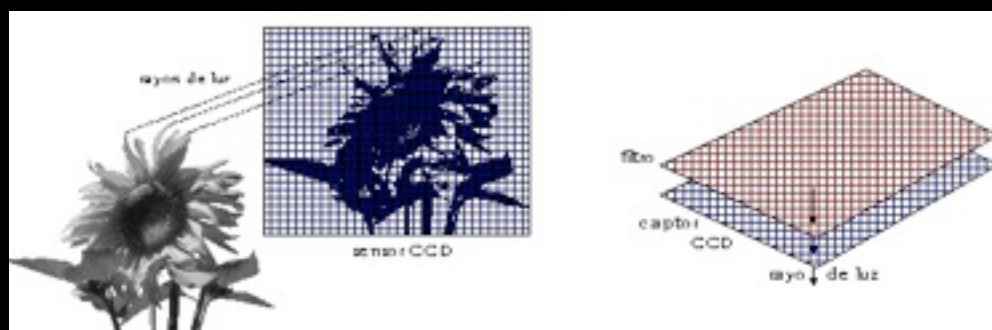
Sensors can also be passive or active:

Passive sensors only receive signals, e.g. a photoresistor or light sensor.

Active sensors emit energy that is reflected by external objects and measure the returned energy, e.g. a camera equipped with a flash, an ultrasonic sensor.







Concepts (5)

Passive sensors are non-intrusive and tightly dependent on environmental conditions, whereas active sensors are intrusive and can affect the conditions upon which a stimuli is measured.

Intrusiveness is a **major concern** when measuring parameters of **living organisms**.

Concepts (6)

Sensors can also be classified as inner or outer sensors.

Inner or proprioceptive sensors measure the own individual parameters of the holder, e.g. position of its joints, level of its battery, etc.

Outer or external sensors measure parameters of the holder's surrounding area, e.g. humidity, color of objects, etc.These can also be classified as contact and non-contact sensors, e.g. switches and video-cameras, respectively.

Concepts (7)

Range or field of view (fov): the set of values of a physical stimuli to which a sensor is able to react, e.g. $-10^0 – 50^0$, 0 - 5kg.

Sensitivity: a measure of the degree of variation in the signal returned by a sensor according to changes of the physical stimuli that is measured, e.g. 1^0, 1 gr.

Concepts (8)

Noise and **artifacts**: abnormalities, non-sense or unwanted information produced by interferences when measuring or transmitting a signal.

Concepts (9)

The quality of the output of a sensor depends on the manner as the physical stimuli is transformed into digital values.

Examples of de transformations for an 8-bit processor (Jones & Flynn, 1999).

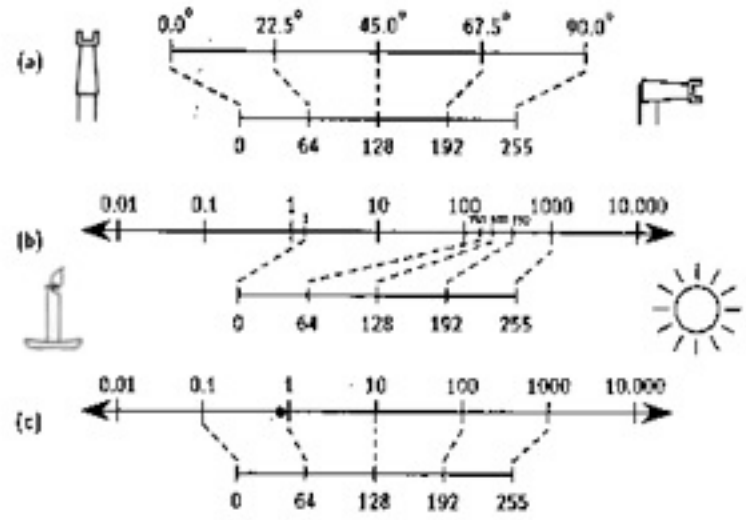


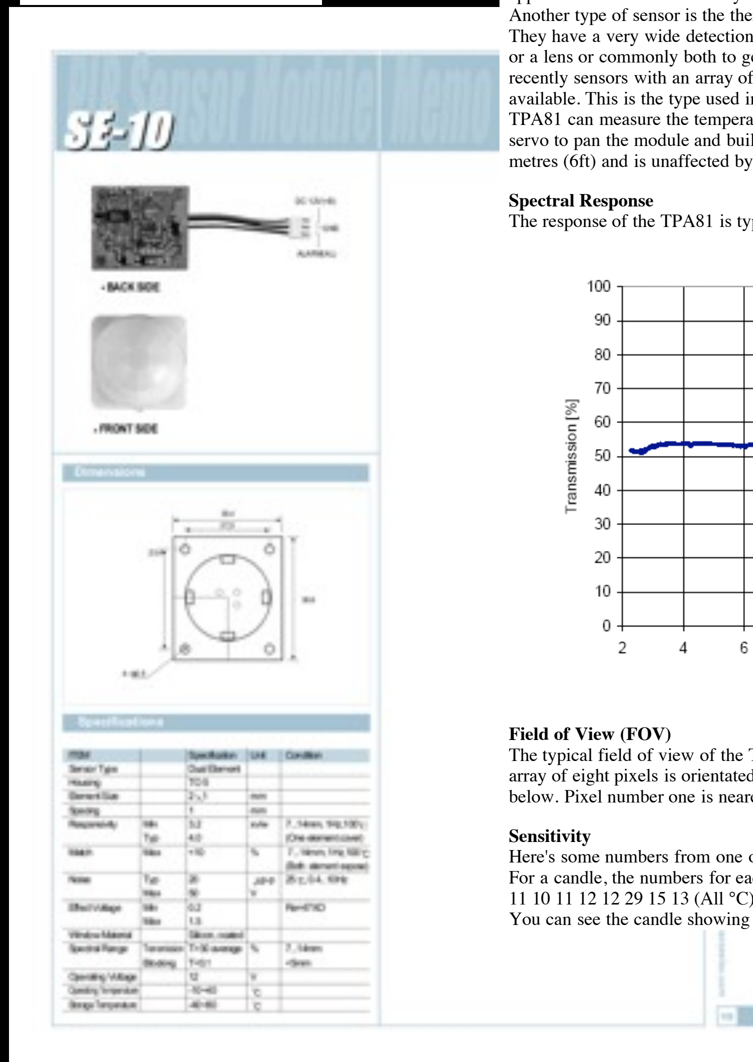
Figure 5.7: It is always necessary to consider how the quantity measured by a sensor will be mapped into the range of digital values available to the microprocessor. (a) The linear mapping illustrated here would map an arm joint angle of 0° from the vertical to the number 0 and an angle of 90° to 255. (b) A linear mapping of illumination units to numbers would map 250 illumination units to the number 64 and 1,000 illumination units to 255. (c) A logarithmic mapping gives a larger dynamic range, from 0.1 illumination units to 1,000 illumination units for an 8-bit (0 to 255) A/D converter.

Concepts (10)

"Mood devices"

The operation of physical sensors might be affected by various factors, such as power supply, natural lightning, temperature/ humidity of the environment, magnetic materials, etc.

Consult datasheet to know the average sensor's performance documented by the designer and to know how much you can trust a sensor!



TPA81 Thermopile Array

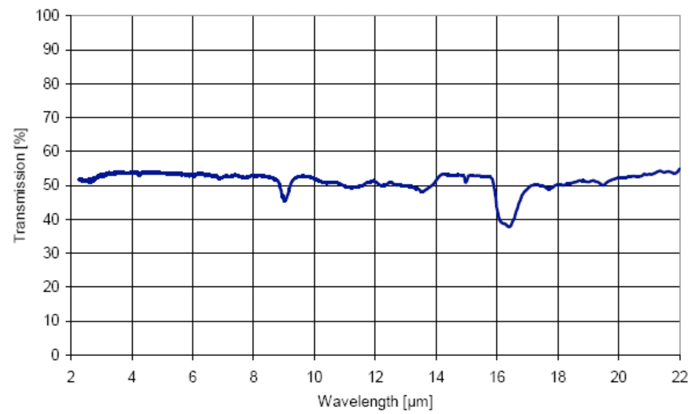
Technical Specification

Introduction

The TPA81 is a thermopile array detecting infra-red in the 2um-22um range. This is the wavelength of radiant heat. The Pyro-electric sensors that are used commonly in burglar alarms and to switch on outside lights, detect infra-red in the same waveband. These Pyro-electric sensors can only detect a change in heat levels though - hence they are movement detectors. Although useful in robotics, their applications are limited as they are unable to detect and measure the temperature of a static heat source. Another type of sensor is the thermopile array. These are used in non-contact infra-red thermometers. They have a very wide detection angle or field of view (FOV) of around 100° and need either shrouding or a lens or commonly both to get a more useful FOV of around 12°. Some have a built in lens. More recently sensors with an array of thermopiles, built in electronics and a silicon lens have become available. This is the type used in the TPA81. It has a array of eight thermopiles arranged in a row. The TPA81 can measure the temperature of 8 adjacent points simultaneously. The TPA81 can also control a servo to pan the module and build up a thermal image. The TPA81 can detect a candle flame at a range 2 metres (6ft) and is unaffected by ambient light!

Spectral Response

The response of the TPA81 is typically 2μm to 22μm and is shown below:



Field of View (FOV)

The typical field of view of the TPA81 is 41° by 6° making each of the eight pixels 5.12° by 6°. The array of eight pixels is orientated along the length of the PCB - that's from top to bottom in the diagram below. Pixel number one is nearest the tab on the sensor - or at the bottom in the diagram below.

Sensitivity

Here's some numbers from one of our test modules:

For a candle, the numbers for each of the eight pixels at a range of 1 meter in a cool room at 12°C are:

11 10 11 12 12 29 15 13 (All °C)

You can see the candle showing up as the 29°C reading. At a range of 2 meters this reduces to 20°C -

Finding patterns

Finding patterns (1)

How can we exploit the information provided by a sensor?

How can we associate raw readings with events of interest?

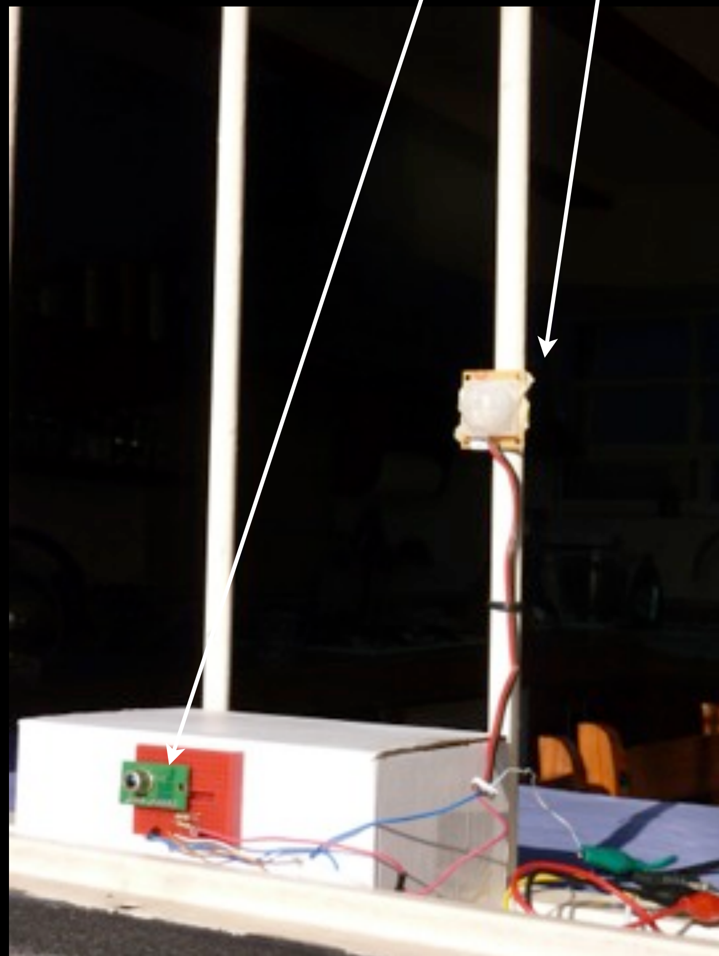
How can we identify **patterns/regularities** in data sets related to “soft phenomena” (human actions, human parameters, etc.) that are by definition uncertain, incomplete and noisy?

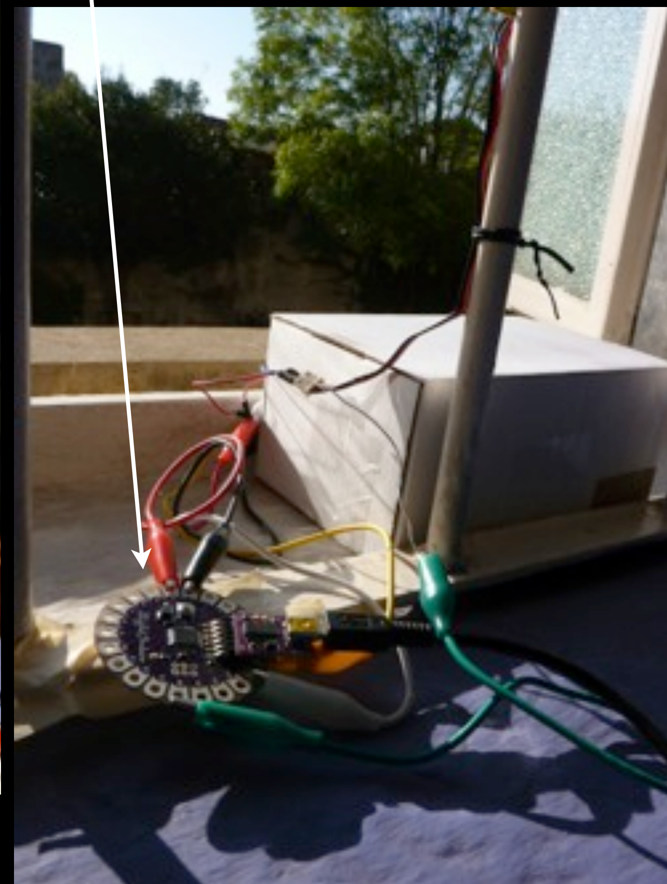
Finding patterns (2)

A naive experiment: counting people that traverse a corridor in two senses using cheap and discrete sensors.

Finding patterns (3)

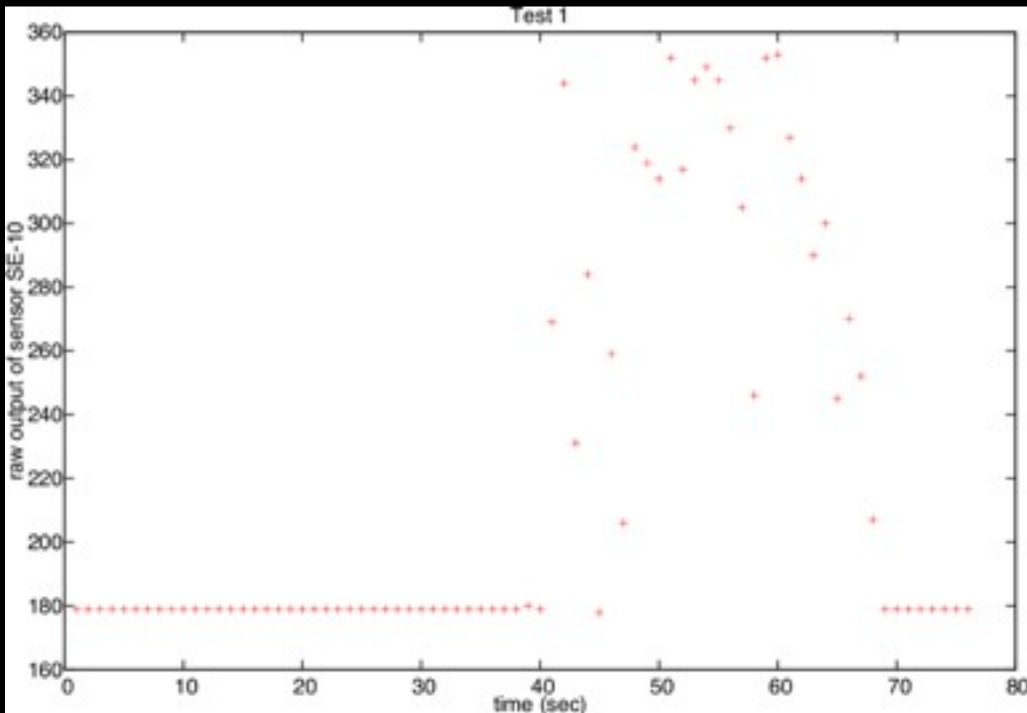
1 TPA81 thermopile array from Devantech,
1 SE-10 motion sensor,
1 Lilypad main board (ATMega 328) from Arduino.





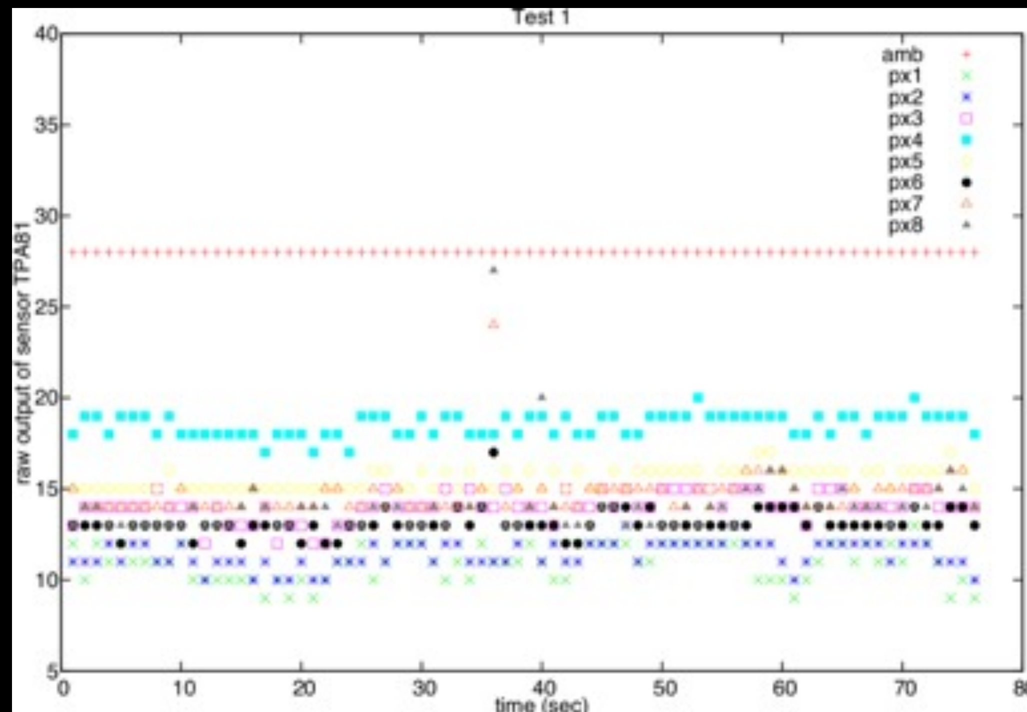
Experimental setup: back ⬆,
front ⬆
and main board ➡

Finding patterns (4)



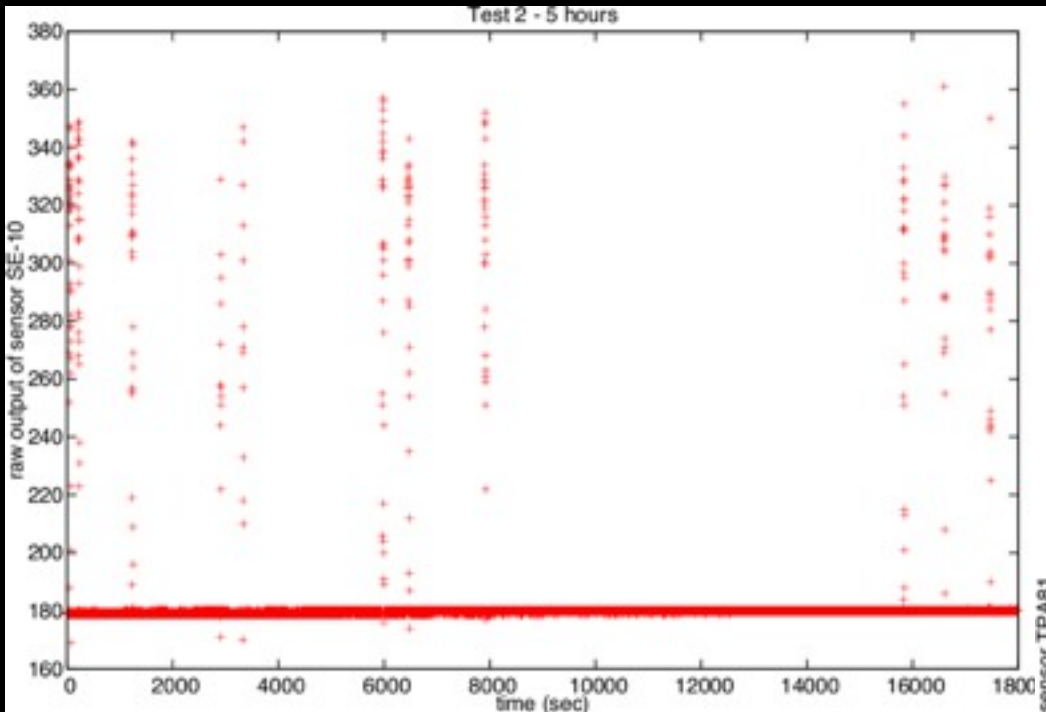
Raw output from
⬅ SE-10 sensor and

TPA81 sensor ⬇



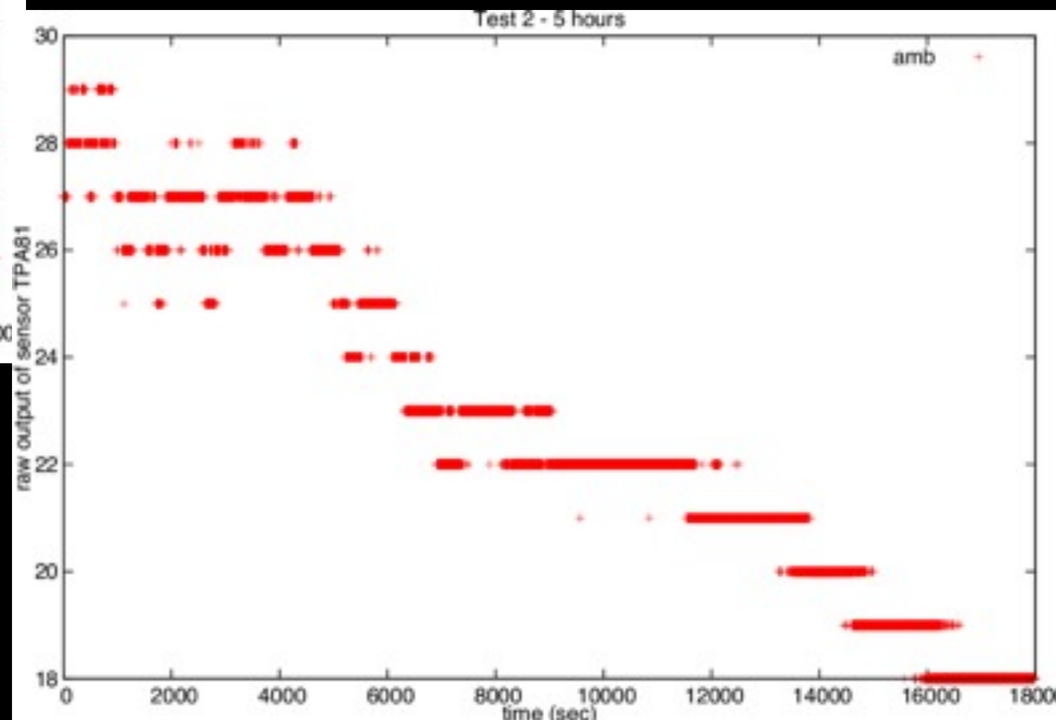
Test1: 1’20”, one person traversed the corridor from left to right, and then from right to left.
1 record each second.

Finding patterns (5)



Raw output from
⬅ SE-10 sensor and

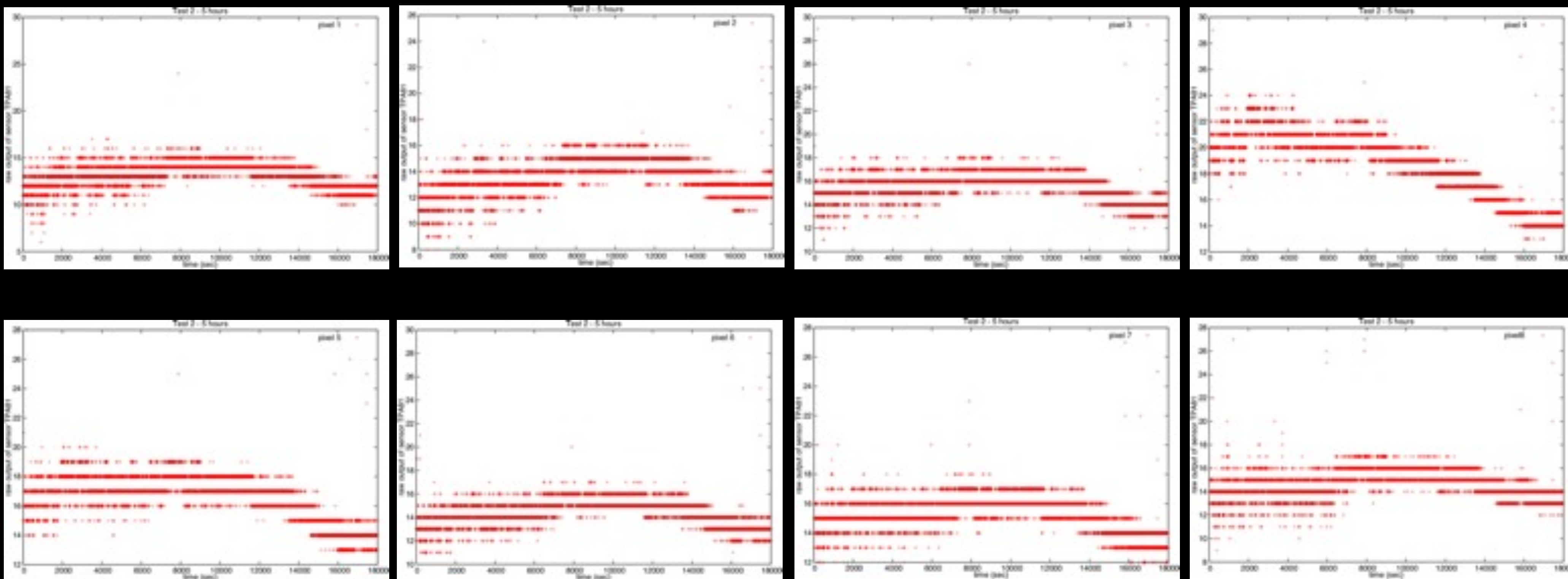
ambient pixel of TPA81 sensor ⬇



Test2: 5 hours (1:45 pm - 6:45 pm)
several persons traversed the corridor in both senses.
1 record each second.

Finding patterns (6)

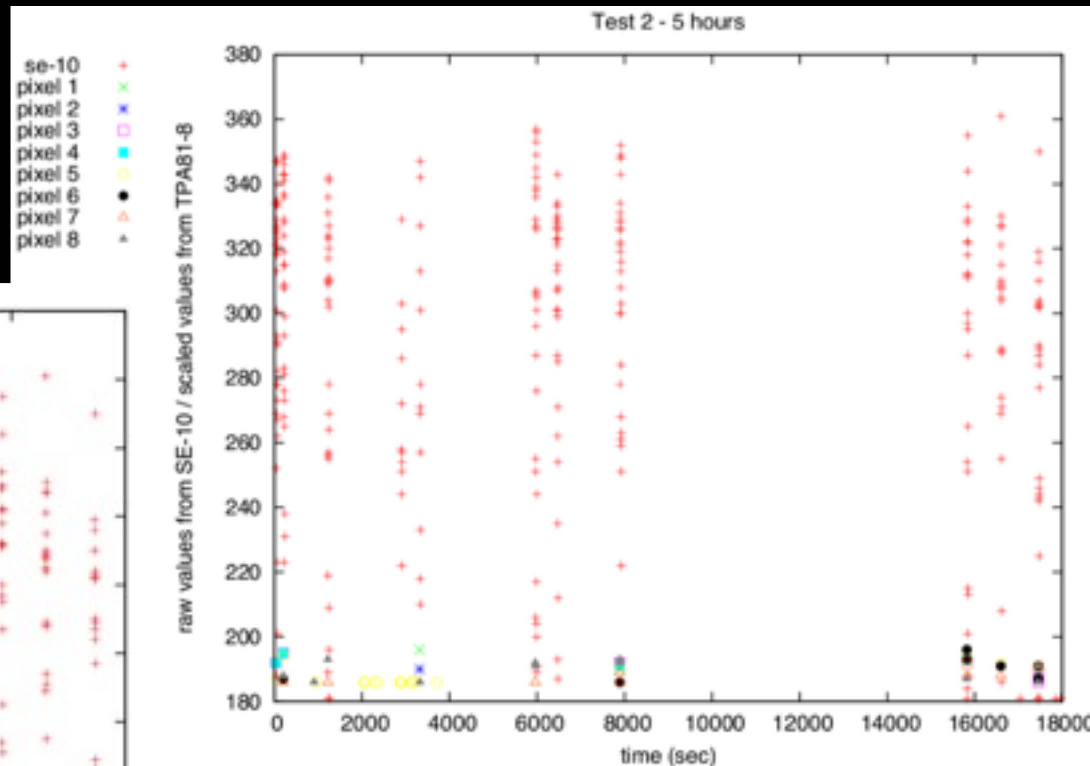
Test2: 5 hours (1:45 pm - 6:45 pm) several persons traversed the corridor in both senses.
1 record each second.

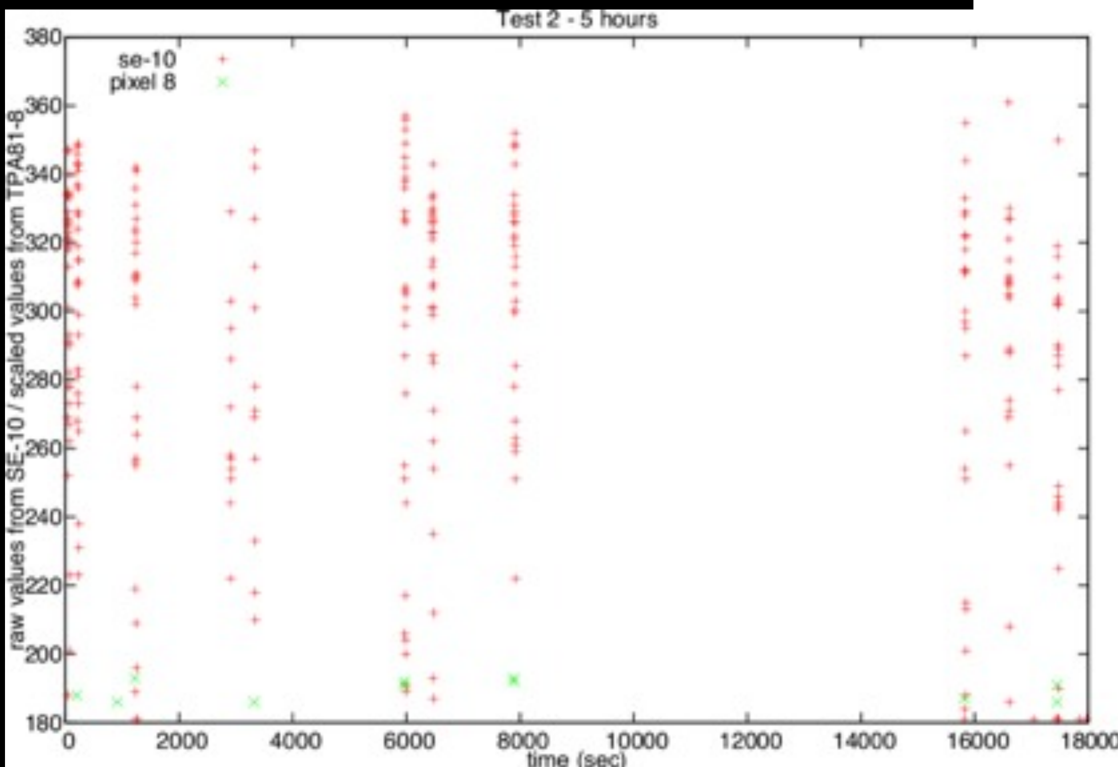


⬆ Test2: Raw output from pixel1 to pixel8 of TPA81 sensor, from left-top figure to right-bottom figure.

Finding patterns (7)

Scaling and matching
⬇ two and nine ➡
"evidences"



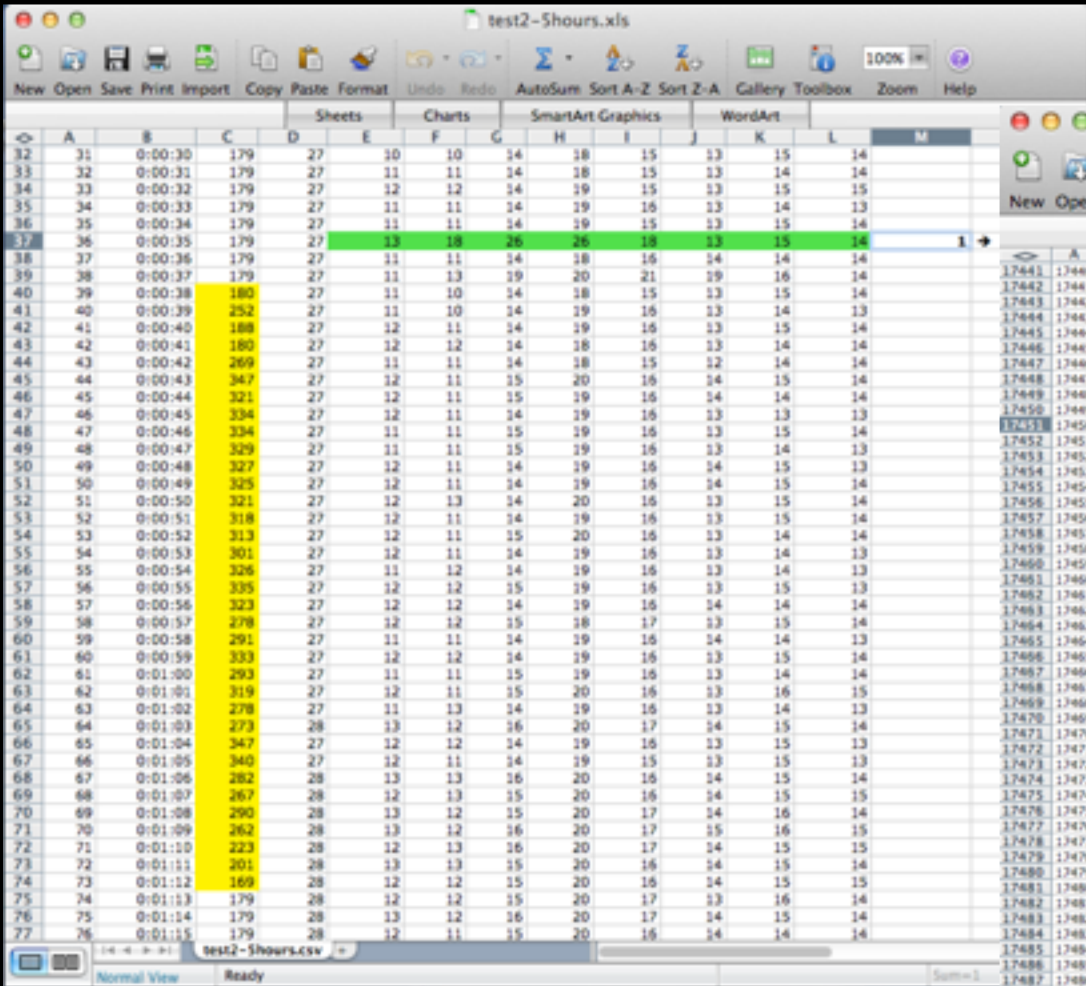


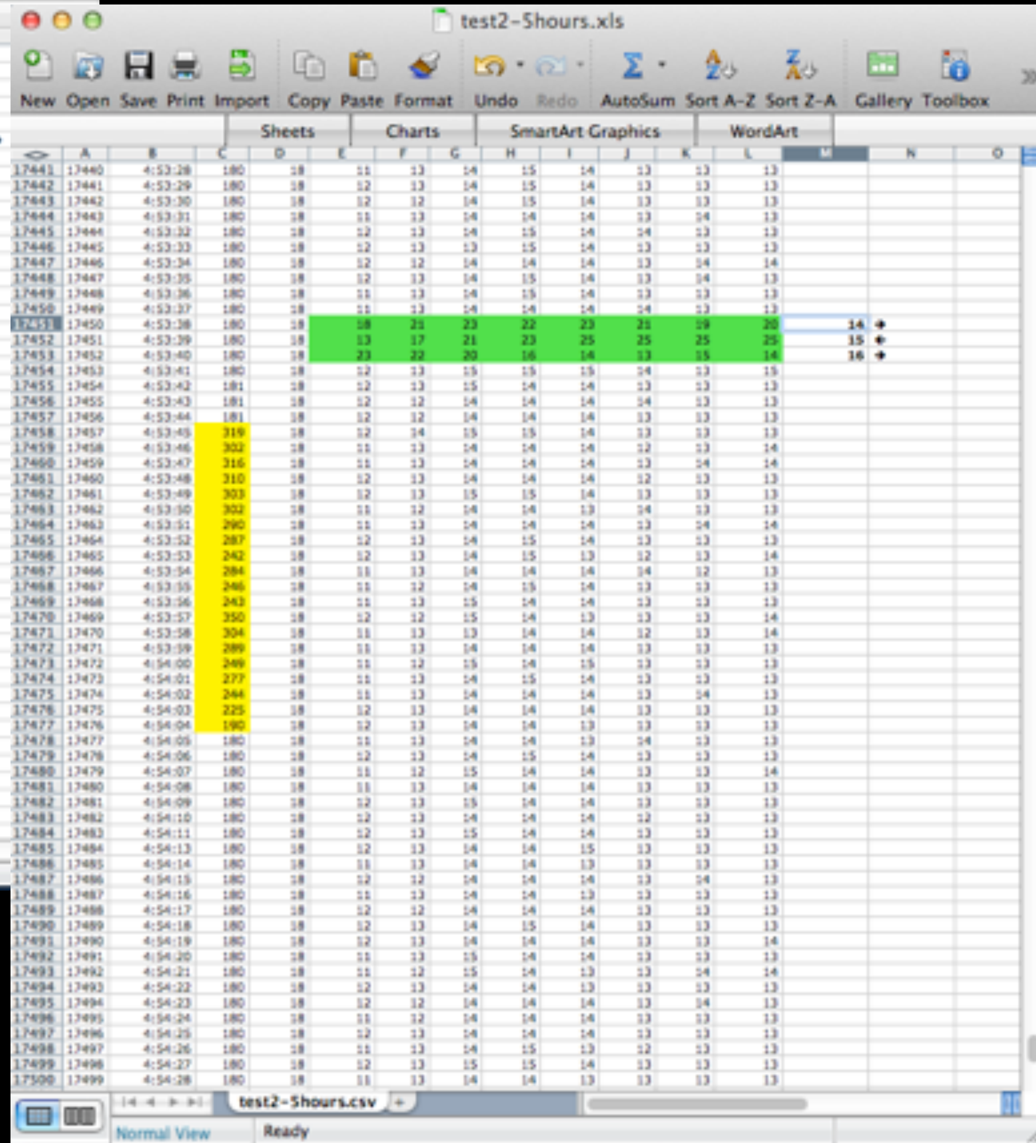
Test2: 5 hours (1:45 pm - 6:45 pm) several persons traversed the corridor in both senses.
1 record each second.

Finding patterns (8)

Test2: 5 hours (1:45 pm - 6:45 pm) several persons traversed the corridor in both senses. 1 record each second.

People can be detected from periods or rows of high values





⬆SD-10: stdev of 0.5 means empty corridor,

stdev of 90.0 means movement.
TDP81:changes of more than 3 degrees ➡ from previous values of individual pixels.

Finding patterns (9)

test2-5hours.xls

	B	C	D	E	F	G	H	I	J	K	L
2890	0:48:36	179	26	13	14	16	22	18	14	15	14
2891	0:48:37	179	27	15	15	18	23	19	15	17	16
2892	0:48:38	179	27	15	14	16	23	19	16	17	15
2893	0:48:39	179	27	13	14	17	23	18	16	16	15
2894	0:48:40	179	27	14	15	18	23	19	15	17	15
2895	0:48:41	179	27	14	14	17	22	18	15	16	15
2896	0:48:42	179	27	14	14	17	23	19	15	16	15
2897	0:48:43	179	26	12	13	16	22	17	14	15	15
2898	0:48:44	180	27	15	15	17	23	19	15	16	16
2899	0:48:45	180	26	13	14	16	22	18	15	15	14
2900	0:48:46	180	27	15	14	17	23	19	15	16	16
2901	0:48:47	180	27	14	15	17	22	19	16	17	15
2902	0:48:48	180	27	14	15	17	23	19	16	16	15
2903	0:48:49	258	27	15	14	16	23	18	15	17	15
2904	0:48:50	180	27	15	14	17	22	19	16	16	15
2905	0:48:51	244	27	14	14	16	23	19	15	16	15
2906	0:48:52	178	27	14	15	16	23	20	15	16	17
2907	0:48:53	171	27	13	14	17	23	19	15	17	16
2908	0:48:54	272	27	13	13	17	22	18	15	15	16
2909	0:48:55	222	27	13	14	16	22	19	15	17	16
2910	0:48:56	180	27	13	14	16	22	19	14	15	16
2911	0:48:57	329	27	15	14	16	22	19	15	16	16
2912	0:48:58	286	27	13	14	16	22	19	15	15	15
2913	0:48:59	303	27	13	13	17	22	17	15	16	15
2914	0:49:00	257	27	13	14	17	22	19	15	16	15
2915	0:49:01	295	27	13	14	16	22	18	15	17	15
2916	0:49:02	254	27	15	13	17	22	19	15	16	15
2917	0:49:03	251	27	14	14	16	22	18	15	16	15
2918	0:49:04	180	27	13	14	17	22	18	15	16	15
2919	0:49:05	179	27	13	14	17	23	18	16	16	16
2920	0:49:06	179	27	14	14	17	22	19	15	16	15
2921	0:49:07	179	27	13	14	16	22	18	15	16	16
2922	0:49:08	179	27	13	14	17	23	18	15	17	15
2923	0:49:09	179	27	14	14	16	22	19	16	17	15
2924	0:49:10	179	27	13	15	17	22	18	16	17	16
2925	0:49:11	179	27	14	14	17	22	18	15	17	15
2926	0:49:12	180	27	14	15	17	22	19	15	16	16
2927	0:49:13	179	27	14	14	16	22	19	15	16	16
2928	0:49:14	179	27	14	15	16	22	18	15	16	15
2929	0:49:15	179	27	13	14	17	21	18	14	16	15
2930	0:49:16	179	27	15	14	16	22	18	15	16	15
2931	0:49:17	180	27	14	14	17	22	18	15	15	14
2932	0:49:18	179	27	14	14	16	21	18	15	16	15
2933	0:49:19	179	27	14	14	16	22	19	15	16	15
2934	0:49:20	179	27	15	14	16	22	18	15	16	14
2935	0:49:21	179	27	13	14	17	21	18	15	16	15

test2-5hours.csv

Test2: 5 hours (1:45 pm - 6:45 pm) several persons traversed the corridor in both senses.
1 record each second.

← Sometimes people are only detected by one sensor (SE-10), that is not by the way the most accurate sensor!

Finding patterns (10)

How is it possible that sometimes a poor sensor outperforms a highly accurate sensor?

Any idea?

Finding patterns (11)

Preliminary results based
⬇ on previous regularities

	SD-10	TPA-81	SD-10 & TPA-81	Ground truth
	1	1	1	1 adult
	1	1	1	1 adult
	1	1	1	1 adult
	1	0	1	1 kid
	1	2	2	2 adults
	1	2	2	2 adults
	1	0	1	2 kids
	1	3	3	3 adults
	1	2	2	2 adults
	1	1	1	1 adult
	1	3	3	3 adults
Totals	11	16	18	19

Finding patterns (12)

There are many other techniques and filters to detect regularities in datasets of soft phenomena.

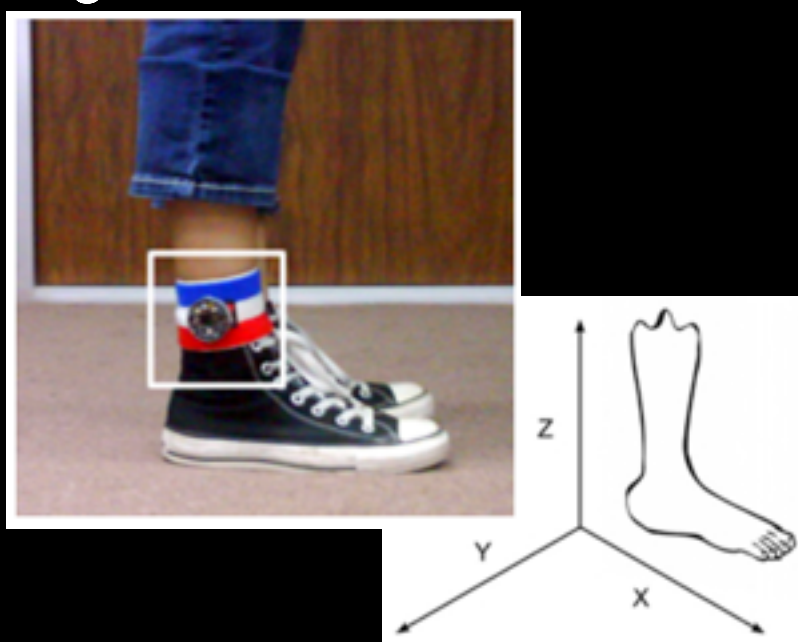
Some key ideas:

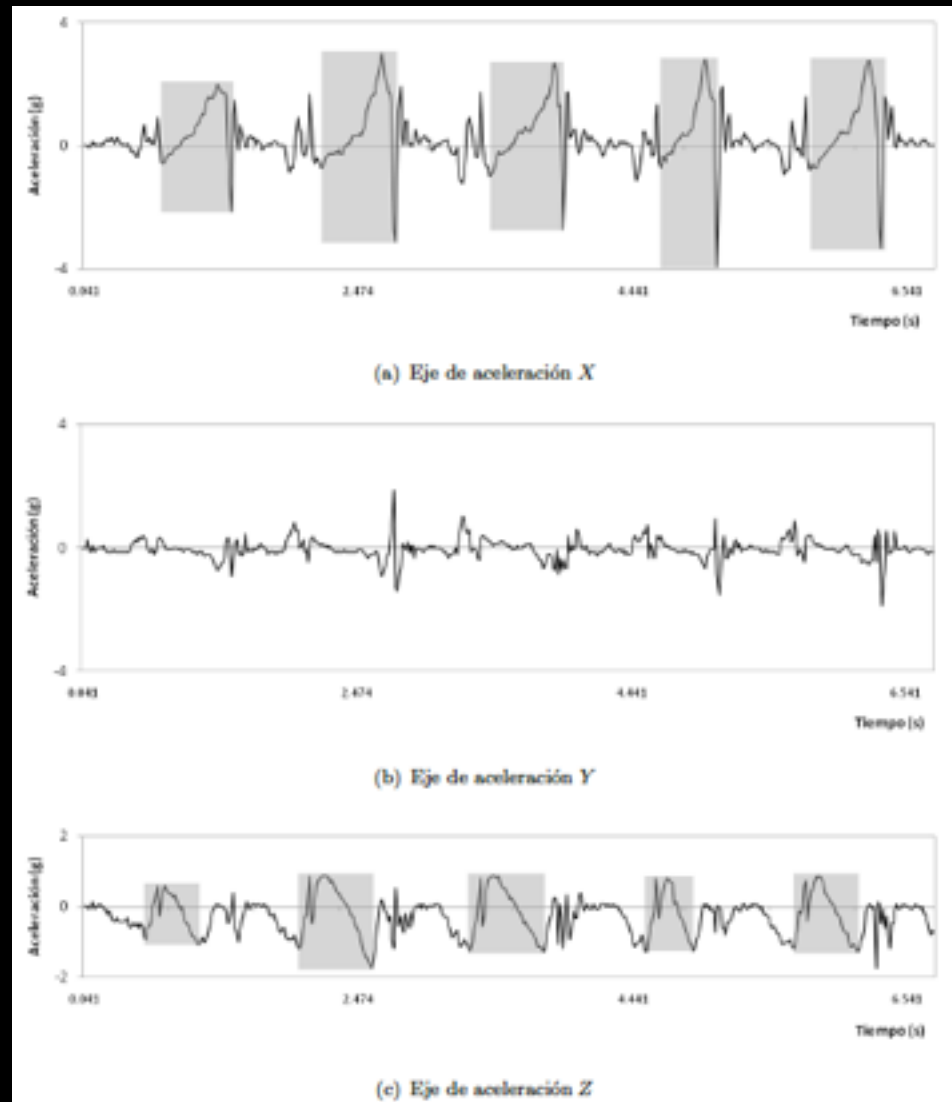
- combine & complement different sensors
- use reliable patterns based on dynamic/flexible thresholds or features of the sensor’s signal.
- apply known filters, such as Kalman, particle filter, etc.
- apply machine learning algorithms.

Finding patterns (13)

Some examples used in our research

related characteristic peaks in two axis in acceleration signals for estimating parameters of the human gait.

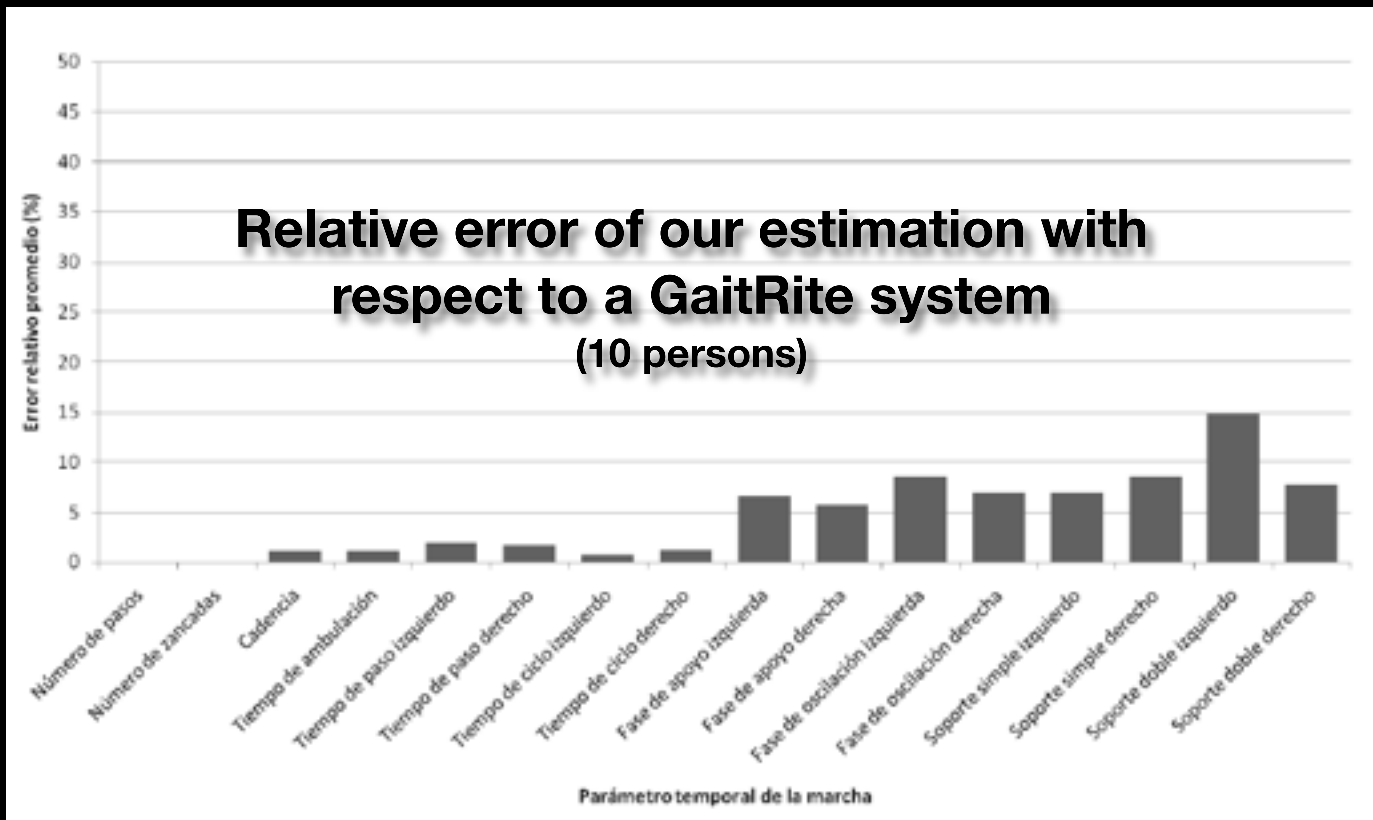




Finding patterns (14)

Some examples used in our research

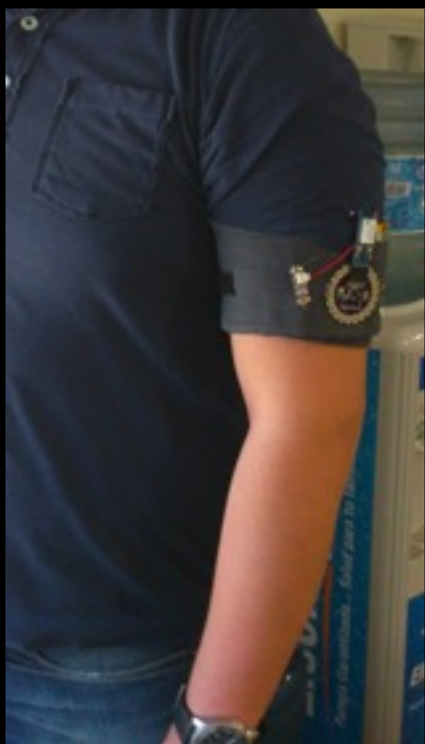
related characteristic peaks were competitive for estimating temporal parameters of the human gait using two wearable triaxial accelerometers (ZStar3 from Freescale, Austin, TX USA) under controlled conditions when compared to a GaitRite System (from CIR Industries, Clifton, NJ USA).



Finding patterns (15)

Some examples used in our research

features of intervals of acceleration signals, such as tendency, changes of area of gravity.

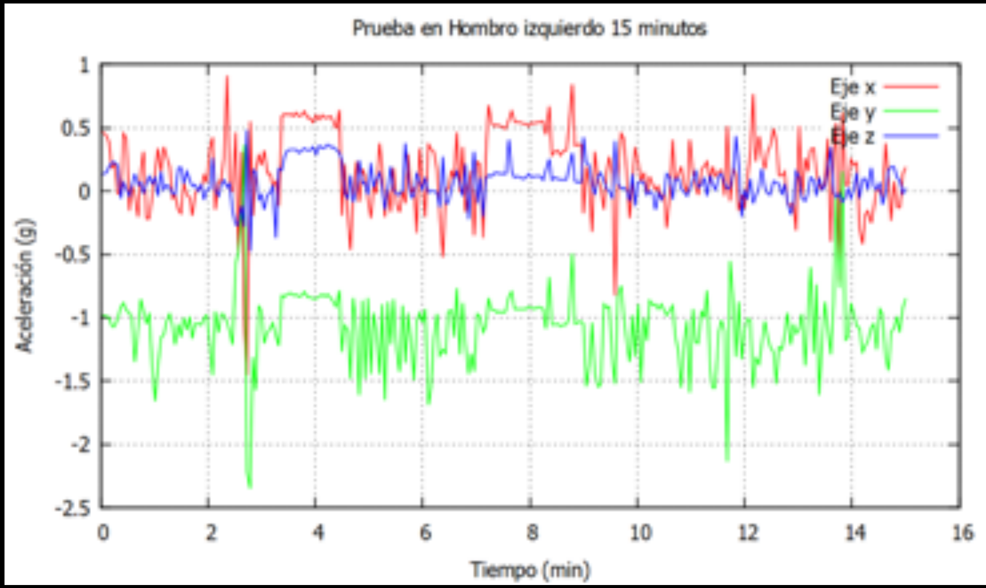


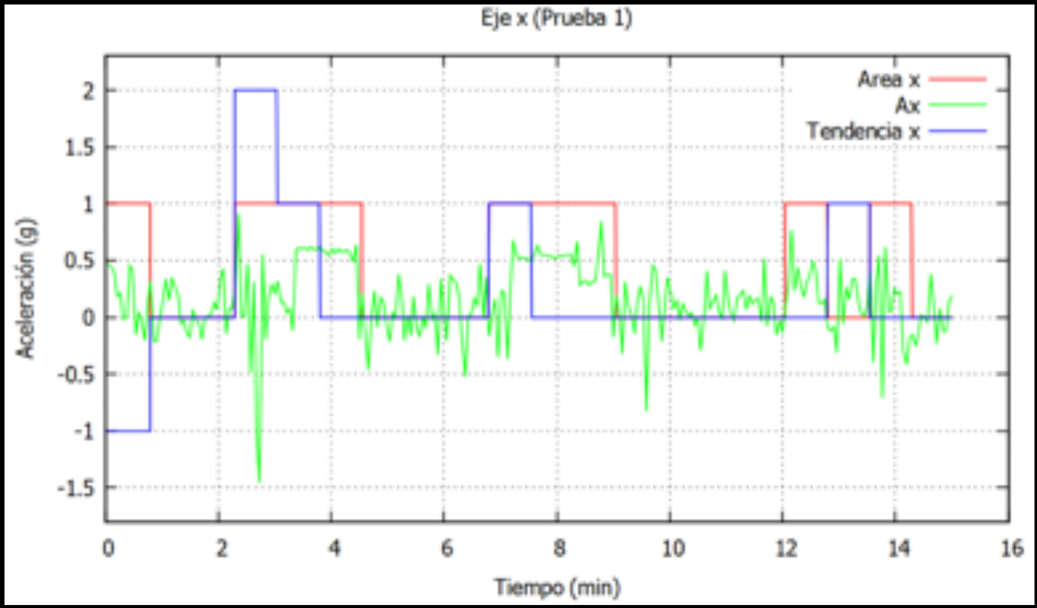
UBI Health UBI Health UBI Health UBI Health

Finding patterns (16)

Some examples used in our research

features of intervals of acceleration signals, such as tendency, changes of area of gravity.

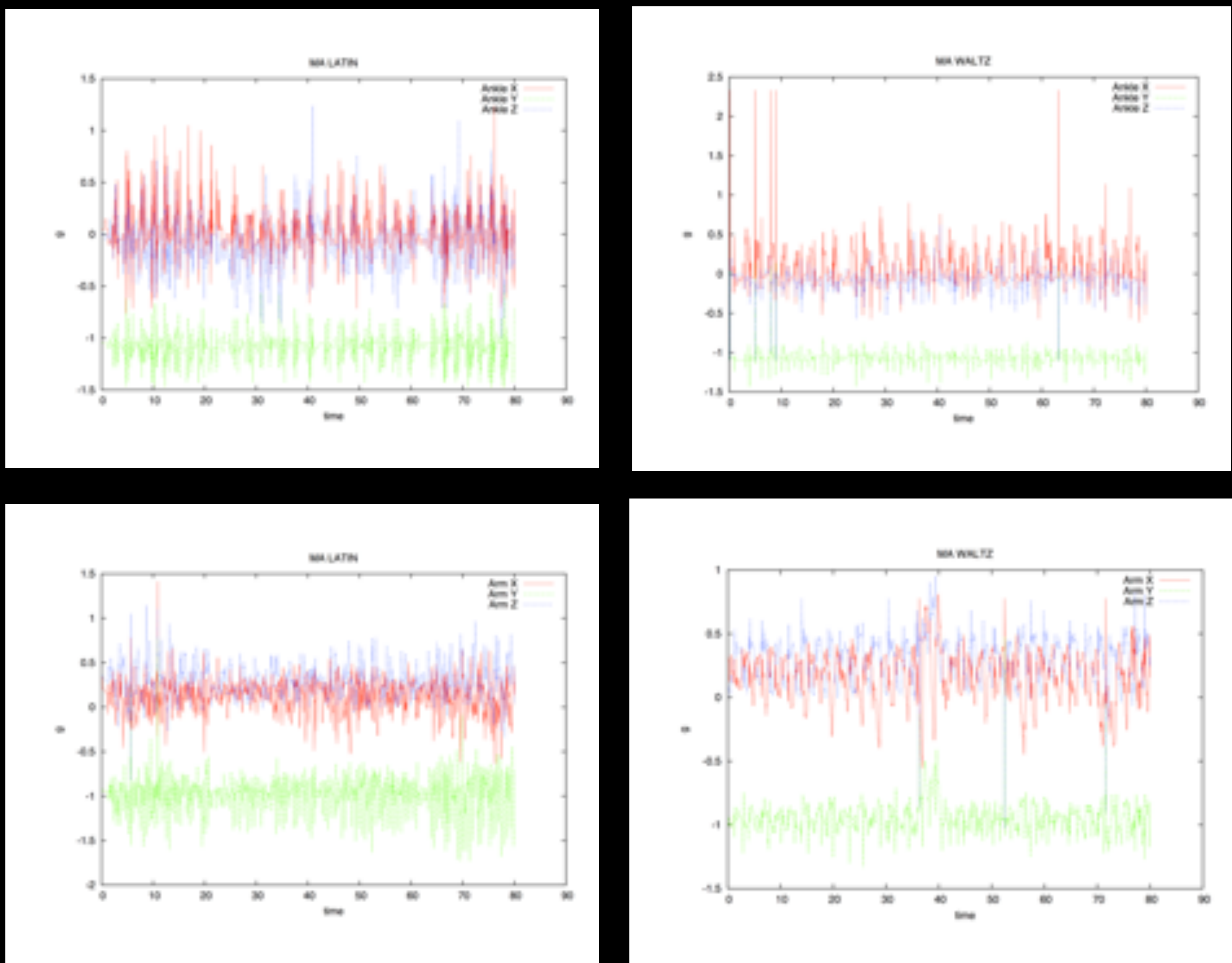




Finding patterns (17)

Some examples used in our research

features of intervals of acceleration signals, such as tendency, changes of area of gravity.



Finding patterns (18)

Some examples
used in our research

Designing sensors

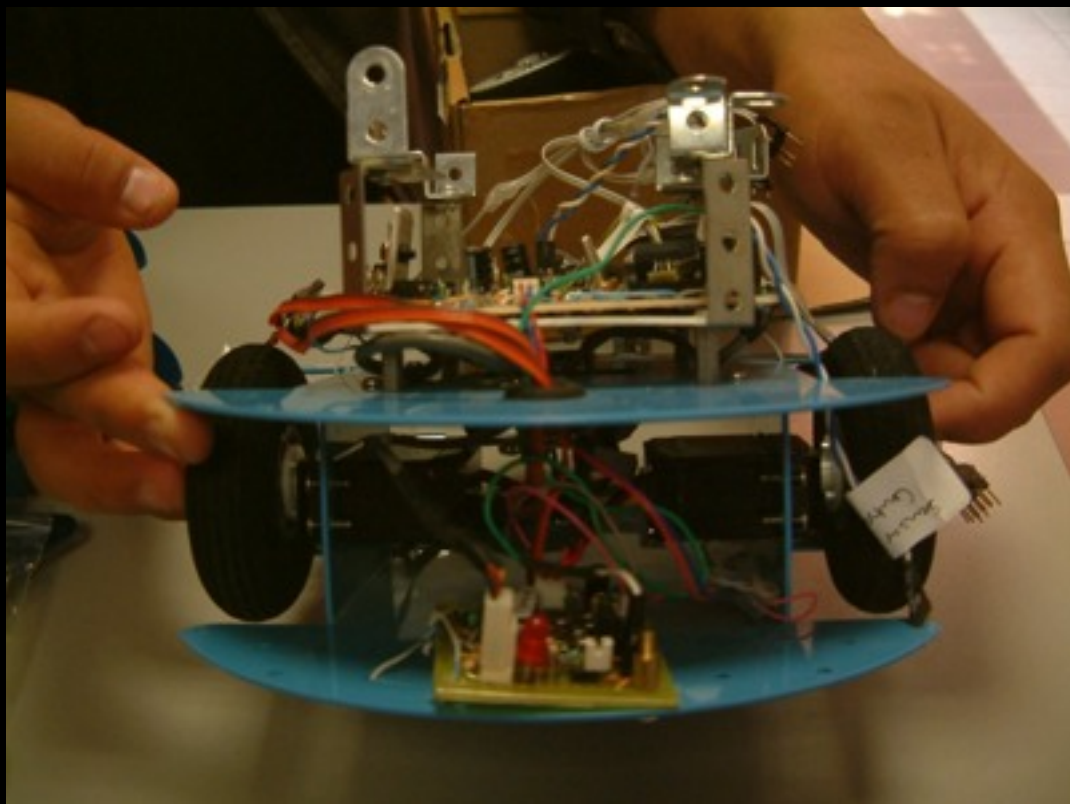
Designing your own sensors (1)

What if the sensor or module needed for your project doesn't exist or require a lot do-it-yourself work?

Consider to build or adapt yourself a module or sensor or consider to collaborate with other people to build it!

Designing your own sensors (2)

Hands-on experience in the design of sensors for micro mobile robots.



Local recognition on some elements of the environment and other robots. Each robot controlled by a Handyboard (MIT, Boston, USA) based on the chip 68HC11 from Motorola.

Main drawback:

limited processing capabilities

Designing your own sensors (3)

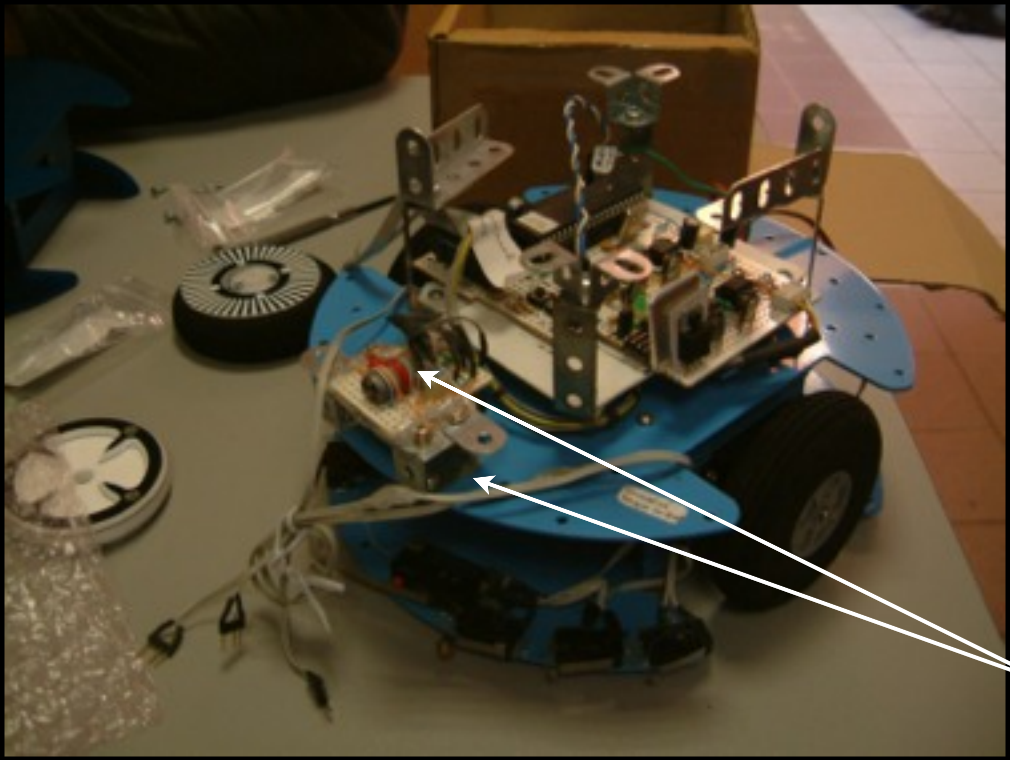
Hands-on experience in the design of sensors for micro mobile robots.

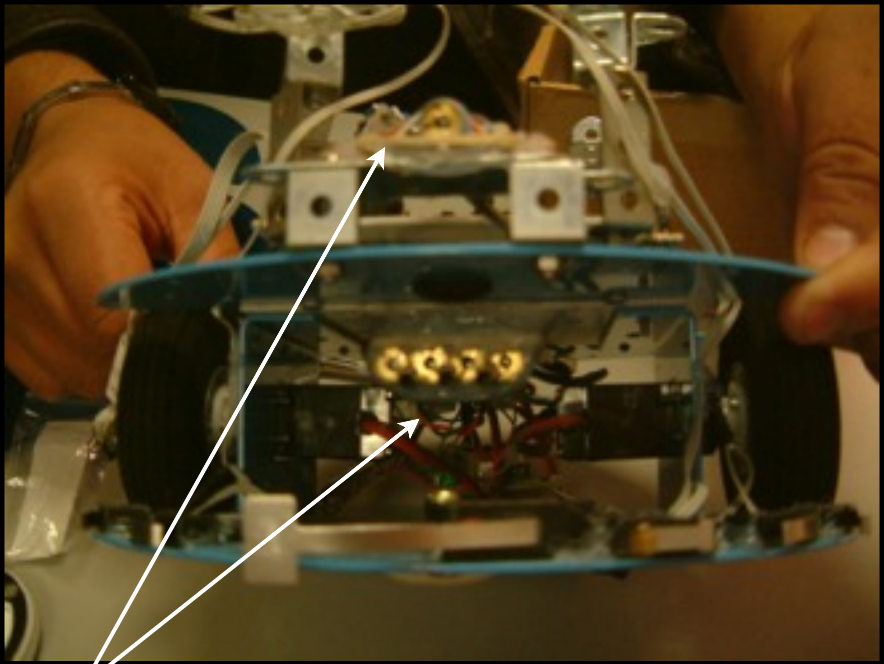
Bar code reader based on past experiences for the recognition of coded information in environmental landmarks and fiducial codes worn by robots.

The original system was developed for the MICROBRES project (University of Paris VI, Paris, France) between 2001-2003 and it relies on a CCD camera.

Designing your own sensors (4)

Hands-on experience in the design of sensors for micro mobile robots.

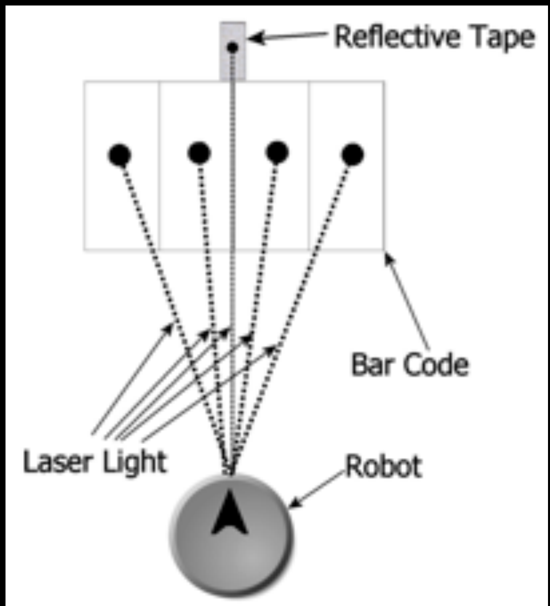


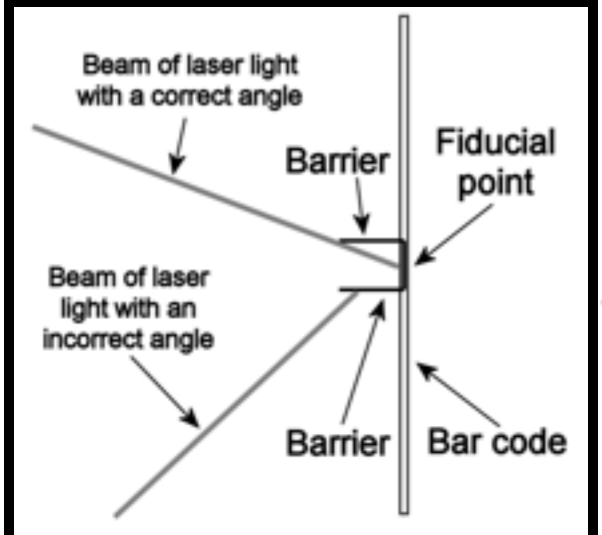


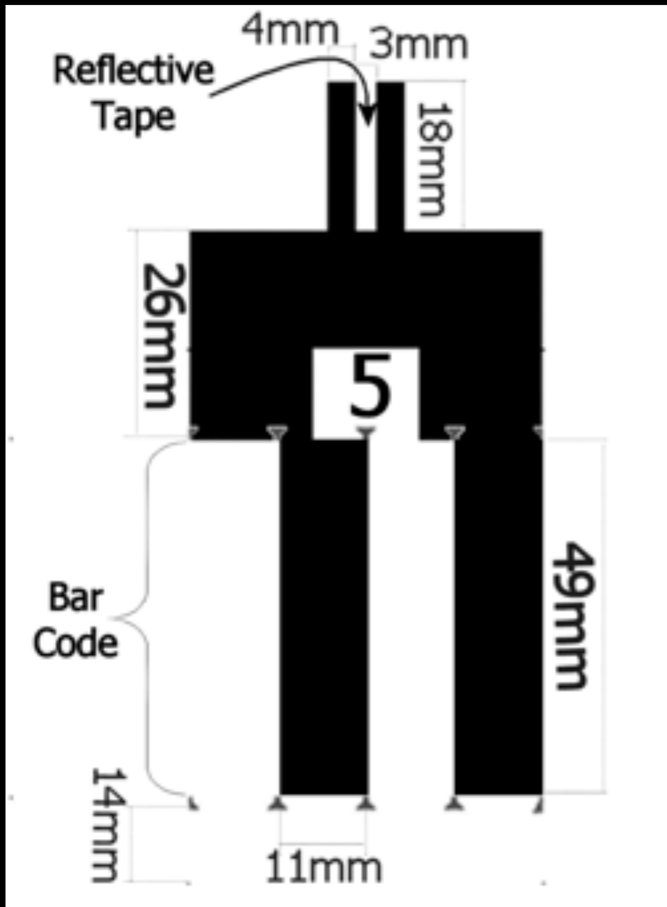
Active bar code reader of 4-bit landmarks.

Designing your own sensors (5)

Hands-on experience in the design of sensors for micro mobile robots.





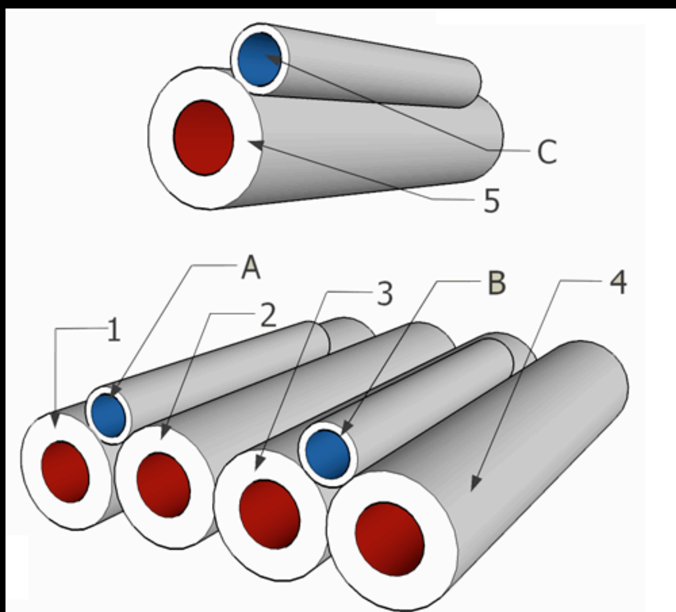


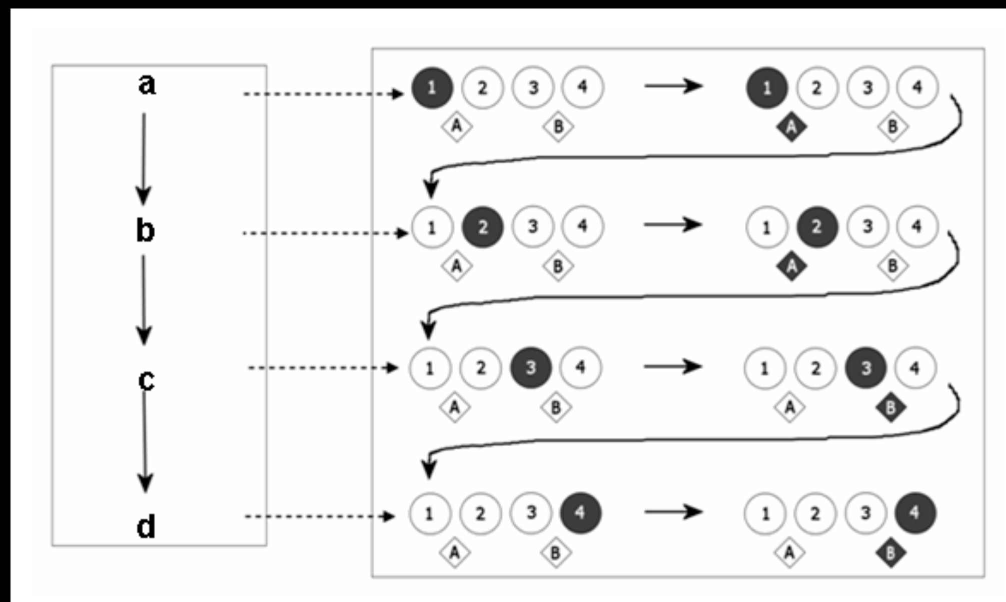
⬆ Robot reading a bar code and ⬆ scheme of functioning (top view)

composition of a bar code (frontal view) ➡

Designing your own sensors (6)

Hands-on experience in the design
of sensors for micro mobile robots.





Scheme of the procedure for reading a bar code once the fiducial point has been detected.

Designing your own sensors (6)

Hands-on experience in the design of sensors for micro mobile robots.

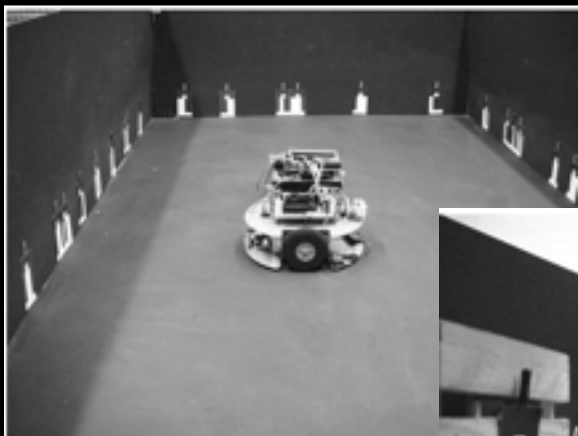


TABLE I

Time (min-secs)	*Bar code actual*	*read*	*Distance (cm)*	*Angle (degrees)*
3'50"	5	5	32.7	85
8'45"	7	7	24.0	60
13'53"	9	1	14.6	80
15'05"	2	2	25.4	83
17'15"	12	12	12.5	66
18'07"	5	1	13.0	70
18'34"	5	5	13.9	65
29'25"	1	1	11.0	60

TABLE II

Time (min-secs)	*Bar code actual*	*read*	*Distance (cm)*	*Angle (degrees)*
2'43"	13	11	10.0	50
17'45"	12	12	20.2	89
18'07"	11	11	10.2	63
18'36"	9	9	27.0	89
23'17"	5	5	19.8	85
23'34"	5	1	9.8	62
25'49"	12	12	18.0	77
26'43"	10	10	26.8	66

Robot and environment, and results of recognition when moving at slow (4cm/se) and "fast" (6.33 cm/sec) speed.

Final Remarks

Don’t trust blindly your sensor! Read its datasheet and characterize it.

In spite of their accuracy two different sensors can complement each other.

A lot of work has to be done for synthesizing features provided by sensors.

Ad-hoc sensors need a lot of do-it-yourself work.

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Many thanks!

More information

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