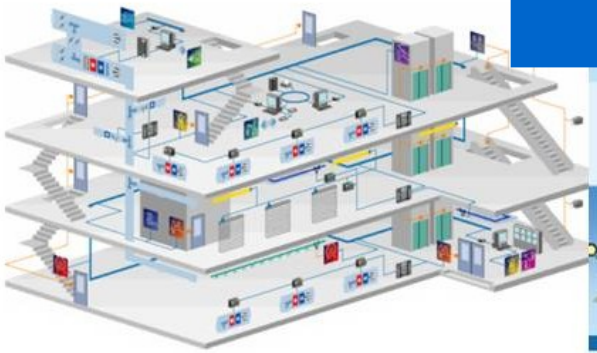
Sabbatical - ITIV-KIT Karlsruhe
Jan. 2022 – Mar. 2023



Machine Learning Algorithms for Occupancy-based Energy Efficient Smart Buildings

Prof. Adolfo Bauchspiess

LARA- Automation and Robotics Laboratory
Departamento de Engenharia Elétrica
Universidade de Brasília - Brazil

Summary

1 – Brazil – Brasília – UnB

2 – Short CV

3 – Some UnB Projects

- UAV Inspection of Power Transmission Lines
- Genetic Algorithm Identification of non-linear systems
- Thermal Comfort + Energy Savings in Buildings (Hybrid Climatization)
- Zero Energy Buildings

4 – Research Proposal at ITIV

- Occupancy-based Automation
  - **Passive** thermal load estimation → Climatization
  - CSI – Channel State Information
  - RSSI – Received Signal Strength Indicator
  - CNN occupancy/activity estimation
- Changing environment – Are NN adequate? How?

5 – Machine Learning Challenges & Perspectives

Brazil-Brasília-UnB

Brazil > Rio de Janeiro - Carnaval - Pelé

Brazil

~8.5 Mio Km^2
~ 190 Mio Habit
~ 8.500 Km Coast

Brasília

1960 – President J. Kubitschek, Architekt O. Niemeyer
Paranoá Lake (articial) 1.000 m over the sea level
~3,1 mio inhabitants (Distrito Federal)

Universidade de Brasília

(Oscar Niemeyer, 1961)

UnB – Technology Faculty (FT)

UnB: Brasília, Gama, Ceilândia, Planaltina
48.045 students
2.818 lecturers
149 courses

FT ~10% da UnB

4 Departamentos
- Eng. Elétrica
- Eng. Mecânica
- Eng. Civil
- Eng. Florestal

10 Cursos (40 vagas/semestre)
- Eng. Elétrica
- Eng. Controle e Automação (Mecatrôni
- Eng. Redes de Comunicações
- Eng. de Computação
- Eng. Mecânica
- Eng. de Produção
- Eng. Civil
- Eng. Ambiental
- Eng. Florestal
- Eng. Química

UnB/FT/ENE

ENE: 60 professors in 5 areas:

Control & Automation, Telecom., Electronics, Power Systems and Network Eng.

- LARA – Automation and Robotics Lab.
- Aerospace Science and Innovation Lab.
- Process Automation Lab.
- ...

www.lara.unb.br

Short CV

Short CV - Adolfo Bauchspiess

graduated and got a master's degree in Electrical Engineering from the University of Brasília (UnB)-Brazil (1986, 1990)

Dr.-Ing. in Electrical Engineering from the Universität Erlangen-Nürnberg/Germany (1991-1995).

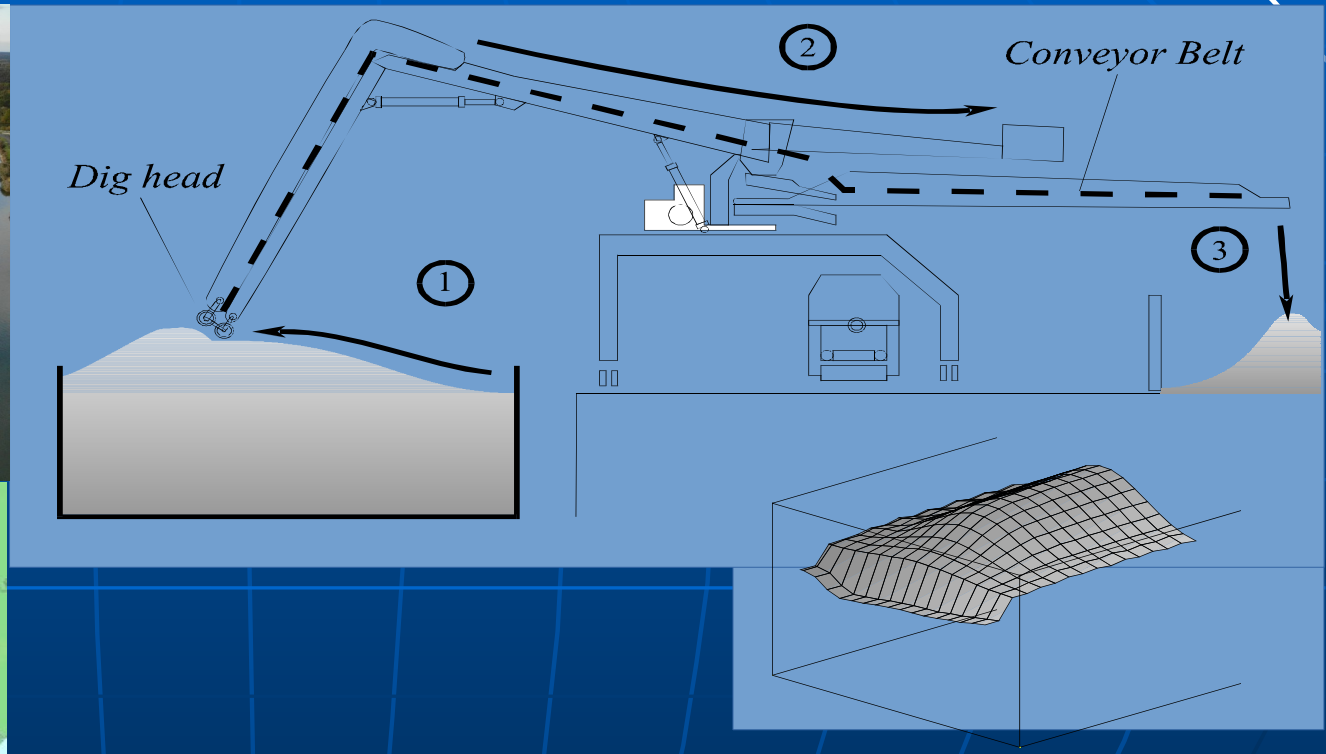
HW Engineer at NOVADATA Sistemas e Computadores (1986-1990)
Electrical Engineering Department – FT – UnB (1995 -)

Lectures at UnB

- **Control of Dynamic Systems**
- Identification of Dynamic Systems
- Computational Inteligence (Machine Learning)
- Building Automation with IoT

Coal Unloading – Erlangen/Germany

Main-Donau-Kanal Elangen/Germany



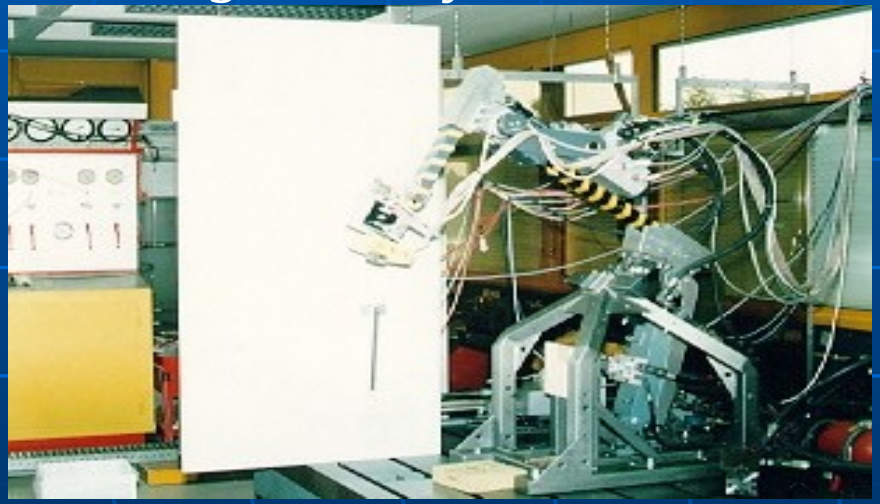
"Redundant Sensor Guided Unloading Crane"– MAN

*Trajectory Planning - **Fuzzy***

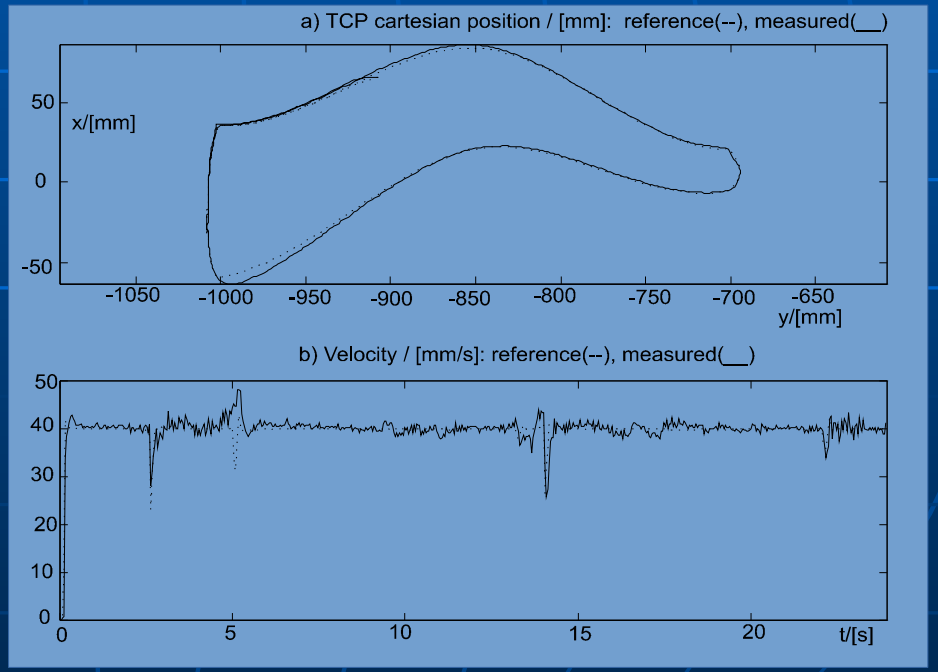
Bauchspiess, 1995

Universität – Erlangen-Nürnberg

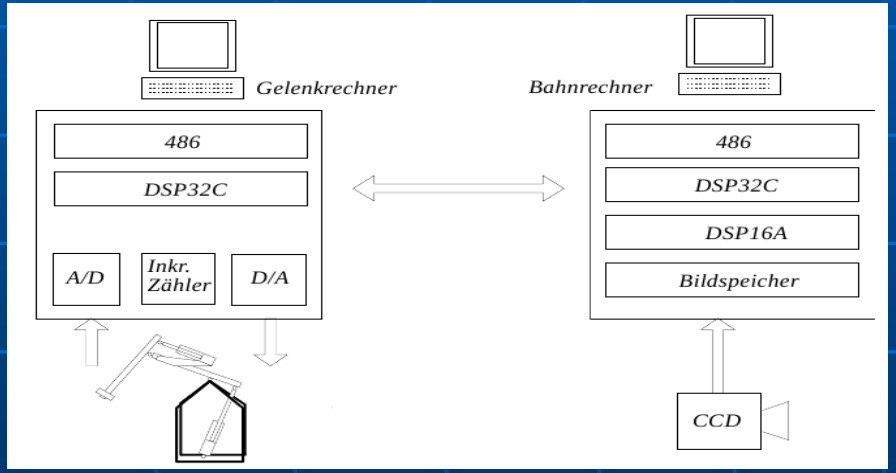
Sensor guided Hydraulic Robot

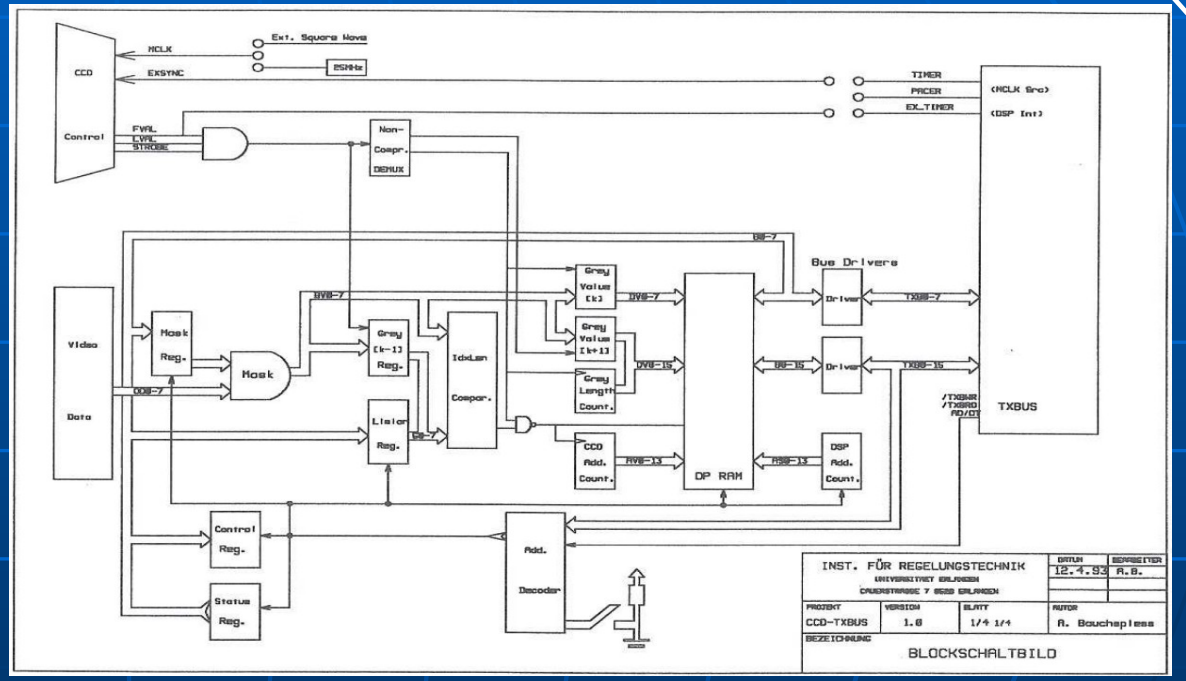


Bauchspiess, 1995



Universität – Erlangen-Nürnberg





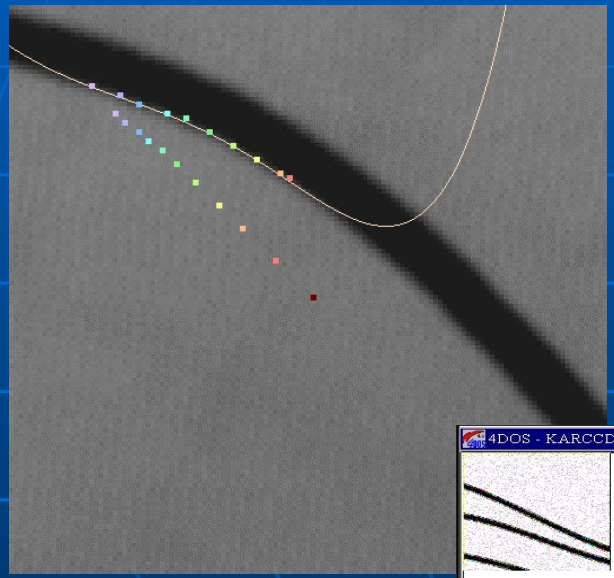
Multi-Processor System

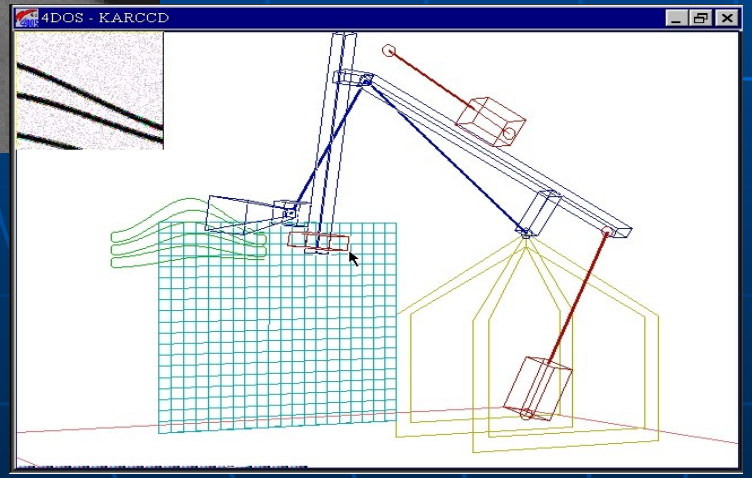
Running-Length Coding Framegrabber

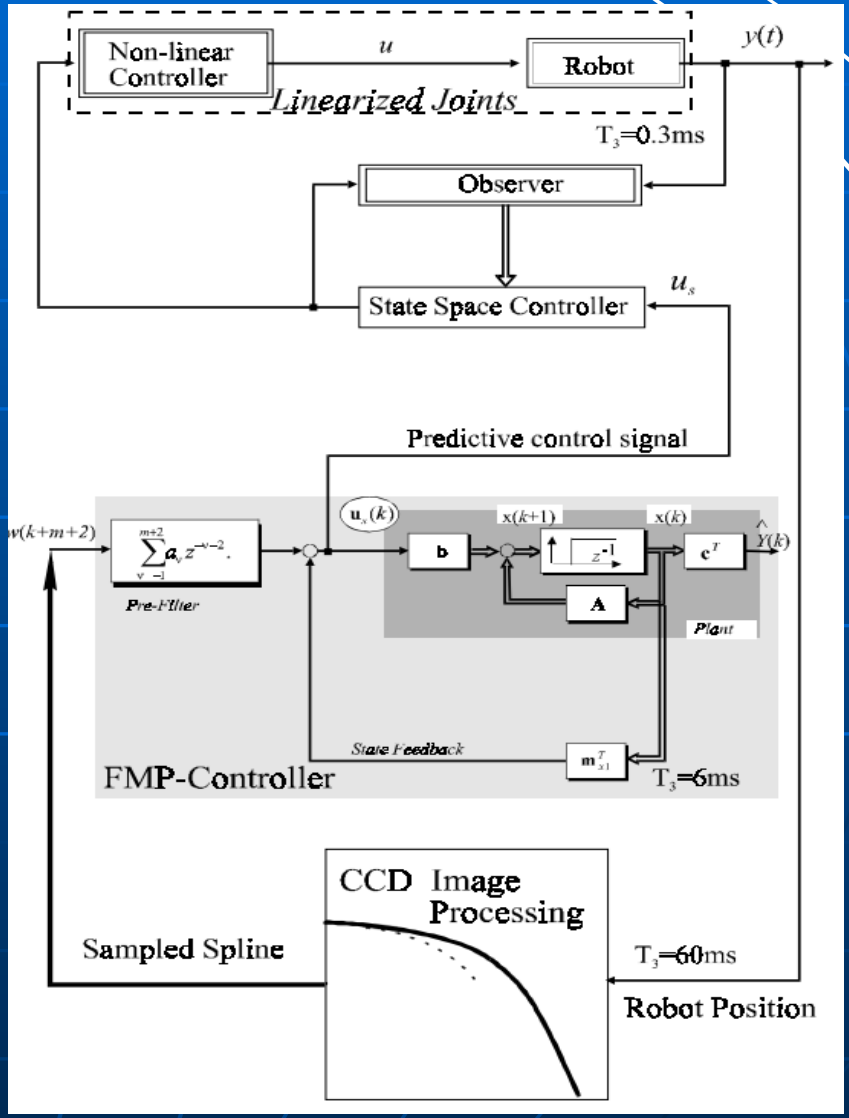
Stored Edges → future trajectory points

Bauchspiess, 1995

Following-Model Predictive Path Tracking







Machine Learning related "hot" Terms

- *Cybernetics*
- *Artificial Intelligence*
- *Computational Intel.*
- Soft computing
- *Machine Learning*
- *Ambient Intelligence*
- *Ubiquitous Computing*
- *Cyber Physical Systems*
- ***Smart** Cities*

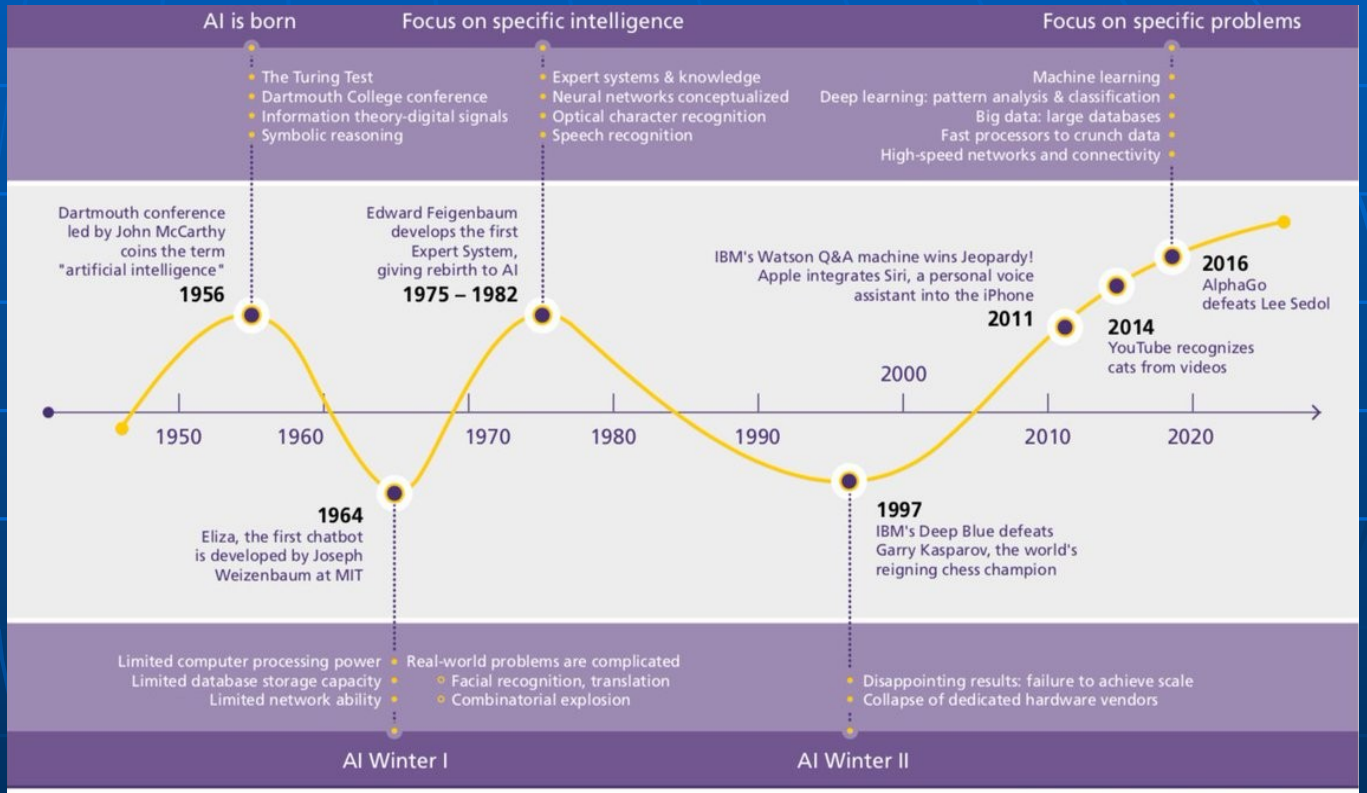
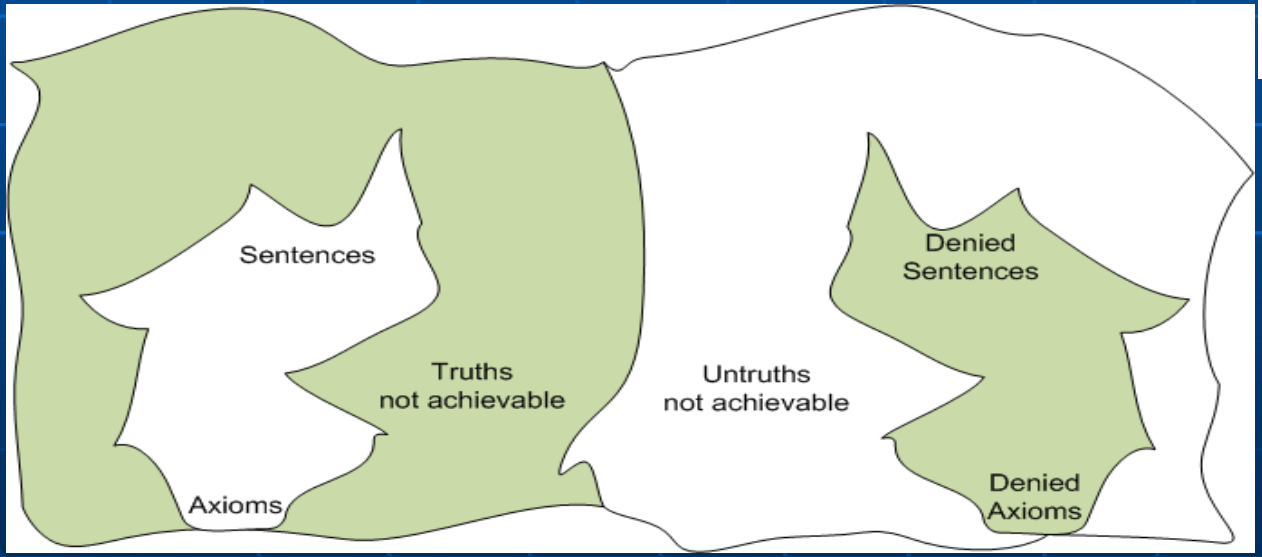
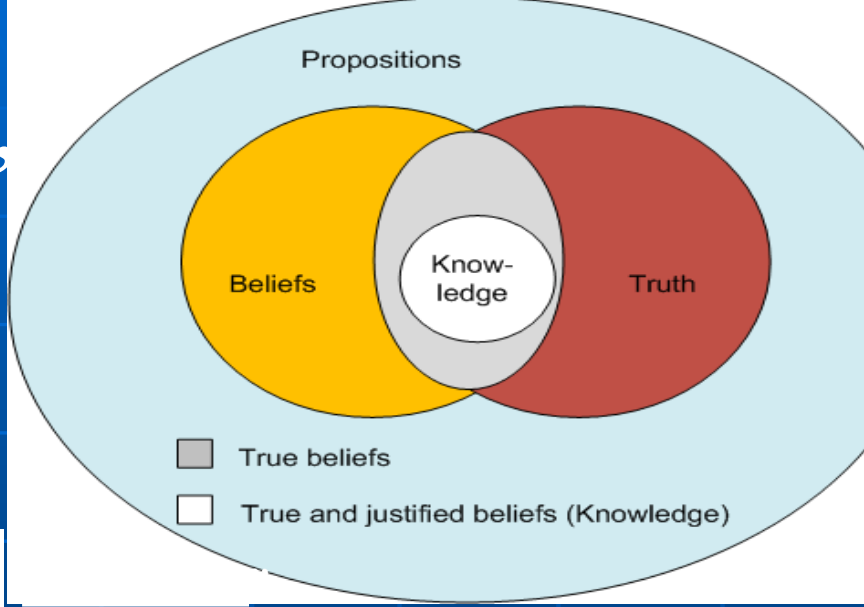


Figure 1: An AI timeline; **Source:** Lavenda, D./Marsden, P. source dhl via @mikequindazzi

“Philosophy of Knowledge”

Gödel's incompleteness theorems, 1931





A way that works,
but you do not know why.

“Sub-optimal solutions”
The brain is ***expert*** in finding
good heuristics!

Artificial Intelligence?

From Natural Intelligence to Artificial Intelligence

Ex. – Dislexia?

I cnduo't bvleiee taht I culod aulaclty uesdtannrd waht I was rdnaieg. Unisg the icndeblire pweor of the hmuan mnid, aocdcrnig to rseecrah at Cmabrigde Uinervtisy, it dseno't mttaer in waht oderr the lterets in a wrod are, the olny irpoamtnt tihng is taht the frsit and lsat ltteer be in the rhgit pclae. The rset can be a taotl mses and you can sitll raed it whoutit a pboerlm. Tihs is bucseae the huamn mnid deos not raed ervey ltteer by istlef, but the wrod as a wlohe. Aaznmig, huh? Yaeh and I awlyas tghhuot slelinpg was ipmorantt!

See if yuor fdreins can raed tihs too.

Some UnB Projects

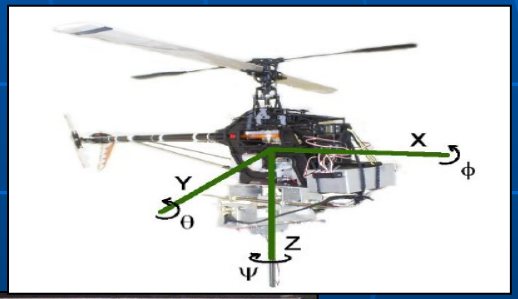
Inspection of Power Transmission Lines

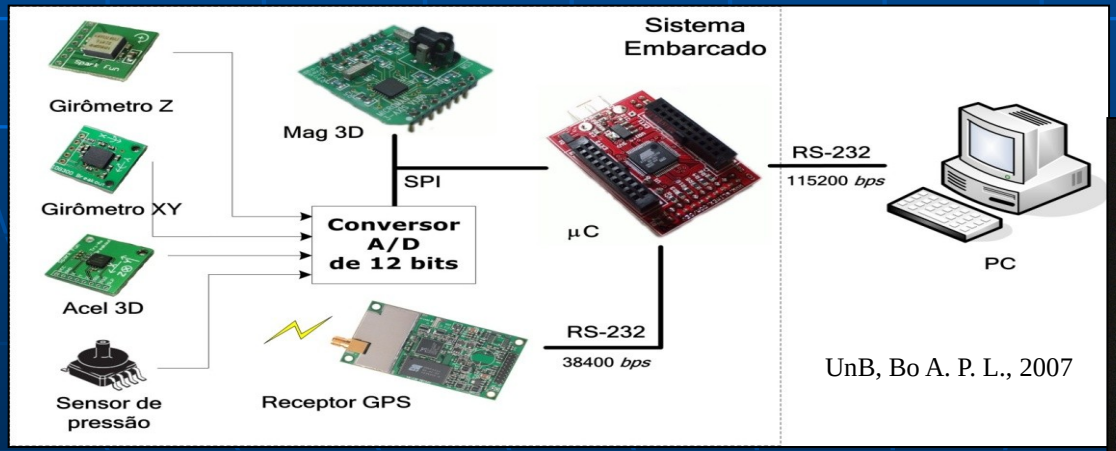
Traditional vs Autonomous system
- visual inspection of electricity transmission lines
- detection of flaws in the gripper of the line spacers

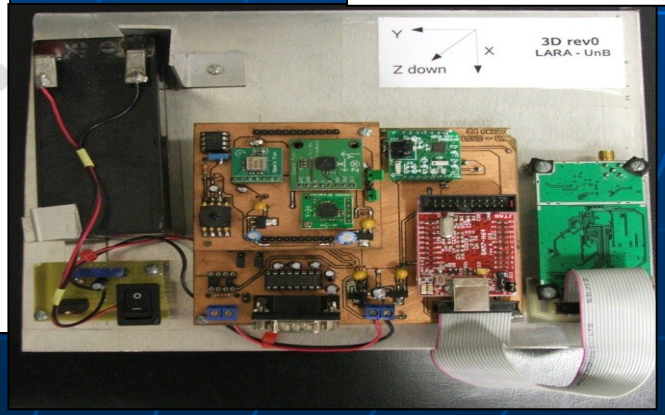
Need Maintenance!!

Inspection of Power Transmission Lines

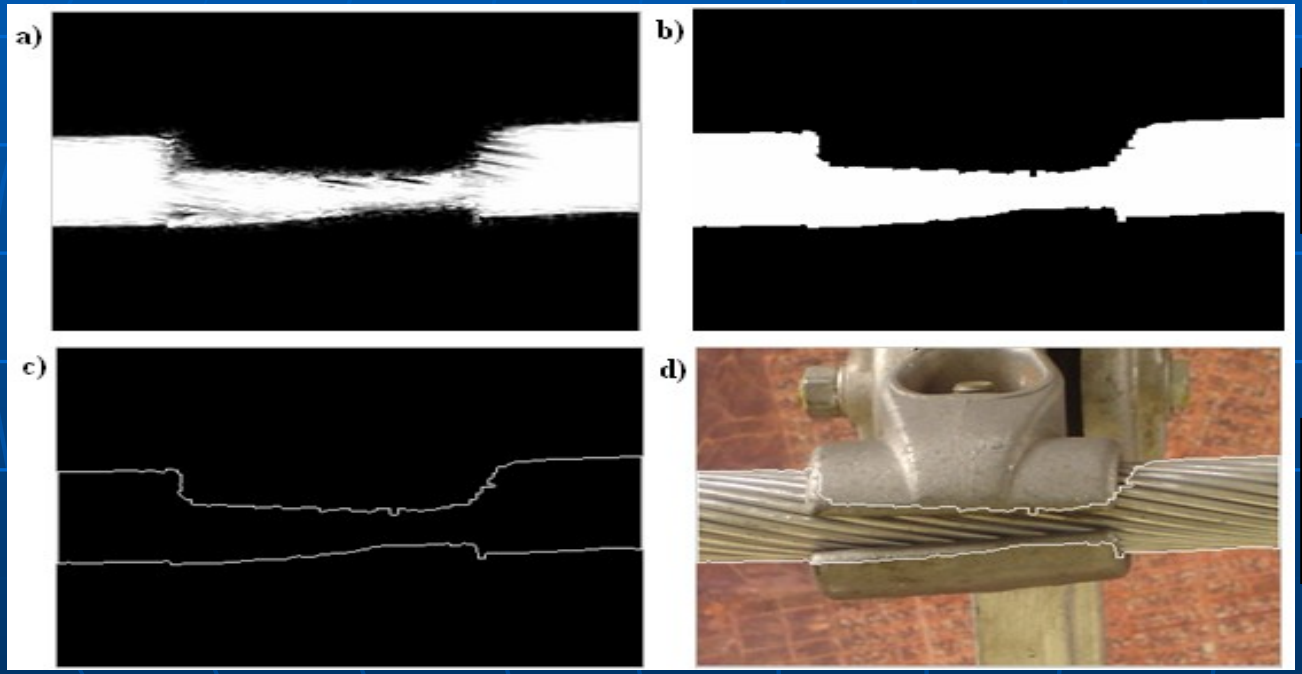
- Adaptation of Unmanned Aerial Vehicles (UAVs)
- Research project UNB / ANEEL - Expansion
  - Development of an UAV to aid inspecting transmission lines



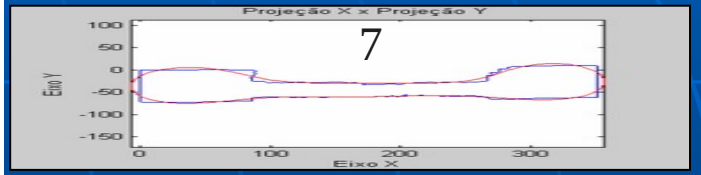


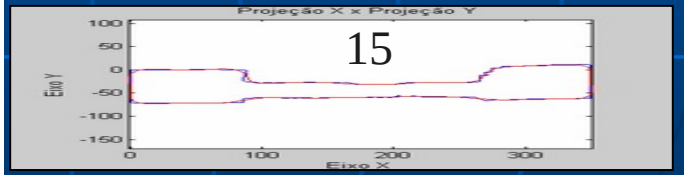


Gripped cable contour:
FFT coefficients of directional chains



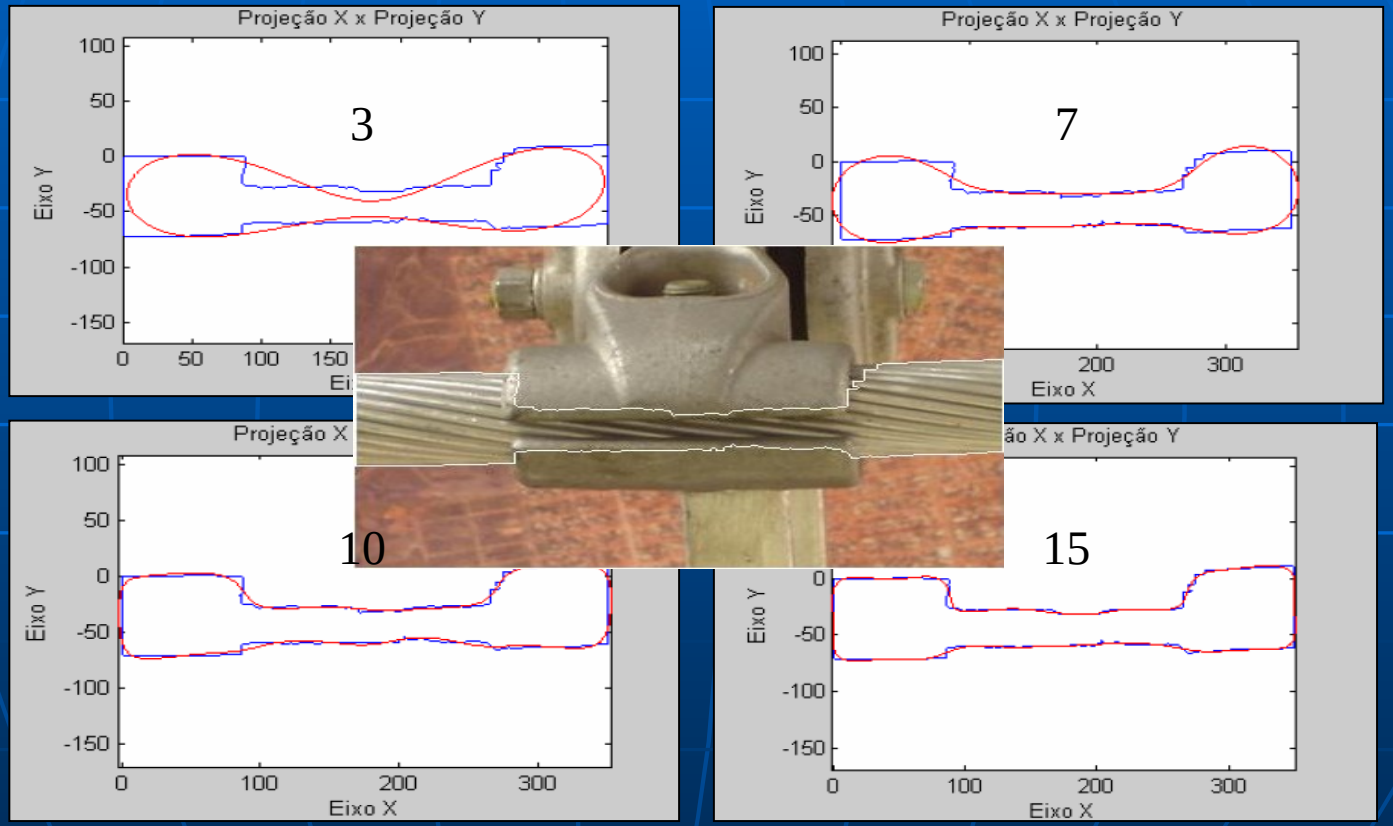
a) Gabor – b) Closing – c) Border – d)Image



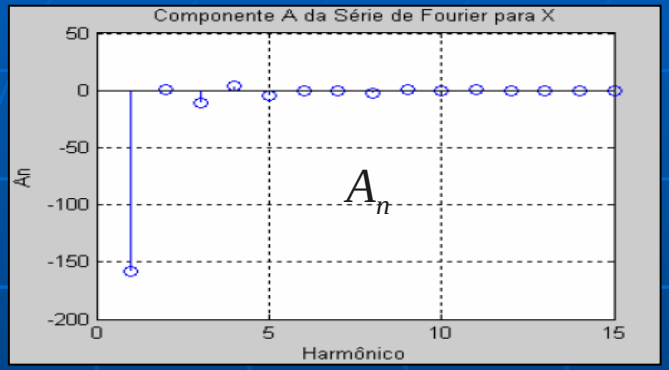


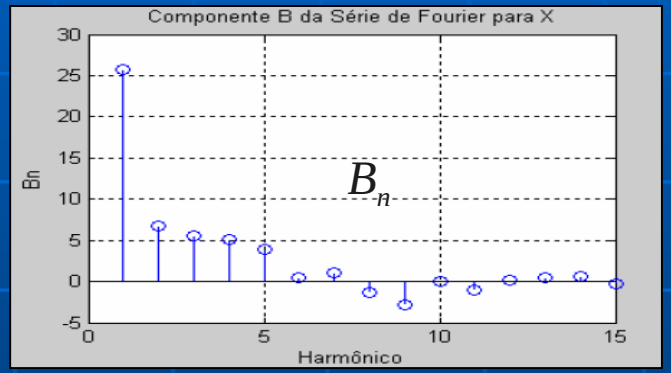
Reconstruction -
7 and 15 Harmonics

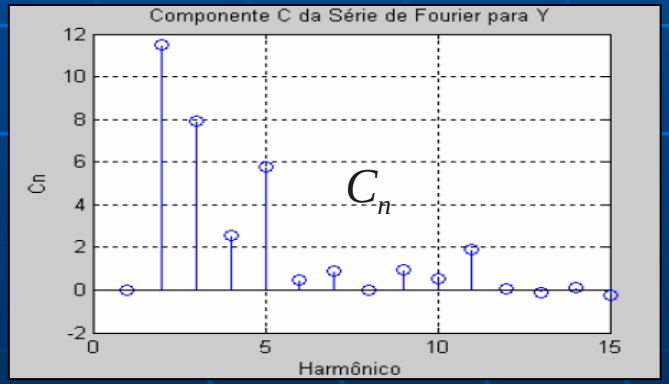
Results – Representation of the contour

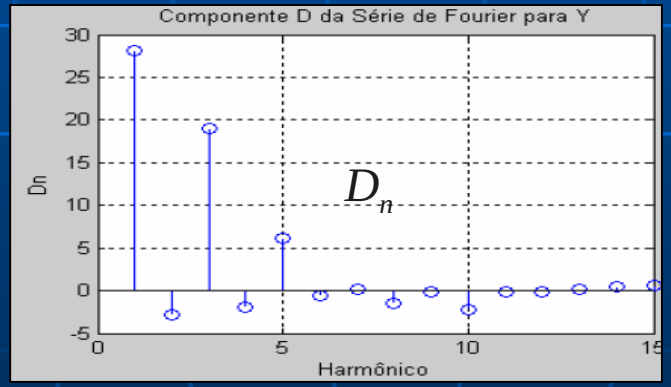


Gripped cable contour:
FFT coefficients of directional chains



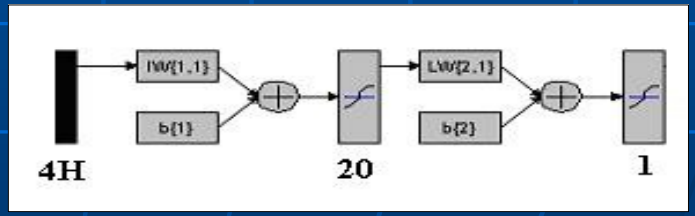






- ANN –
- “Need Maintenance”
- classification

- Training, Test, Validation
- 80, 25, 25 images

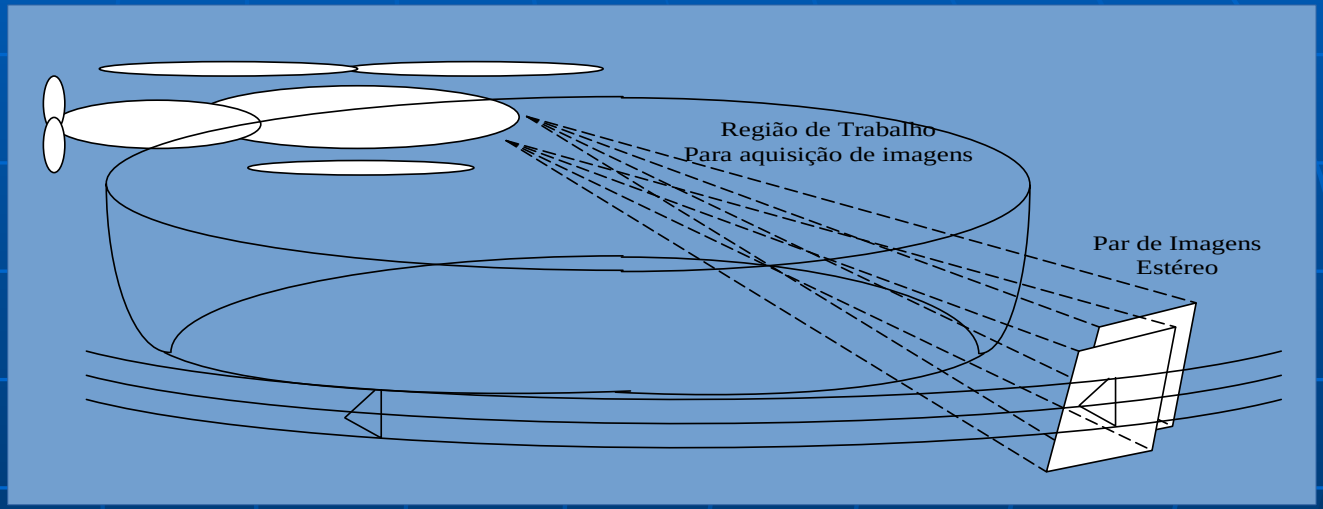


H=10 ➔ 2 Misclassified images
H=12 ➔ 1 Misclassified image

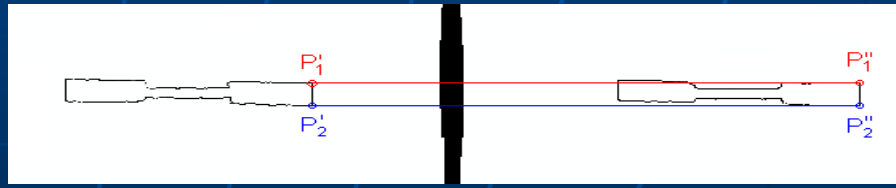
Flávio Oliveira & Alexandre Dias, 2007

Gripper inspection with 3D reconstruction

- It is not possible to train an ANN for every position/orientation in the visual field of the UAV
- ANN trained for a fixed point of view.
- Build 3D contour model
- Reproject 3D contour to ANN point of view
- Classify with ANN

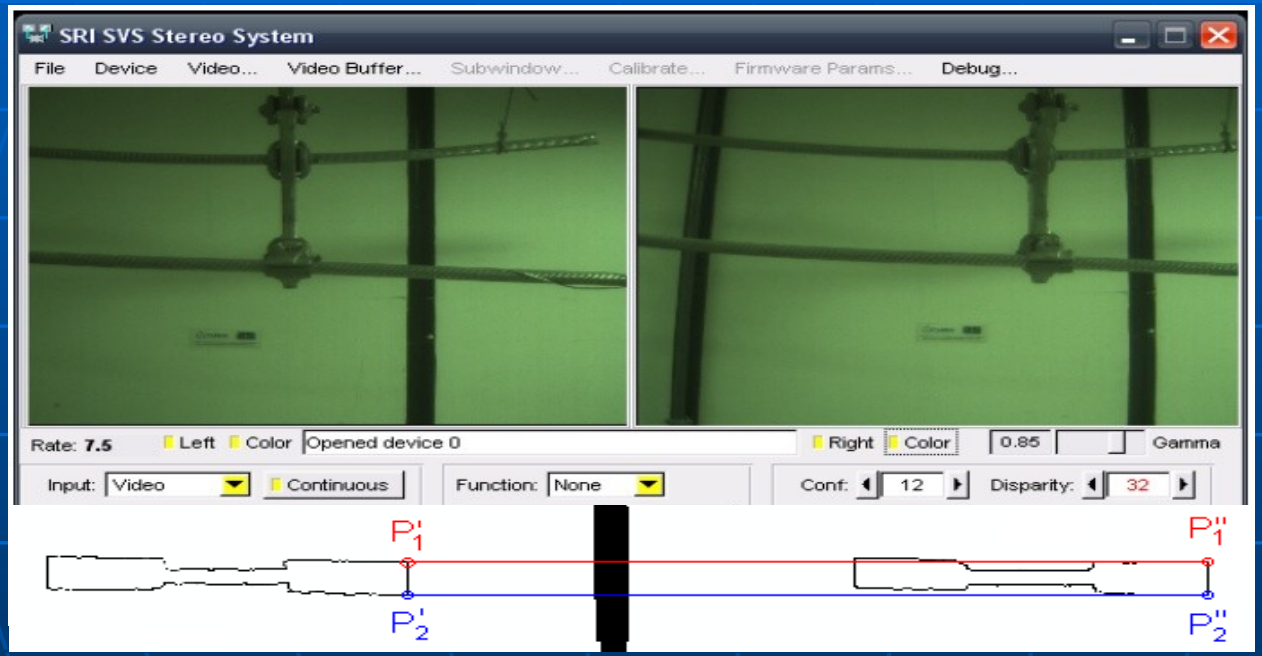


Different ROI's

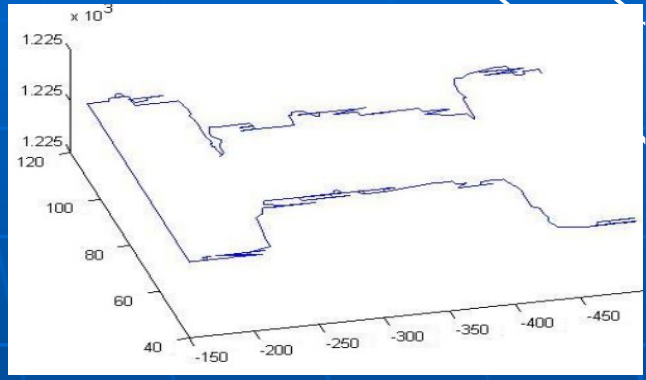


Correspondence –ROI contour in stereo pair

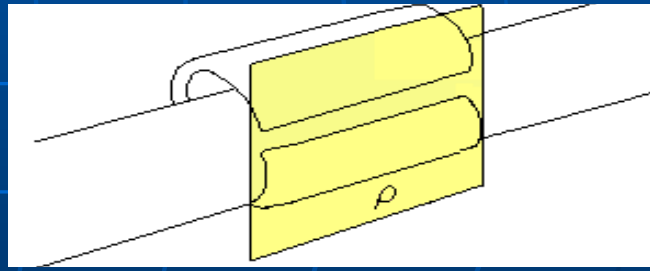
Stereo Vision of Gripped Cable



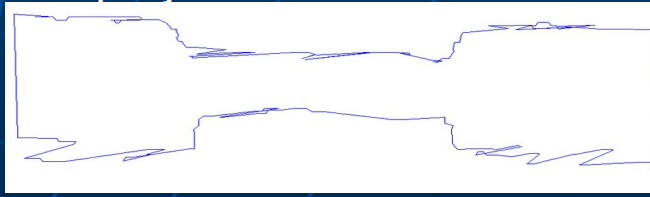
3D Reconstruction



ANN data bank Image plane



Reprojected contour for ANN



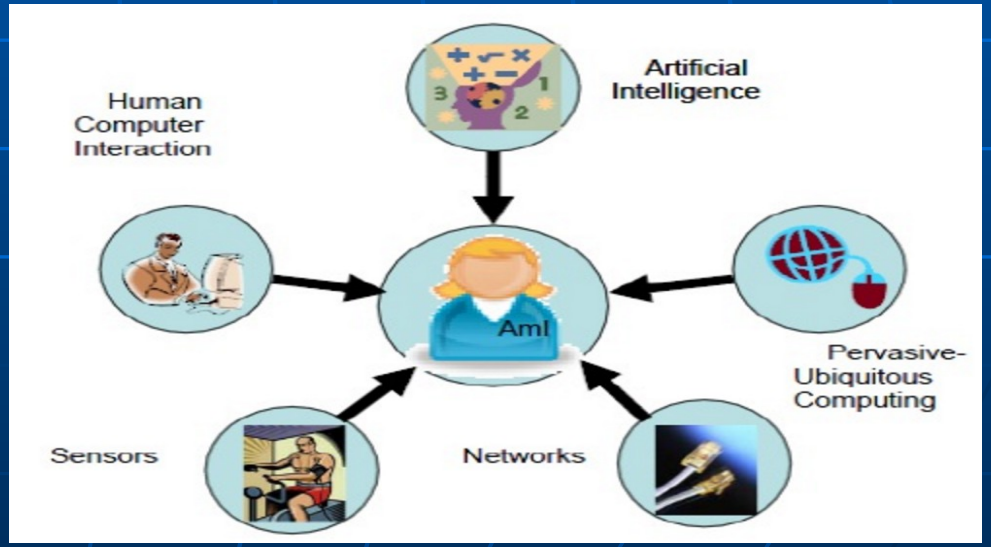
TestResults:
20 stereo pairs – 1 false pos., 1 false neg.
Elder Oroski, 2011

Ambient Ingelligence

PROBRAL UnB/TU Kaiserslautern
CAPES/DAAD 2007-2013

"Provide services to the users of an ambient through an almost invisible wireless sensor and actuator network"

- Energy saving
- Assisted Living
- Activity Tracking



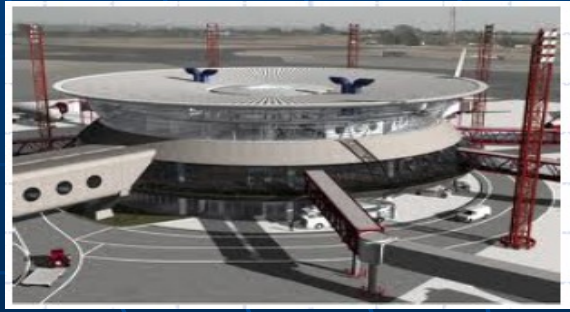
Building Automation - Segments

- ✓ Schools
- ✓ Hospitals
- ✓ Hotels
- ✓ Pharmaceutical
- ✓ Commercial
- ✓ Airports
- ✓ Stadiums
- ✓ Domotics
- ✓ …

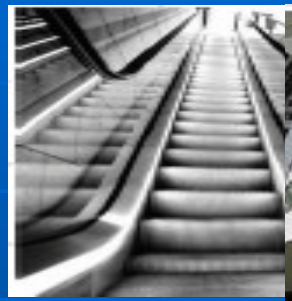








Sub-Systems



- ✓ HVAC
- ✓ Illumination
- ✓ Fire
- ✓ Energy Management
- ✓ Back-Up Power Gen.
- ✓ CC-TV
- ✓ Access Control
- ✓ Elevator/Escalator
- ✓ …

Building Automation- Objetives

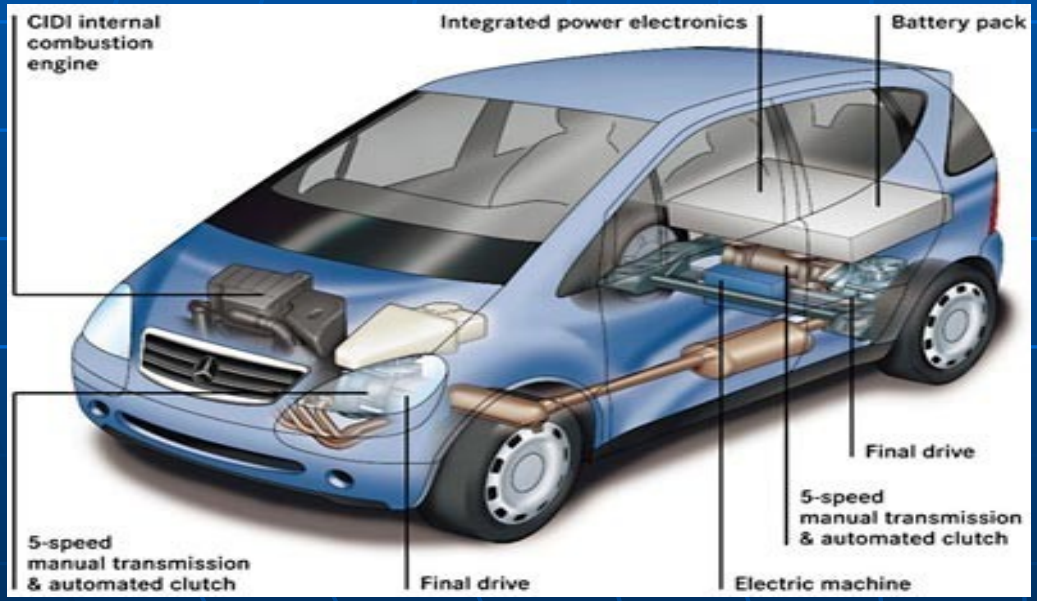
- Safety
- access control
- CC-TV
- Fire detection

- Comfort (Productivity)
- temperature, humidity,… (PMV)
- illumination,
- waiting time for elevators, …
- Health issues
- air quality (renovation, filters…)
- CO_2

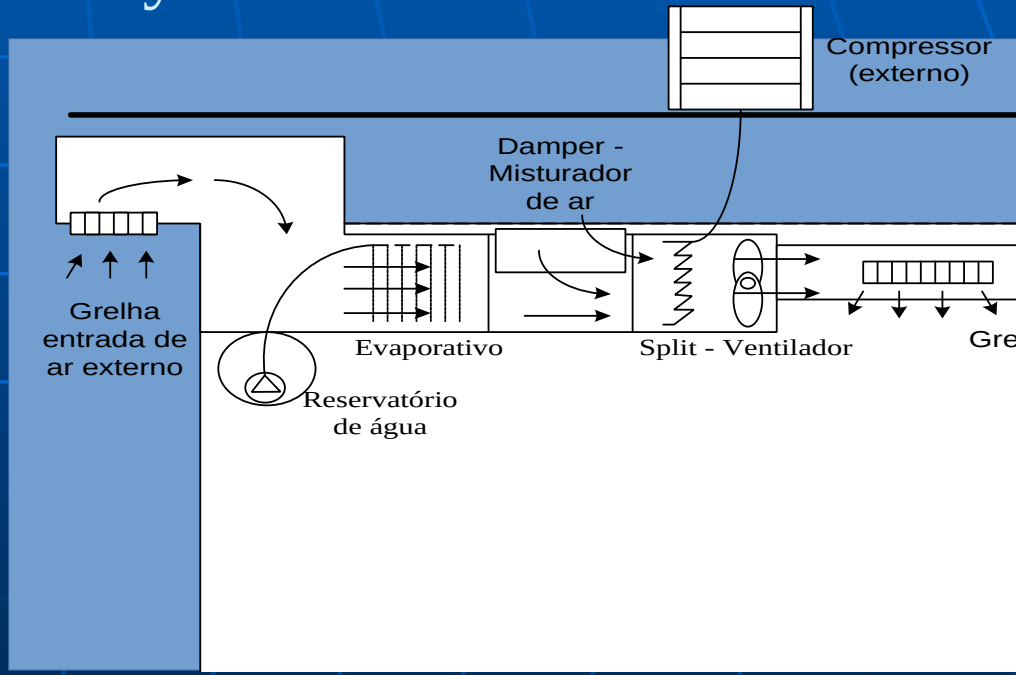
Energy Saving

Energy Saving:

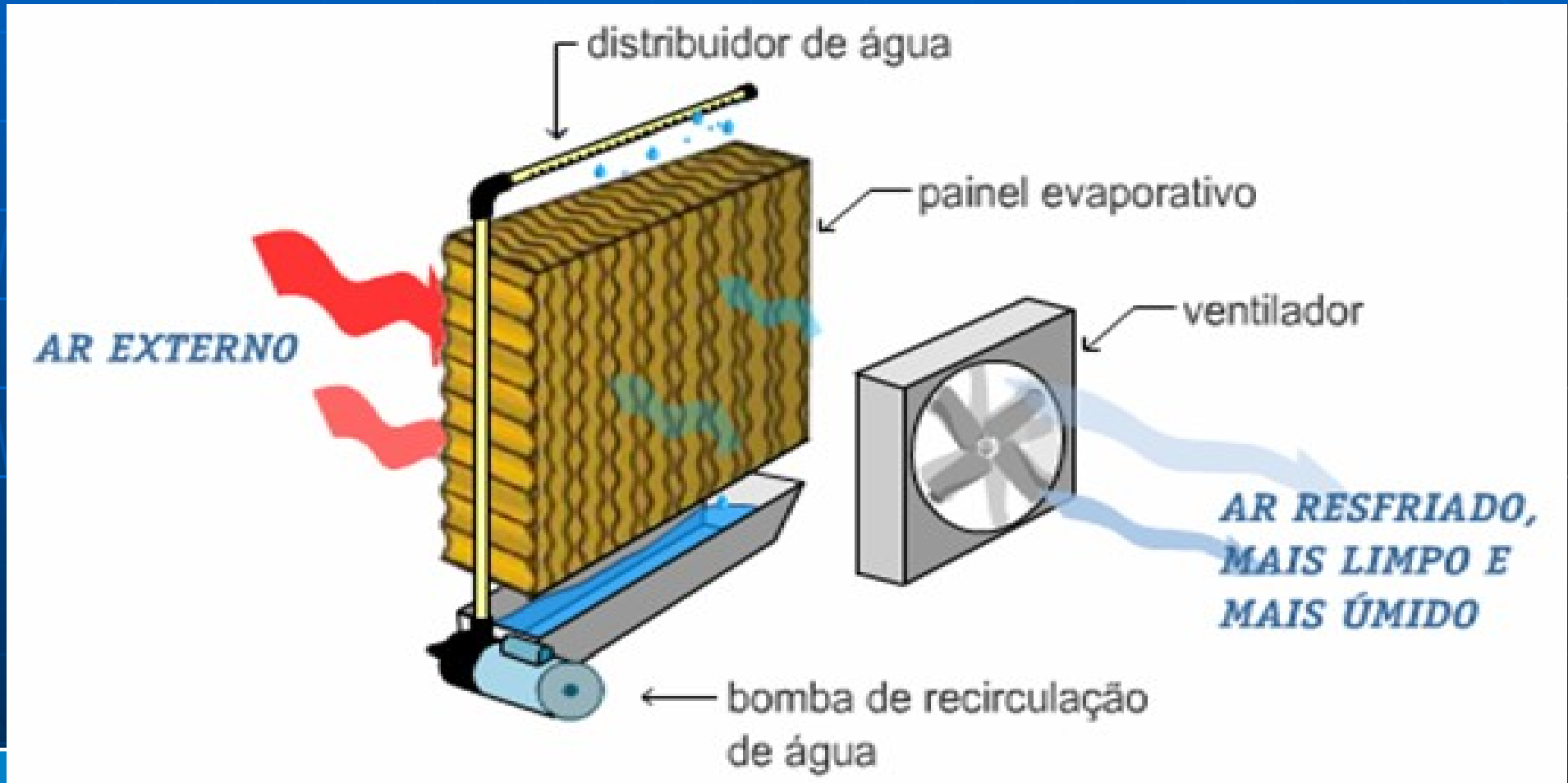
Hybrid Car



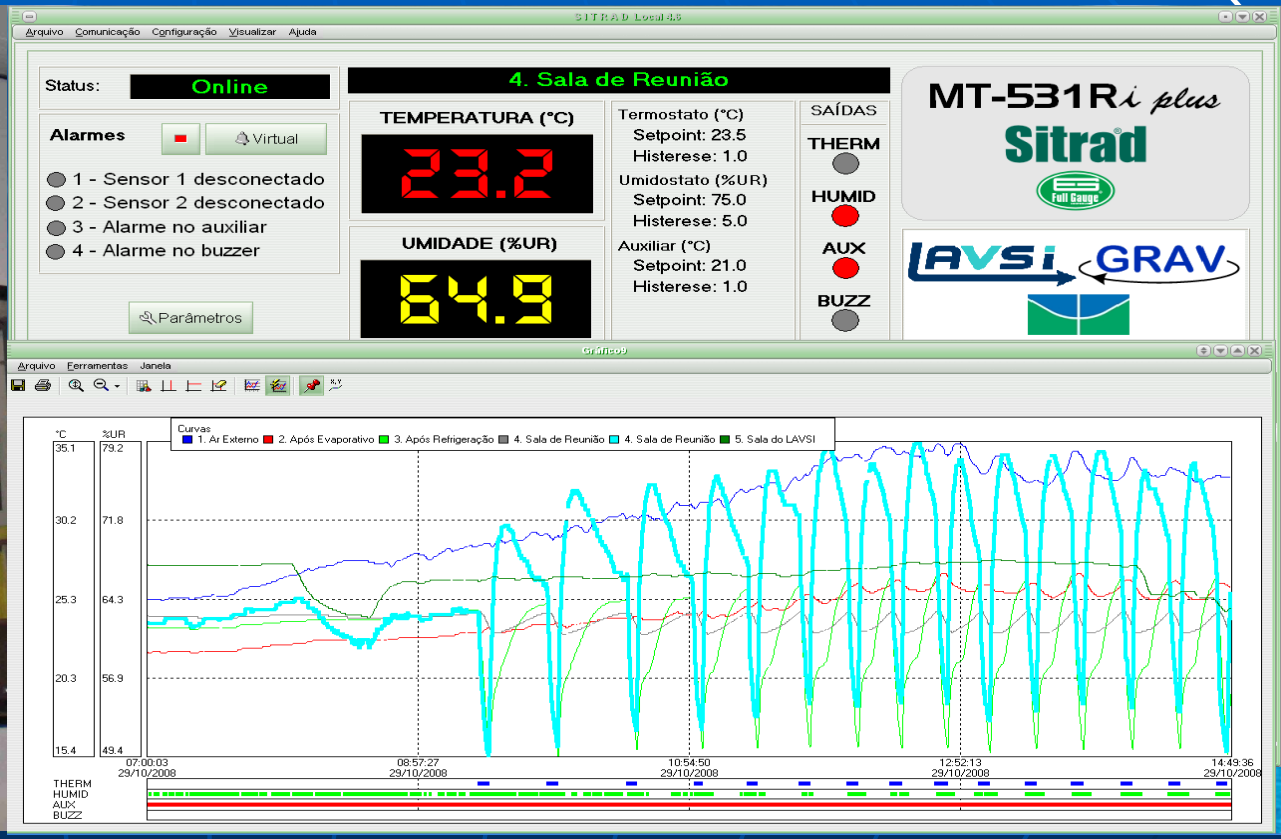
Hybrid Air Conditioner



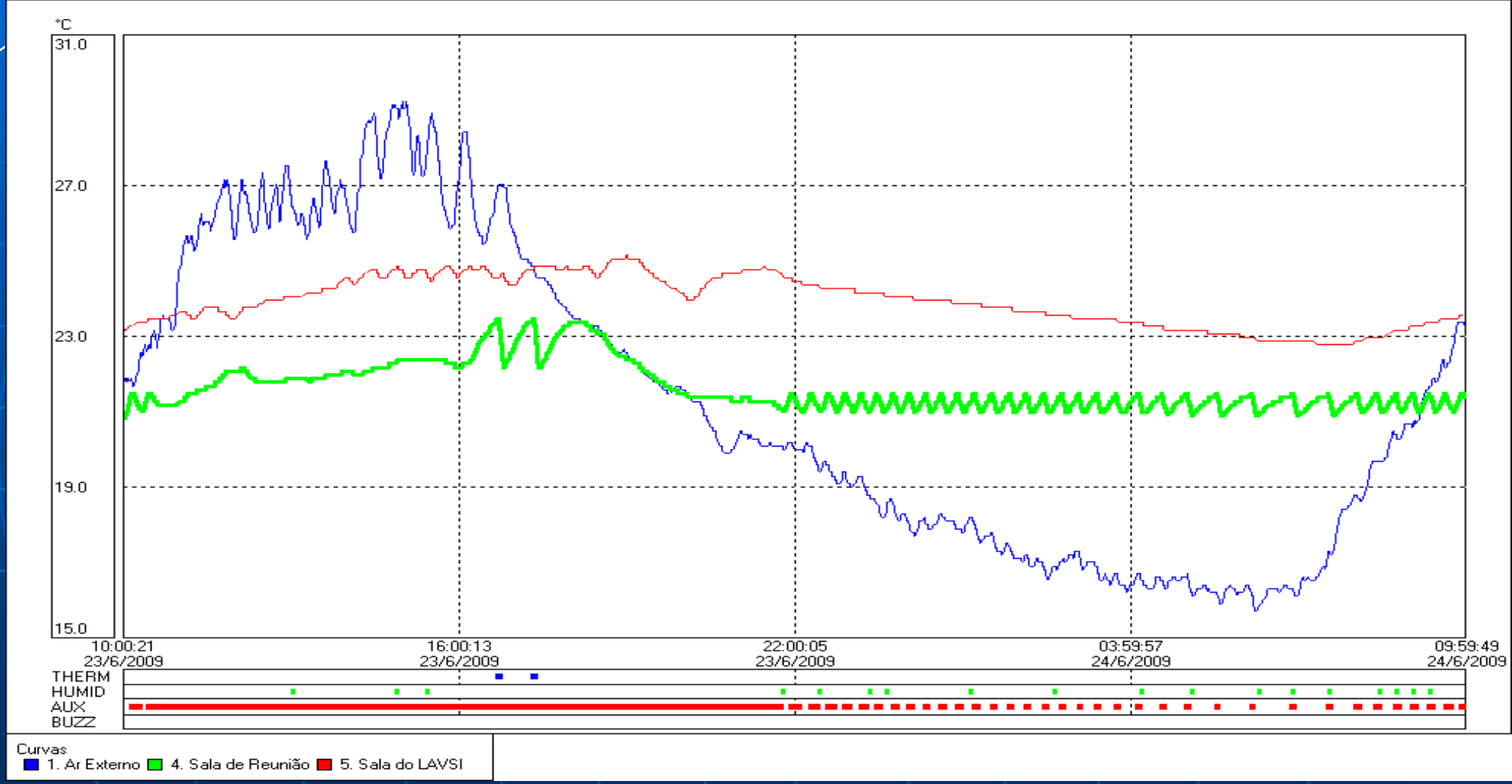
Fundamentals of Evaporative Cooling



Hybrid Climatization: Evaporative + Conventional



M.Sc José Luis Olmos Flores, 2009



Hybrid Mode – Meeting Room Temperature

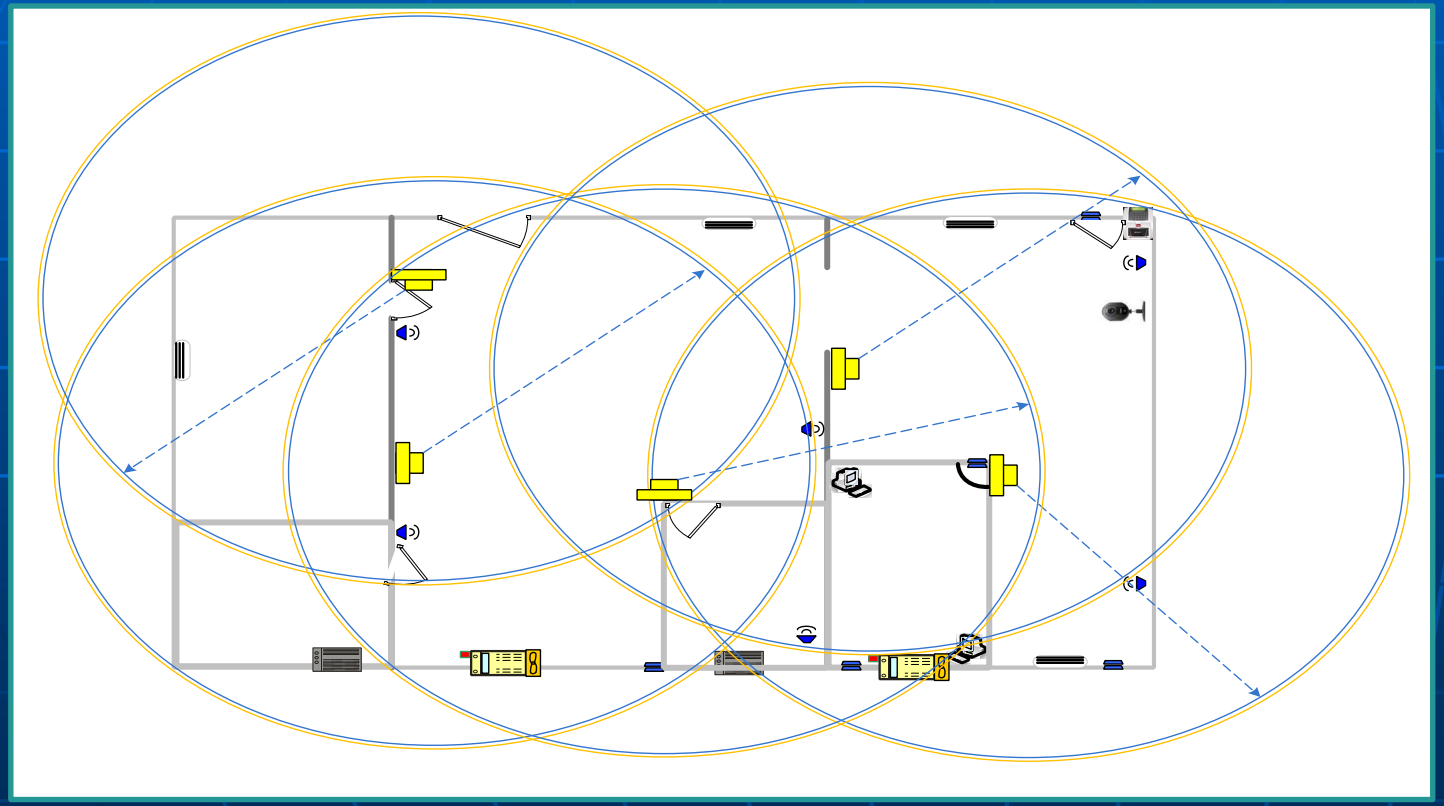
Electric Energy Comparison (24 h)

Modo de Operação	Tempo operação Ventilador	Tempo operação Bomba	Tempo operação Compressor	Consumo total de Energia	Observações
DESL	00h00m00s	00h00m00s	00h00m00s	0,17 kWh	Muito Baixo
VENT	22h15m45s	00h00m00s	00h00m00s	2,23 kWh	Normal
EVAP	13h52m54s	00h29m42s	00h00m00s	1,36 kWh	Normal
REF	22h58m08s	00h00m00s	01h49m57s	5,92 kWh	Alto
HIB	14h56m31s	00h28m40s	00h09m02s	1,95 kWh	Normal

Water pumb (evap) ~ 70W
Split AC ~ 5,275 W (18,000BTU)

70% energy saving!!

RFID occupancy identification for thermal load estimation

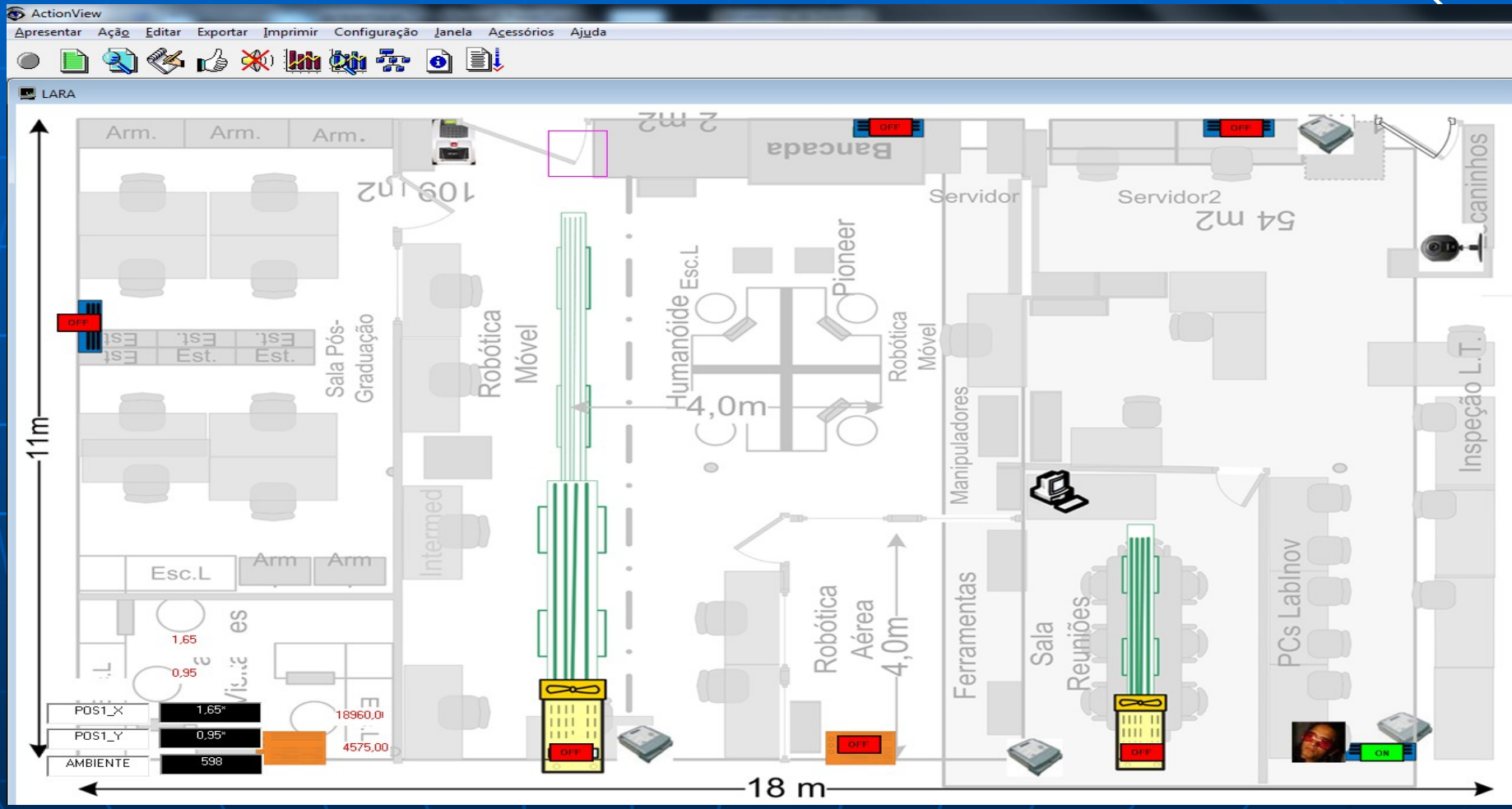


Active RFID Tags:
Battery, Microcontroller,
Motion Detector

39 bytes datagram:
TagID, Age, RSSI, Interval

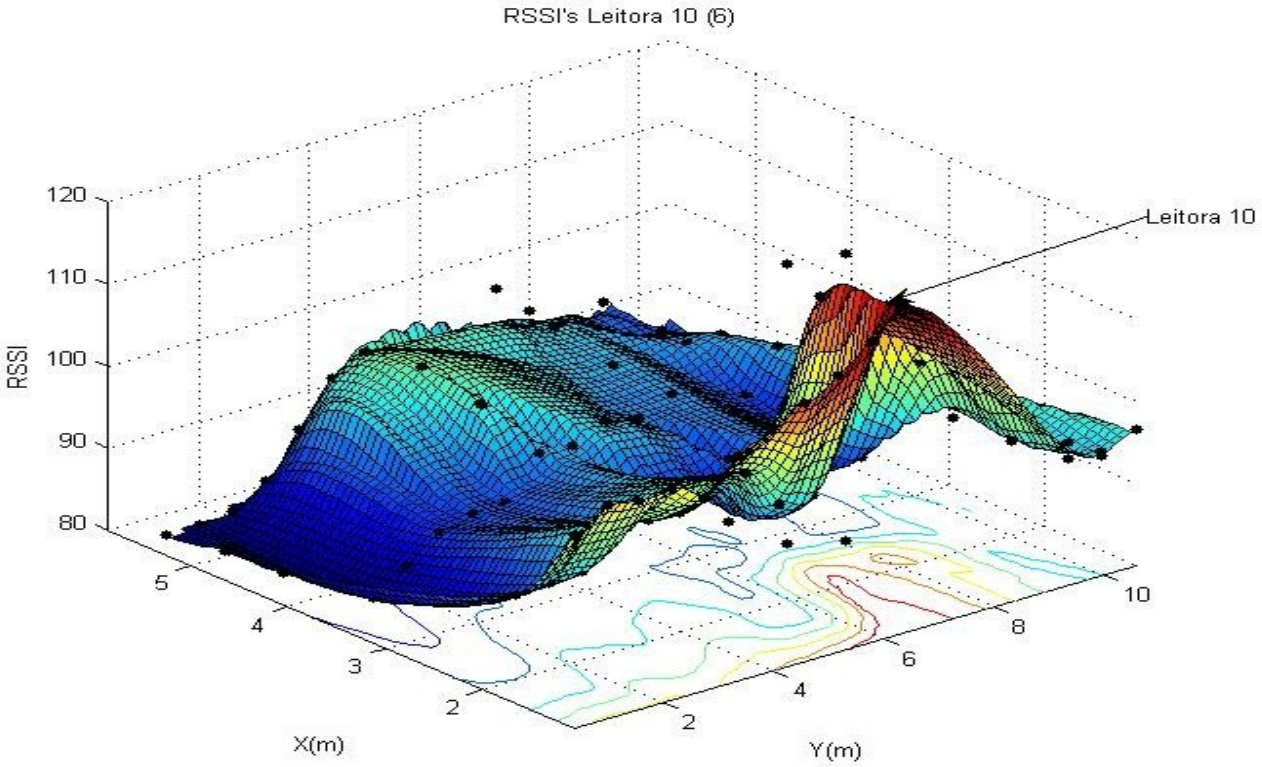
Eng. Josué Souza & Eng. Ariel Souza, 2011

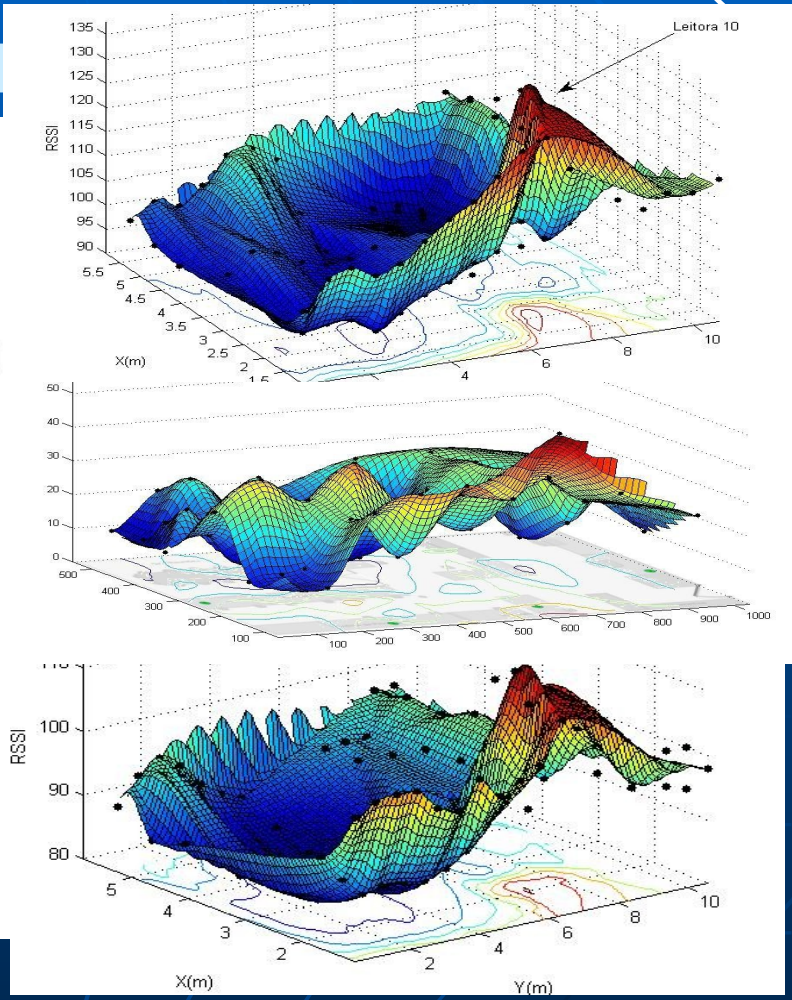
SCADA - Actionview Runtime Screen



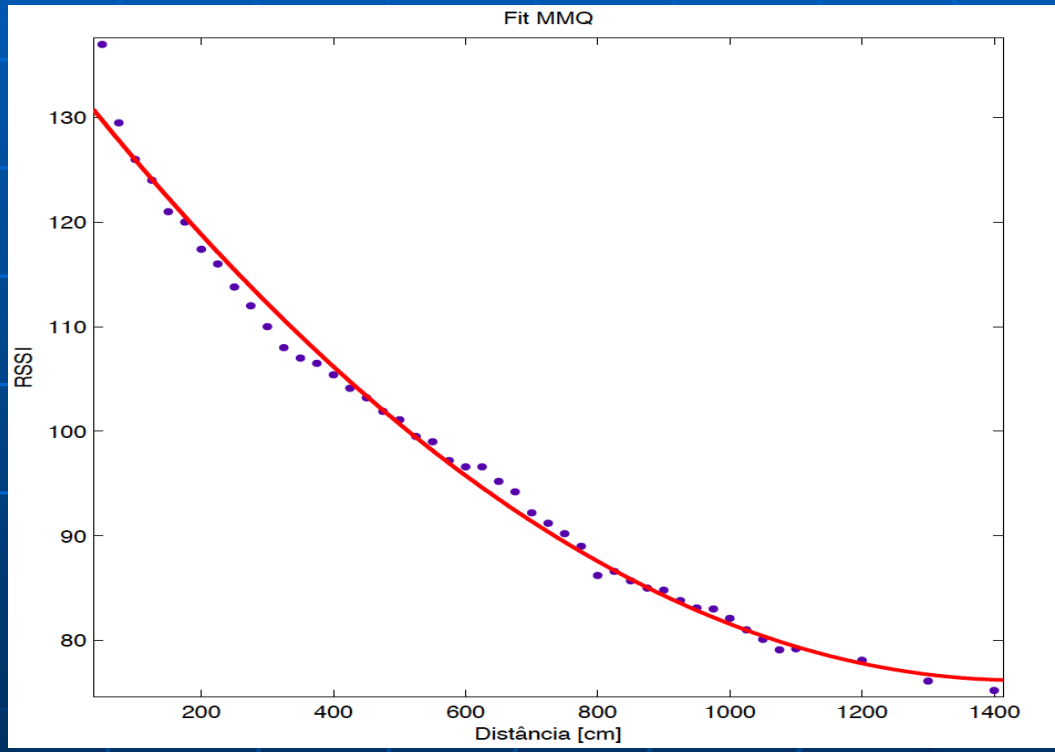
RSSI Mapping –
Data collected by Aramis Mobile I

Interpolated Surfaces
from measured RSSI





RFID free space (Olimpic Center - UnB)

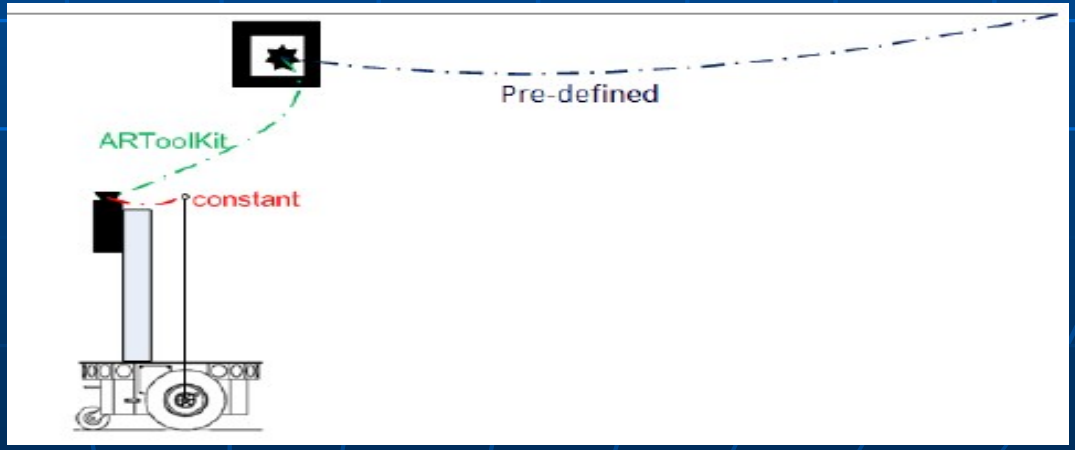


Sistema de Localização para Robô Móvel

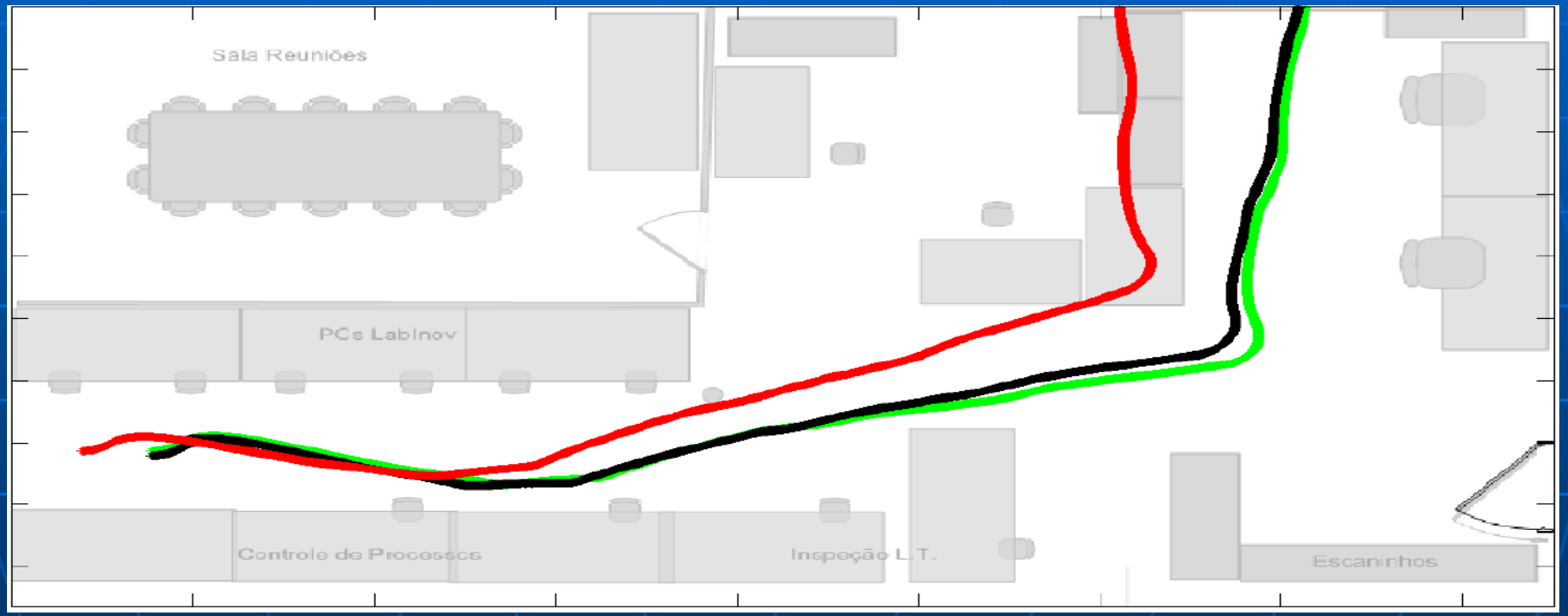
André Luiz Gama Souza, Gabriel Figueiró de Oliveira, 2011

Indoor RFID Localization in the Context of Mobile Robotics with Application in Ambient Intelligence

Augmented Reality Localization System Results



Comparison (Red: odometry, Black: +vision, Green: EKF Sensor Fusion)



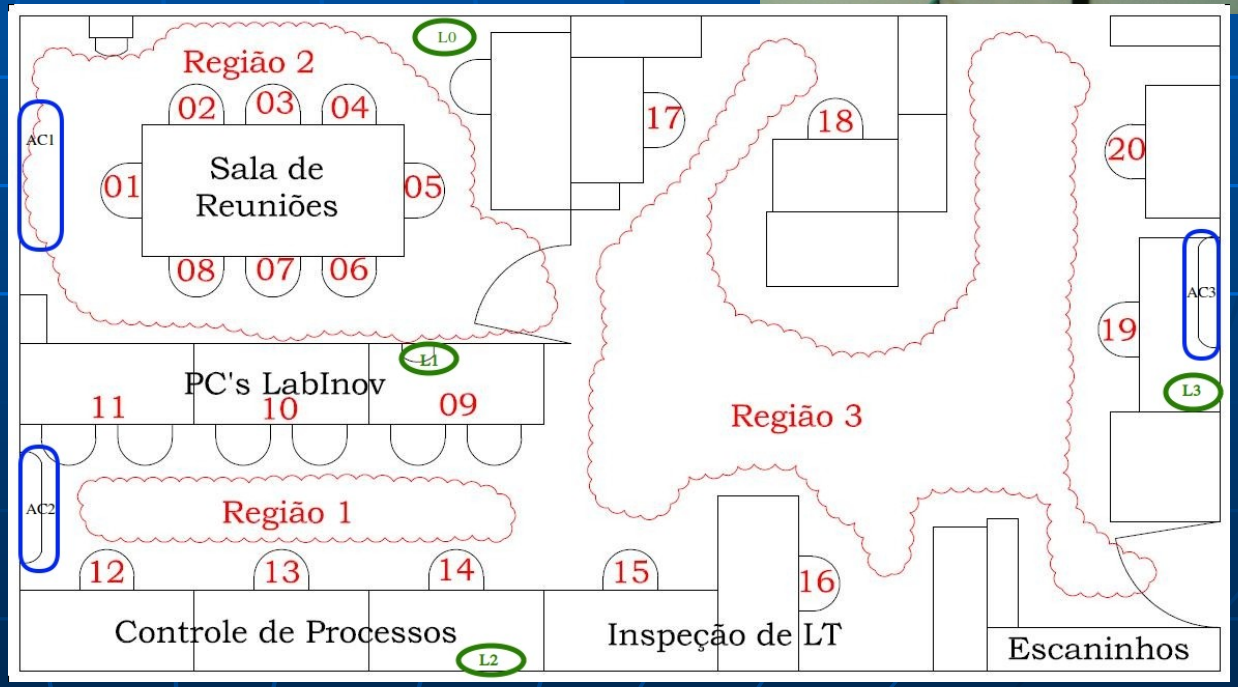
Odometry: mobile robot proprioceptive sensors
Vision: Augmented Reality with Beacons on the ceil
RFID RSSI system

Thermal Load Influence Areas

Occupancy of areas covered by Climatization Devices
RFID – RSSI classification
(Cristovam Silva Jr., 2012)

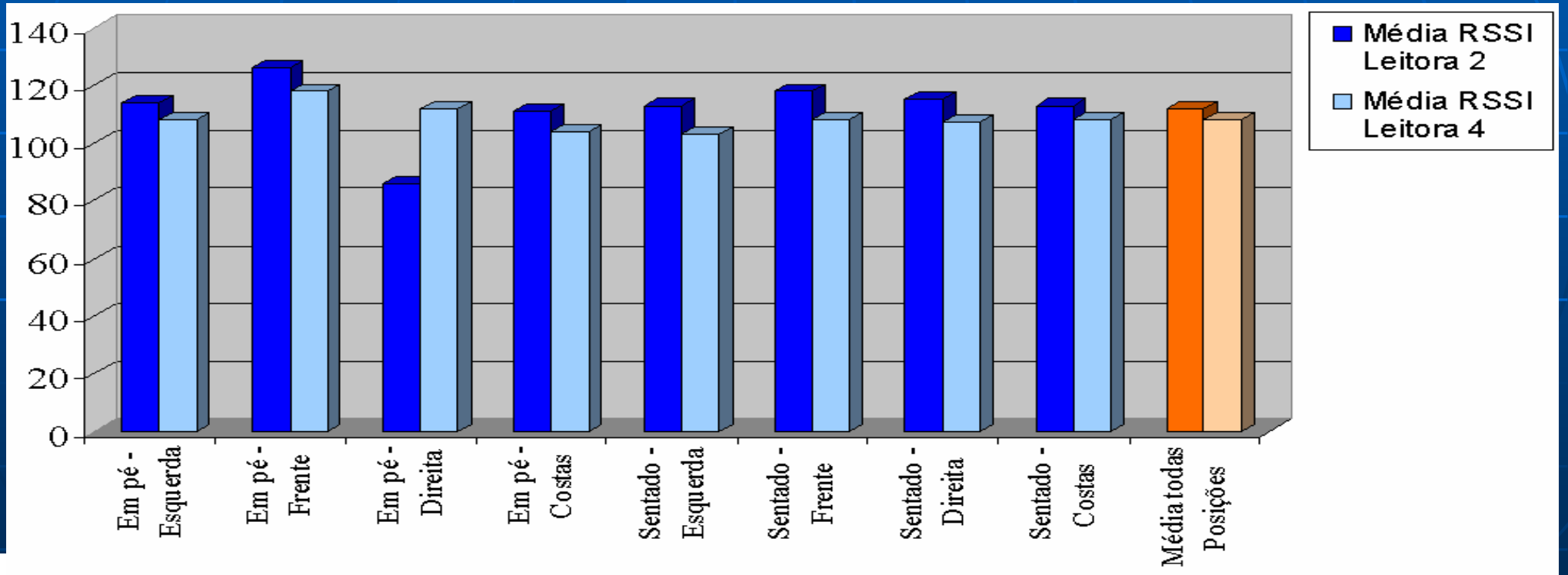
#	Missed RSSI(k)
1	Use data as collected
1E	Method 1 + EKF
2	RSSI = 71
2E	Method 2 + EKF
3	RSSI(k) = RSSI(k-1)
3E	Method 2 + EKF

EKF - Extended Kalman Filter



RSSI Variability

with respect to orientation
Sitting and Standing



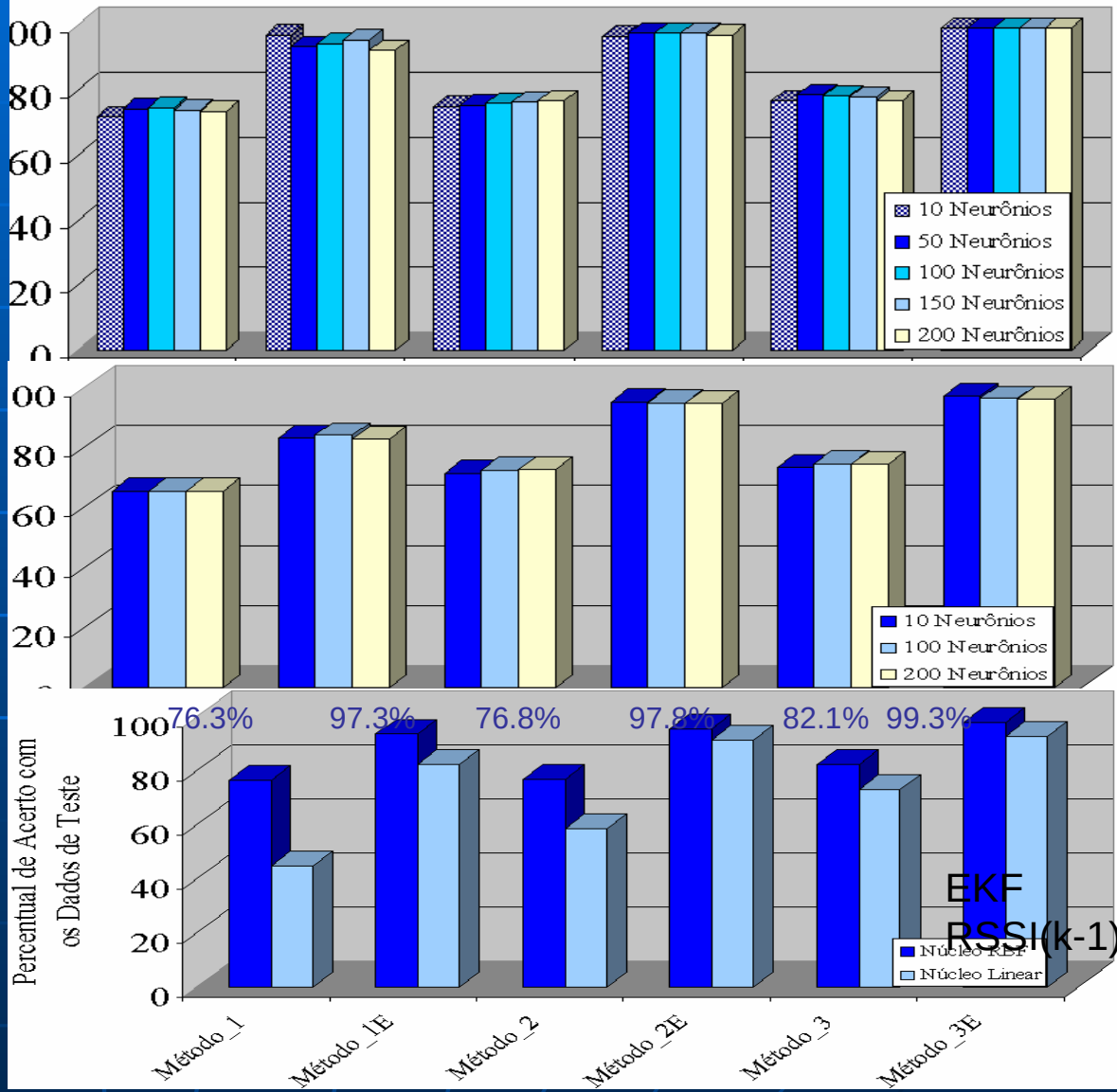
Algorithms Comparison

Test Data Results

MLP

LVQ

SVM

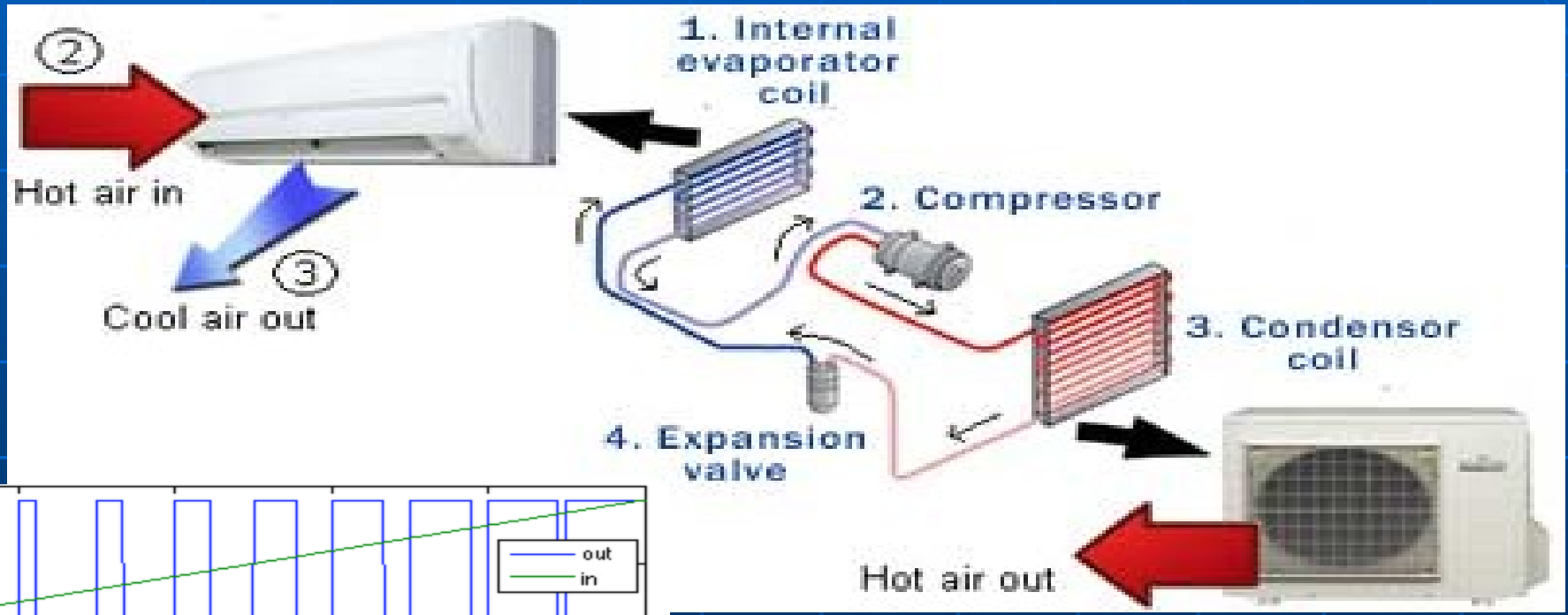


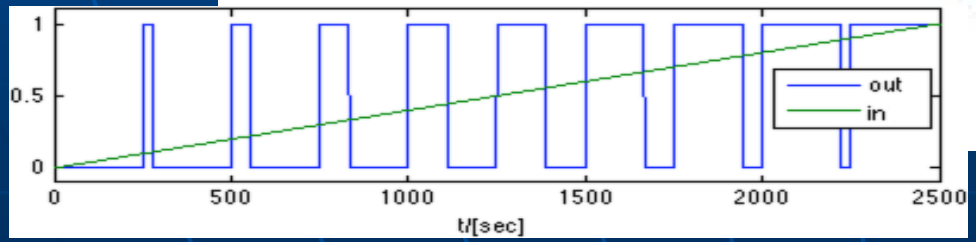
Energy Saving of Adaptive Thermal Control for PWM Driven Air-Conditioners

Enga. Marcella Cortat Campos Melo
Eng. Heyder Antonio Silva de Araújo
2014

- Variable Dynamics
  - Occupancy
  - External Temperature/Humidity
  - Activity
  - Season/Clothing
- Adaptive approach
  - Process Instrumentation
  - Recursive Identification

PWM for split air conditioner



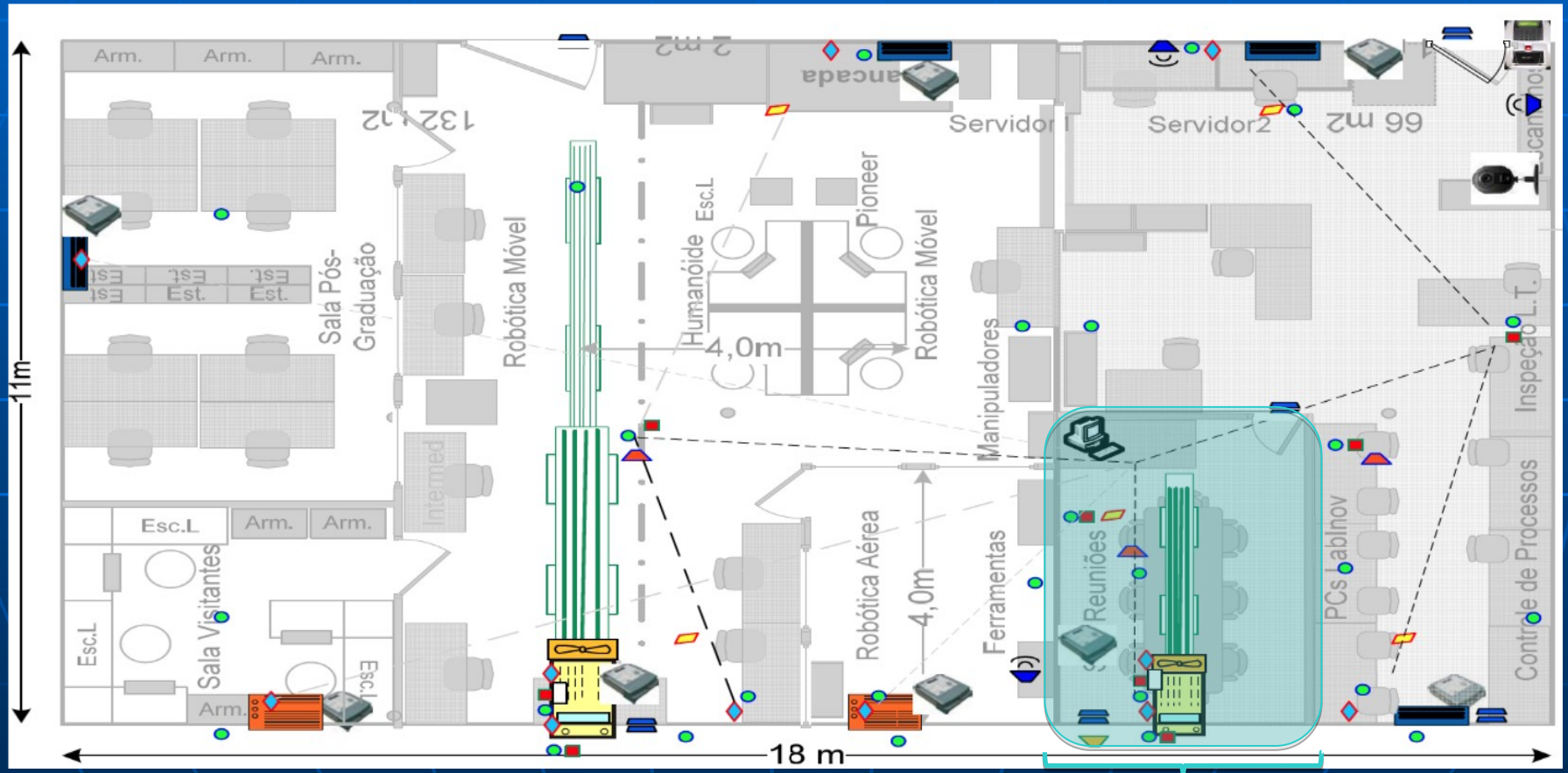


PWM *duty cycle* = 220 *s*

(adapted from airintelligence.co)

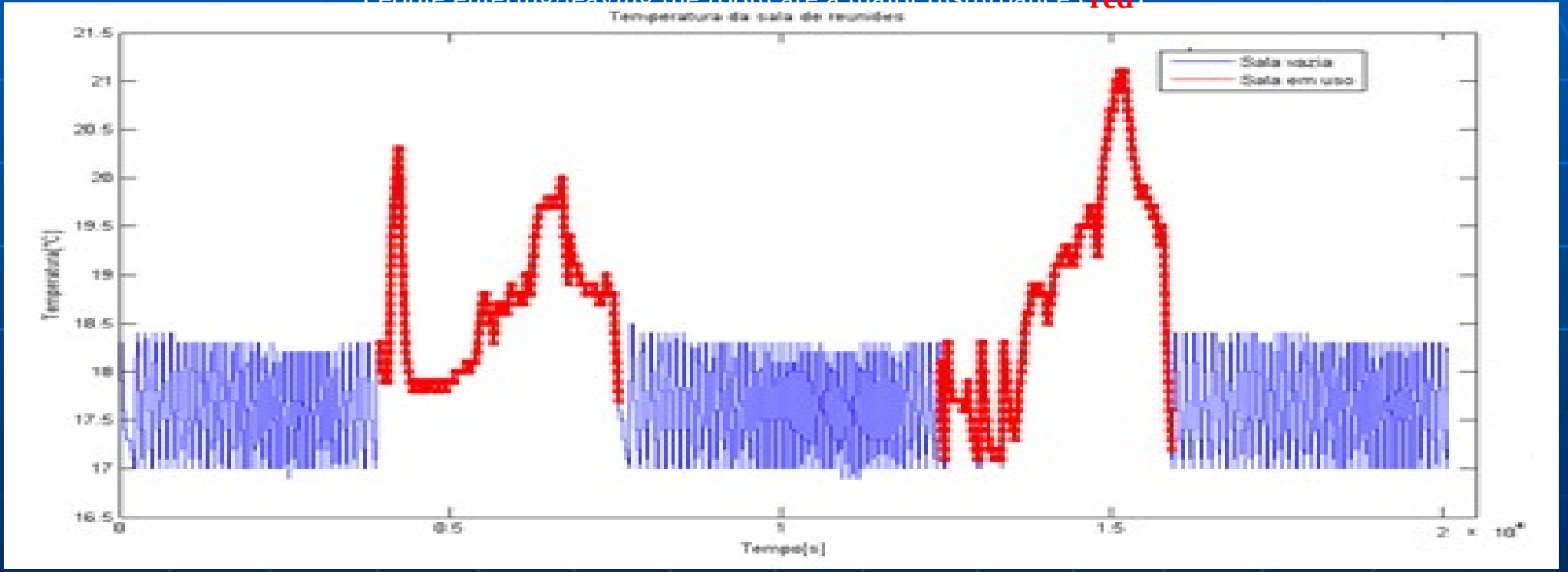
Adaptive Control
TEST ENVIRONMENT

LARA/UnB
Brasília-BRAZIL

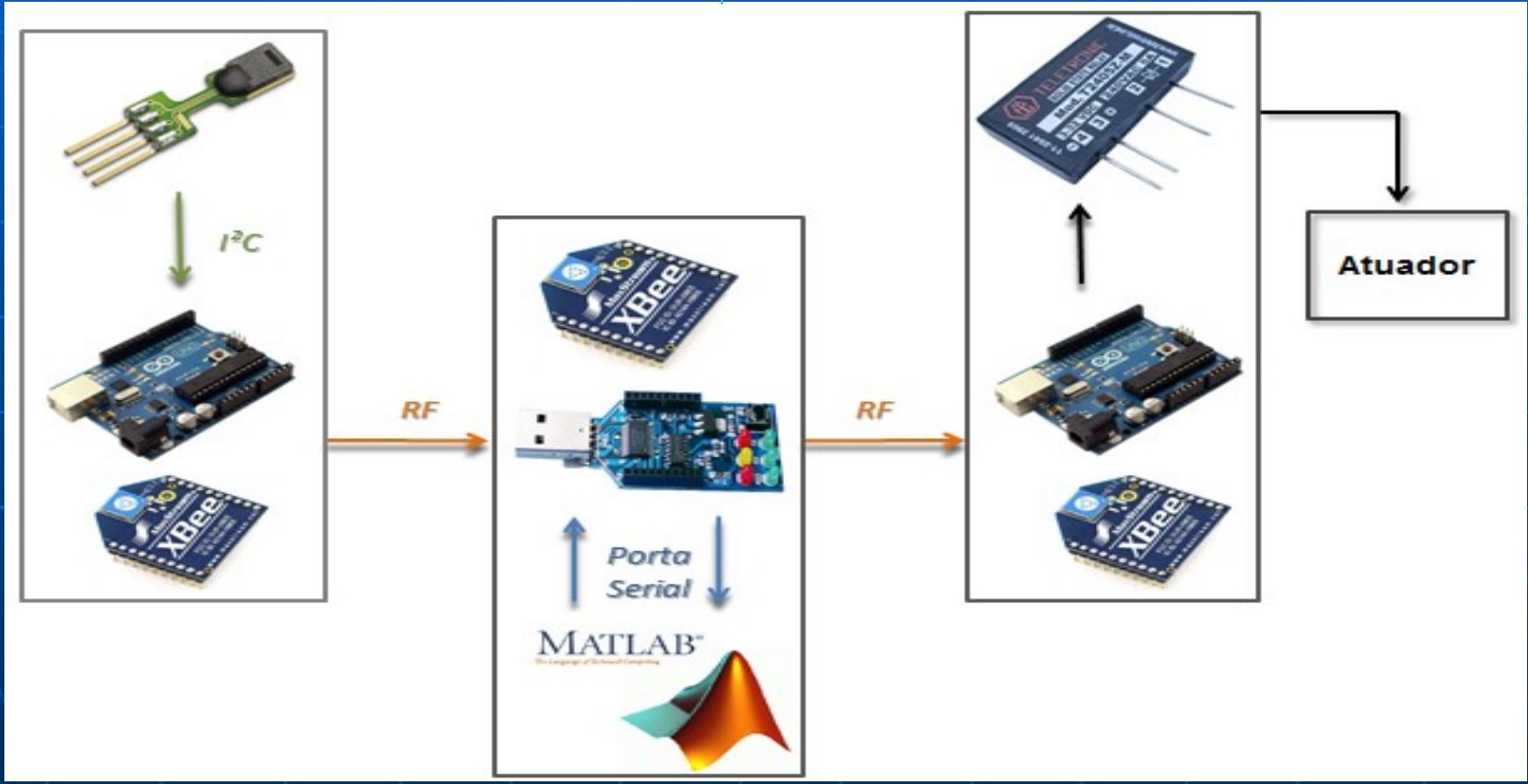


Temperature of the meeting room
- On-Off controller -

People entering/leaving the room are a major disturbance (**red**)



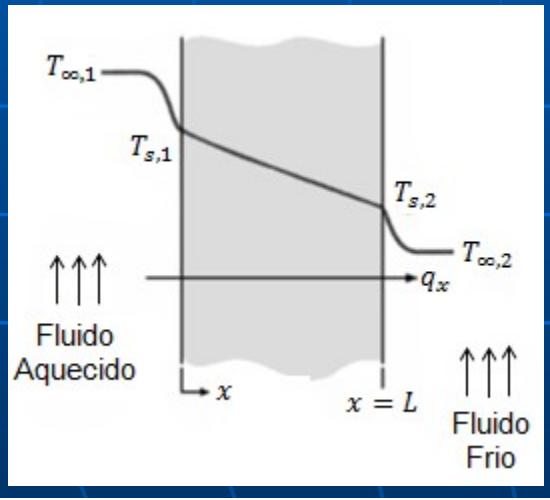
ZigBee Automation NETWORK

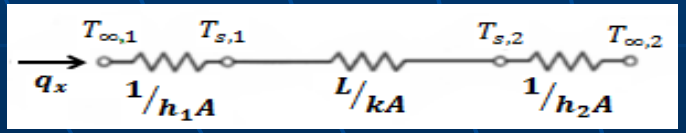


Recursive Identification needs a

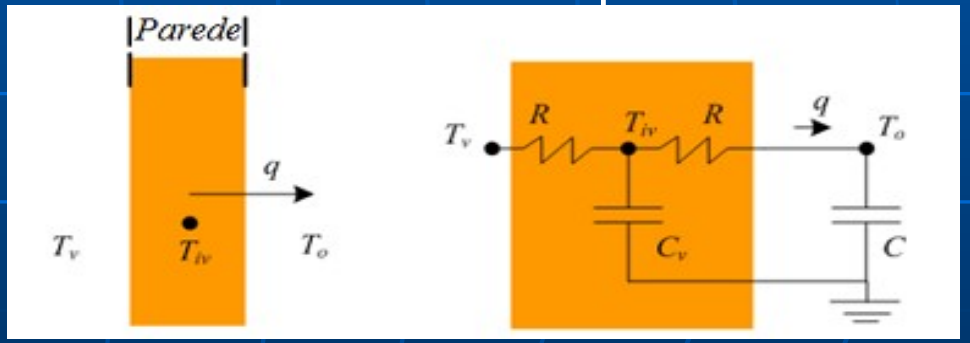
Structure for the Model -> Gray Box

Temperture along a Wall:





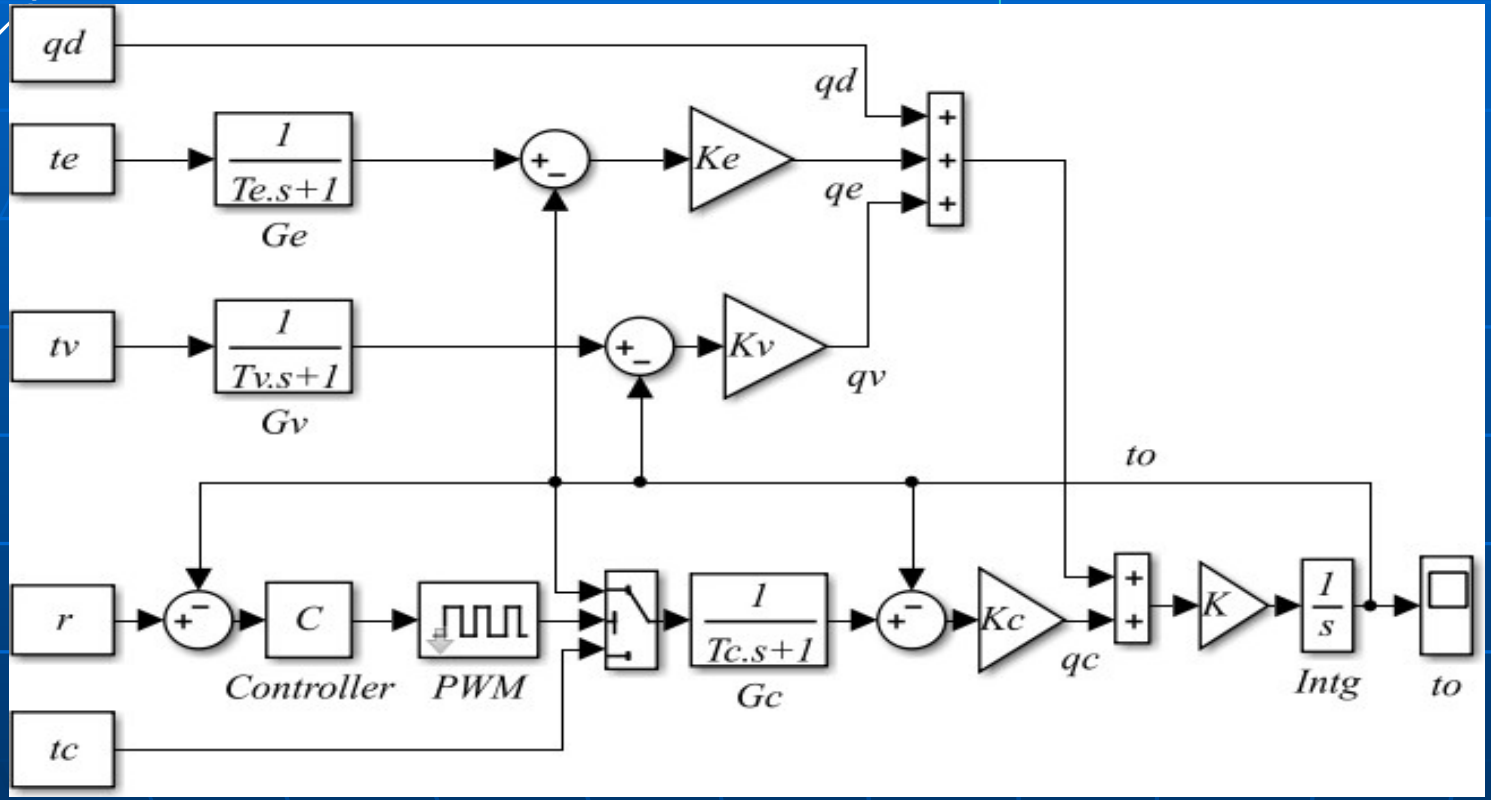
Thermal flow simplifications:



Wall analog Model

First-Principles Based Model

2º Order Dynamics with Perturbations



Temperatures: *r* - reference, *y* - controlled, *te* - external, *tv* -vicinity, *tc* - cooler
Time constants: *Te* , *Tv* , *Tc* . Gains: *Ke* , *Kv* , *Kc* , *K*
Heat flows: *qe* , *qc* , *qv* , *qd*

- Recursive Identification
  - Min. parameter variance
  - No bias
  - Plasticity

$$y(k) = \psi_k^T(k-1)\boldsymbol{\theta_k} + \xi(k)$$

Regressors (measurements)

Parameter vector

Residue

P = covariance matrix
λ = forgetting factor
y-$\psi\boldsymbol{\theta}$ = innovation
K = update gain

$$\begin{cases} K_k = \dfrac{P_{k-1}\psi_k}{\psi_k^T P_{k-1}\psi_k + \lambda}; \\ \boldsymbol{\theta_k} = \boldsymbol{\theta_{k-1}} + K_k[y(k) - \psi_k^T\boldsymbol{\theta_{k-1}}]; \\ P_k = \dfrac{1}{\lambda}\left(P_{k-1} - \dfrac{P_{k-1}\psi_k\psi_k^T P_{k-1}}{\psi_k^T P_{k-1}\psi_k + \lambda}\right). \end{cases}$$

- Adaptive Control (Aström and Wittenmark, 95)

Model with input noise $A(k)y(k) = B(u(k) + v(k))$

Pole assignment controller $Ru(k) = Tr(k) - Sy(k)$ R, S, T - *to be designed.*

$$y(k) = \frac{BT}{AR + BS} r(k) + \frac{BR}{AR + BS} v(k) \qquad A_c = AR + BS$$

Identified Model

$$G(z) = \frac{b_0 z + b_1}{z^2 + a_1 z + a_2} z^{-d}$$

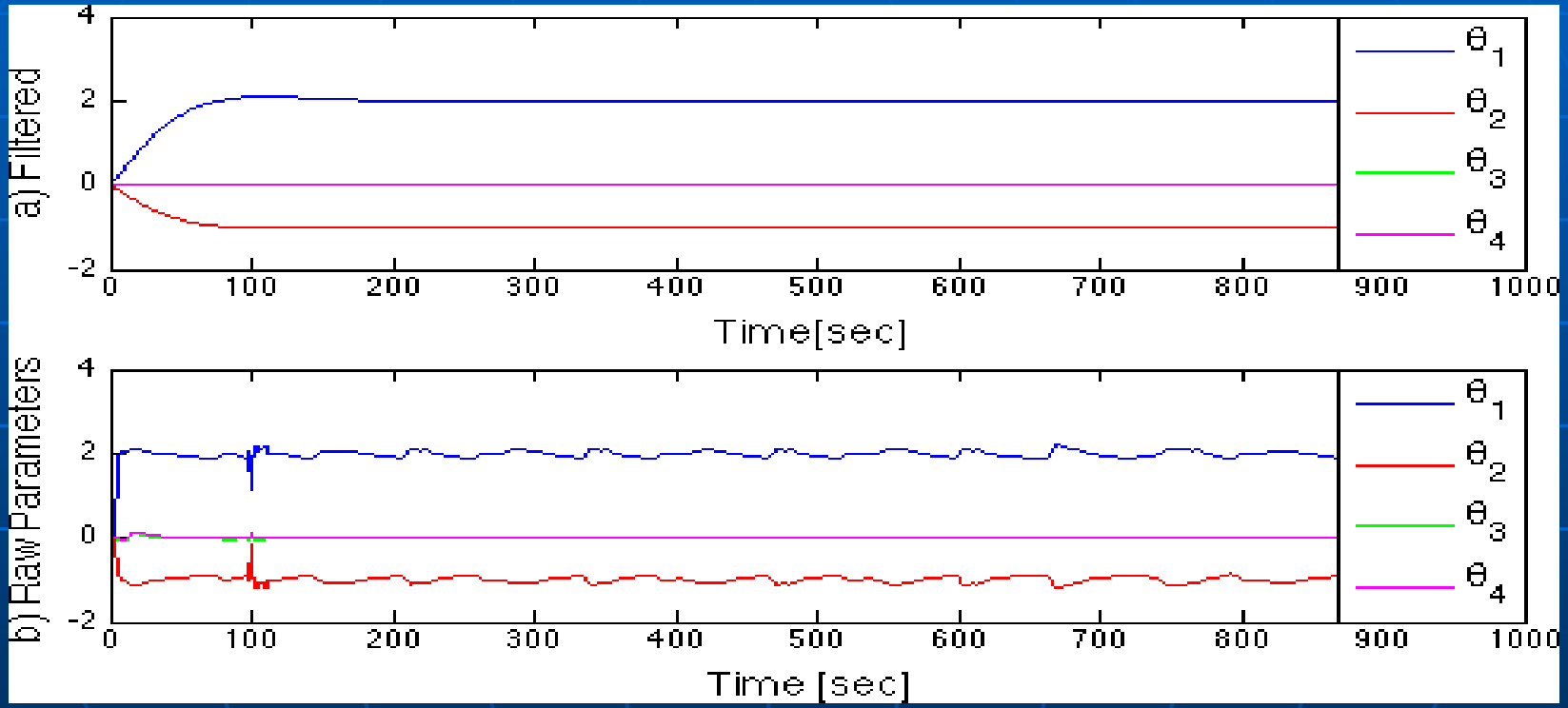
Reference Model

$$A_m y_m(k) = B_m r(k)$$

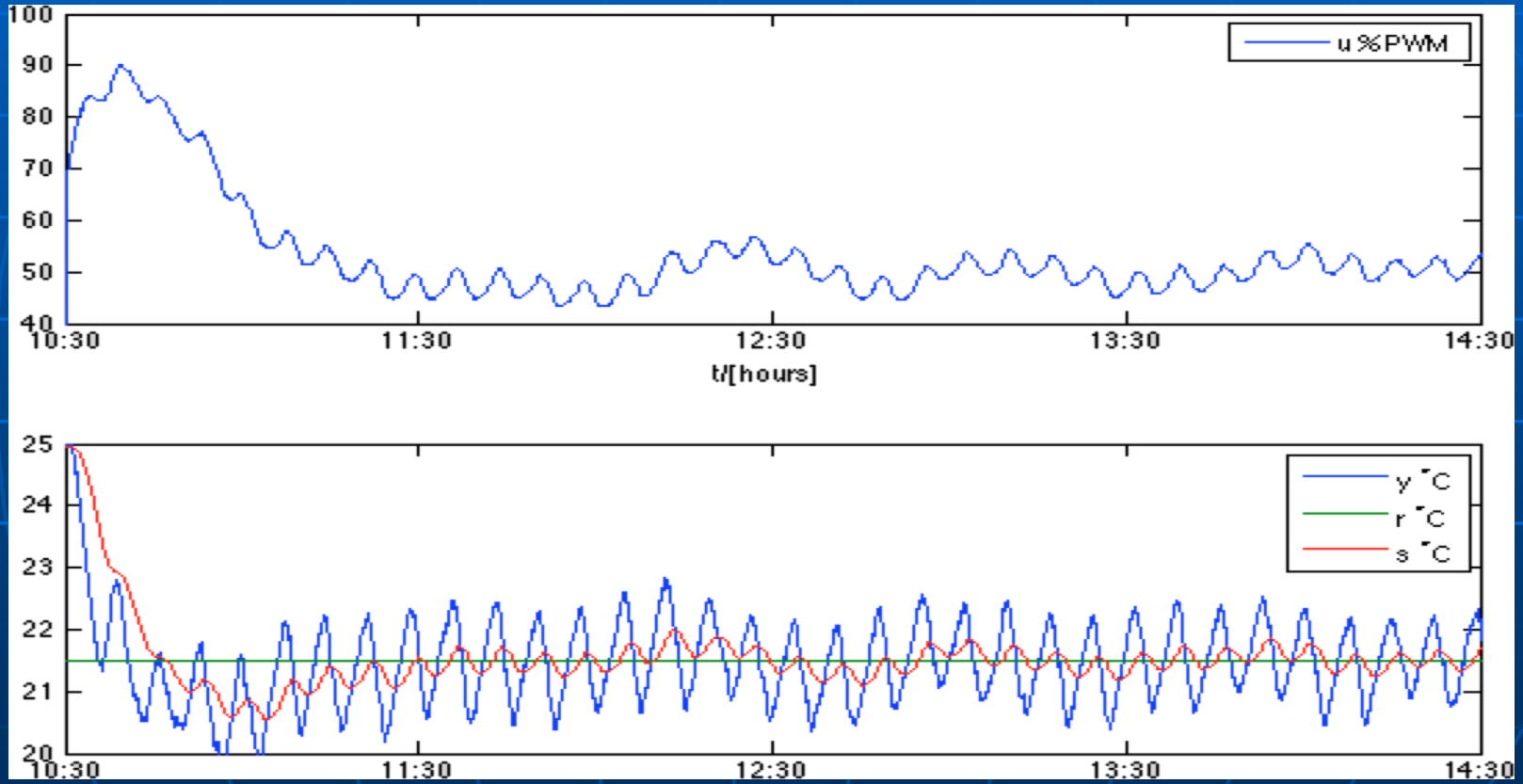
Control Law

...

$$u(k) = f[u(k-1), y(k-2), y(k-1), y(k), r(k), b_2, b_1, a_2, a_1, a_0, b_{m2}, b_{m1}, a_{m2}, a_{m1}, a_{m0}]$$



Estimated model parameters:
a) smooth filtered parameters, b) raw estimated model parameters.



RST controller, variable thermal load.

ERROR - ENERGY

Table 1 - Controller Comparison – RMS error and Energy, 8-hour runs.

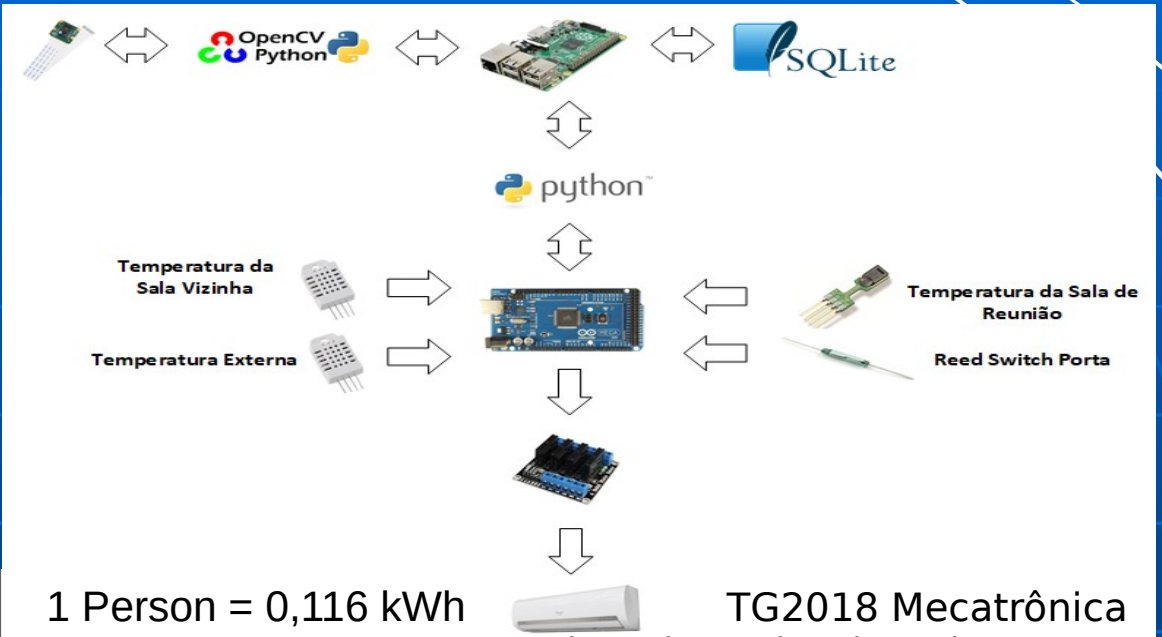
Thermal Load	ON-OFF Controller		PI Controller		Adaptive Controller	
	Error [RMS]	Energy [kWh]	Error [RMS]	Energy [kWh]	Error [RMS]	Energy [kWh]
Constant	0.14	6.69	1.55	3.12	0.53	3.42
Variable	0.12	7.89	1.18	4.84	0.43	4.63

Constant thermal load - empty meeting room's door kept closed.

Variable thermal Load - occupancy change: meetings, studying, and vacancy periods.
Opening of the door -> large heat flow (process parameters change).

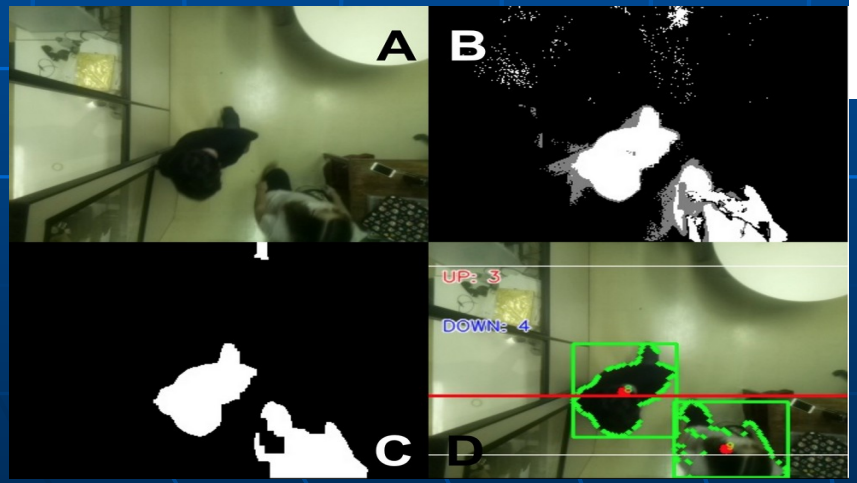
Adaptive controller: model based building climatization:
Lowest energy consumption (quick pay back)
Good thermal comfort
Extra hardware and software necessary

Feed-Forward Disturbance Rejection by Video Thermal Load Estimation



1 Person = 0,116 kWh

TG2018 Mecatrônica
Mariana Pimentel & Alexandre Saran



Occupants (thermal disturb.) Counting

Controller	Energy	RMSE (Comfort)
On-Off	7,92 kWh	0,42
feed-forward	5,81 kWh	0,37
Gain %	26,64%	11,9%

LabZero UnB – PROCEL Edifica Eletrobrás 2020

Demo Lab for Buildings
Energy Efficiency

Power to/from Power Company
- Photovoltaic
- Biogas
- No Batteries (nearly ZEB)

Climatization (Zones):
- Compressor with ducts
- Evaporative
- Solar Chimney
- Geothermal

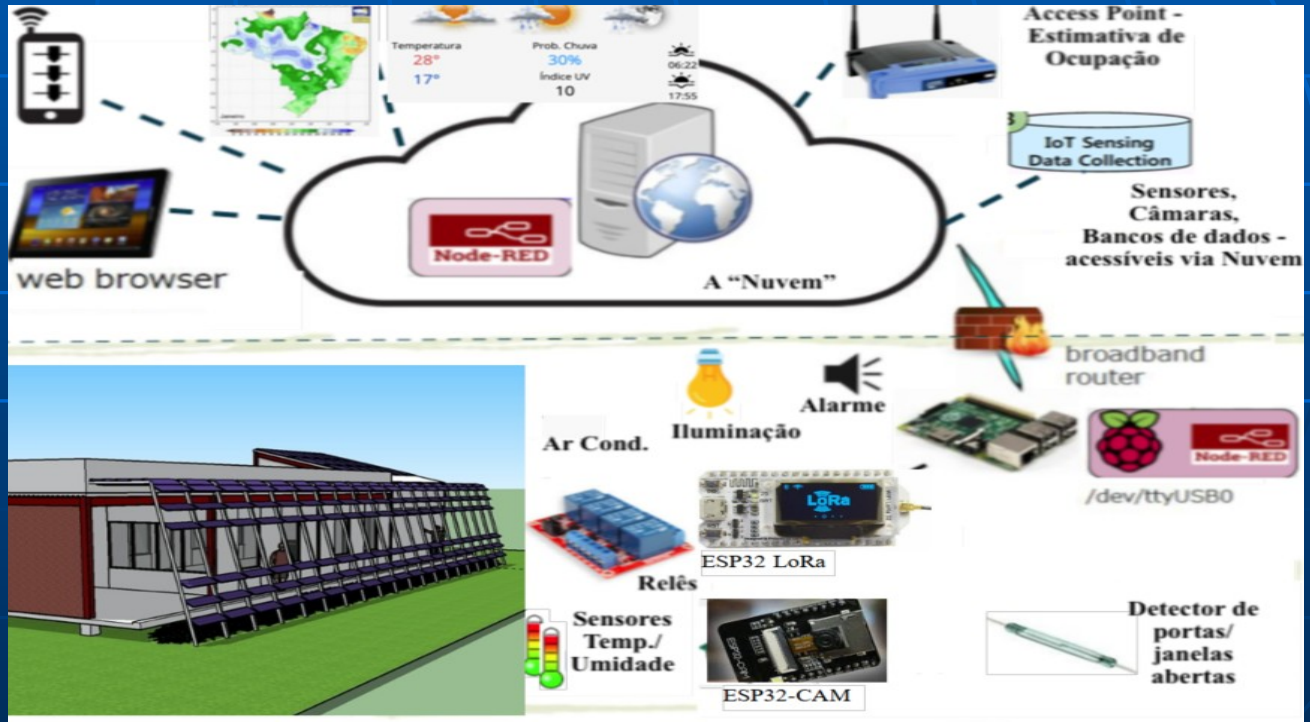
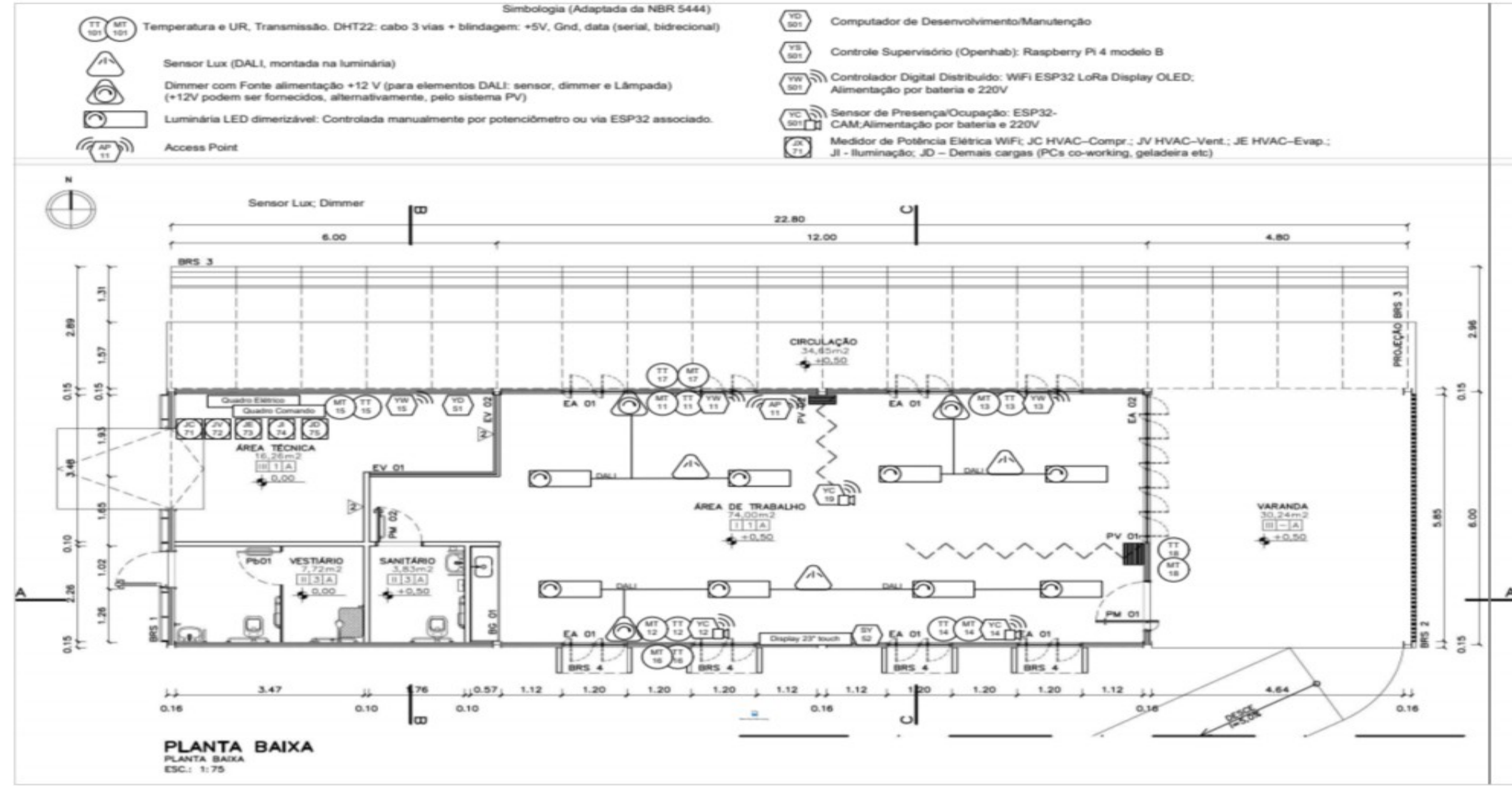


Figura 3.4.1 – **Visão geral da automação do projeto Co-Working ZEB UnB.**

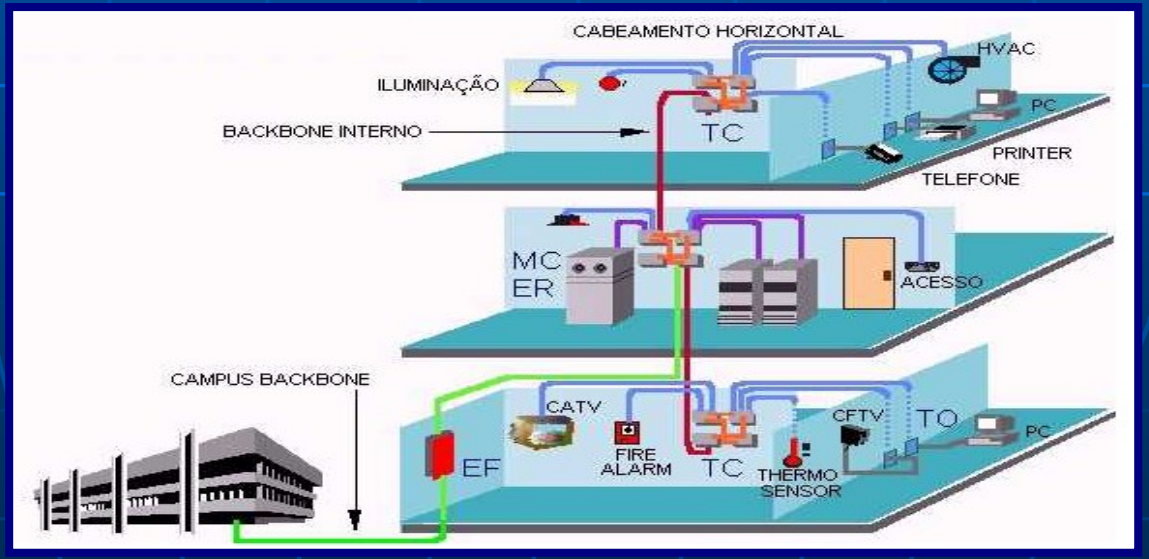
Placa WiFi ESP32 + LoRa; ESP32-CAM

Figura 3.4.3 – No sentido horário: Placa WiFi ESP32 + LoRa; ESP32-CAM, Case, Case c/ antena LORA.


Simbologia (Adaptada da NBR 5444)
Temperatura e UR, Transmissão. DHT22: cabo 3 vias + blindagem: +5V, Gnd, data (serial, bidrecional)
Sensor Lux (DALI, montada na luminária)
Dimmer com Fonte alimentação +12 V (para elementos DALI: sensor, dimmer e Lâmpada)
(+12V podem ser fornecidos, alternativamente, pelo sistema PV)
Luminária LED dimerizável: Controlada manualmente por potenciômetro ou via ESP32 associado.
Access Point
Computador de Desenvolvimento/Manutenção
Controle Supervisório (Openhab): Raspberry Pi 4 modelo B
Controlador Digital Distribuído: WiFi ESP32 LoRa Display OLED;
Alimentação por bateria e 220V
Sensor de Presença/Ocupação: ESP32-
CAM;Alimentação por bateria e 220V
Medidor de Potência Elétrica WiFi; JC HVAC--Compr.; JV HVAC--Vent.; JE HVAC--Evap.;
JI - Iluminação; JD – Demais cargas (PCs co-working, geladeira etc)
Sensor Lux; Dimmer
22.80
6.00
12.00
4.80
BRS 3
CIRCULAÇÃO
34,65m2
ÁREA TÉCNICA
16,26m2
Quadro Elétrico
Quadro Comando
ÁREA DE TRABALHO
74,00m2
VESTIÁRIO
7,72m2
SANITÁRIO
3,83m2
VARANDA
30,24m2
Display 23" touch
PROJEÇÃO BRS 3
PLANTA BAIXA
PLANTA BAIXA
ESC.: 1:75

The “near” future for Smart Buildings

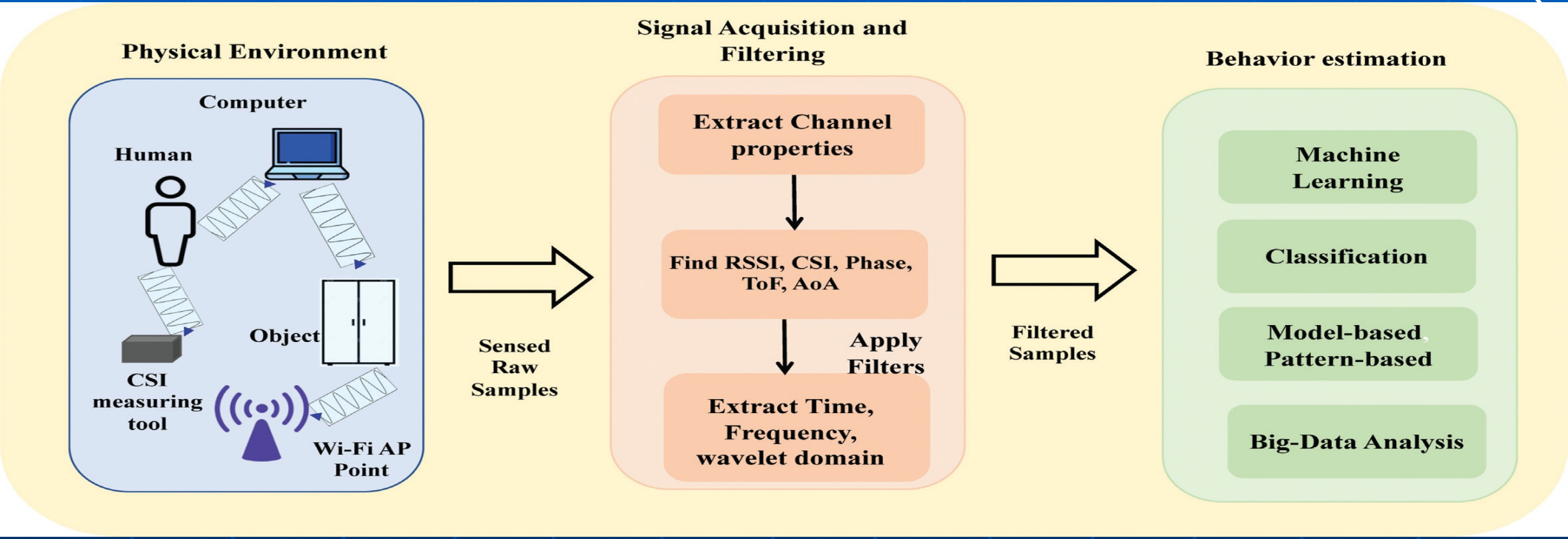
- nearly Zero Energy Building - nZEB
- Assisted Living
- Ambient Intelligence
- IoT



Research Proposal at ITIV

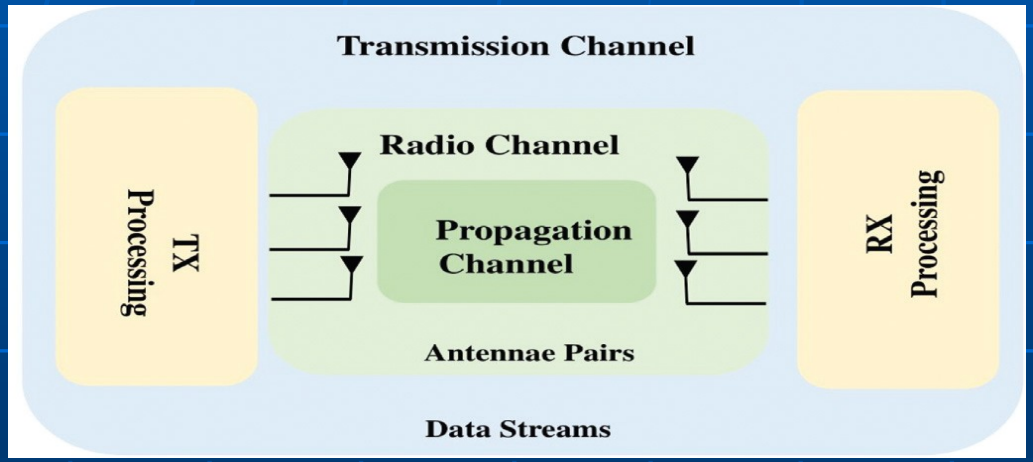
- Occupancy-based Automation -

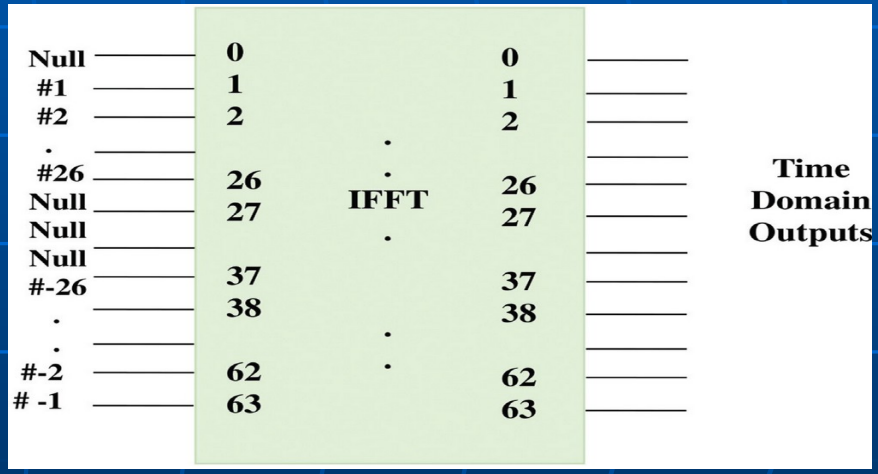
CSI – Indoor Localization / Activity Detection



Atif et al., Wi-ESP—A tool for CSI-based Device-Free Wi-Fi Sensing (DFWS),
Journal of Computational Design and Engineering, 2020, 7(5), 644–656
Center for Imaging Media Research, Korea Institute of Science and Technology (KIST)

802.11n MIMO





Atif et al., Wi-ESP—A tool for CSI-based Device-Free Wi-Fi Sensing (DFWS),
Journal of Computational Design and Engineering, 2020, 7(5), 644–656
Center for Imaging Media Research, Korea Institute of Science and Technology (KIST)

802.11n Aplitude for all subcarriers 1 to 63 (LLTF)

Atif et al., Wi-ESP—A tool for CSI-based Device-Free Wi-Fi Sensing (DFWS),
Journal of Computational Design and Engineering, 2020, 7(5), 644–656
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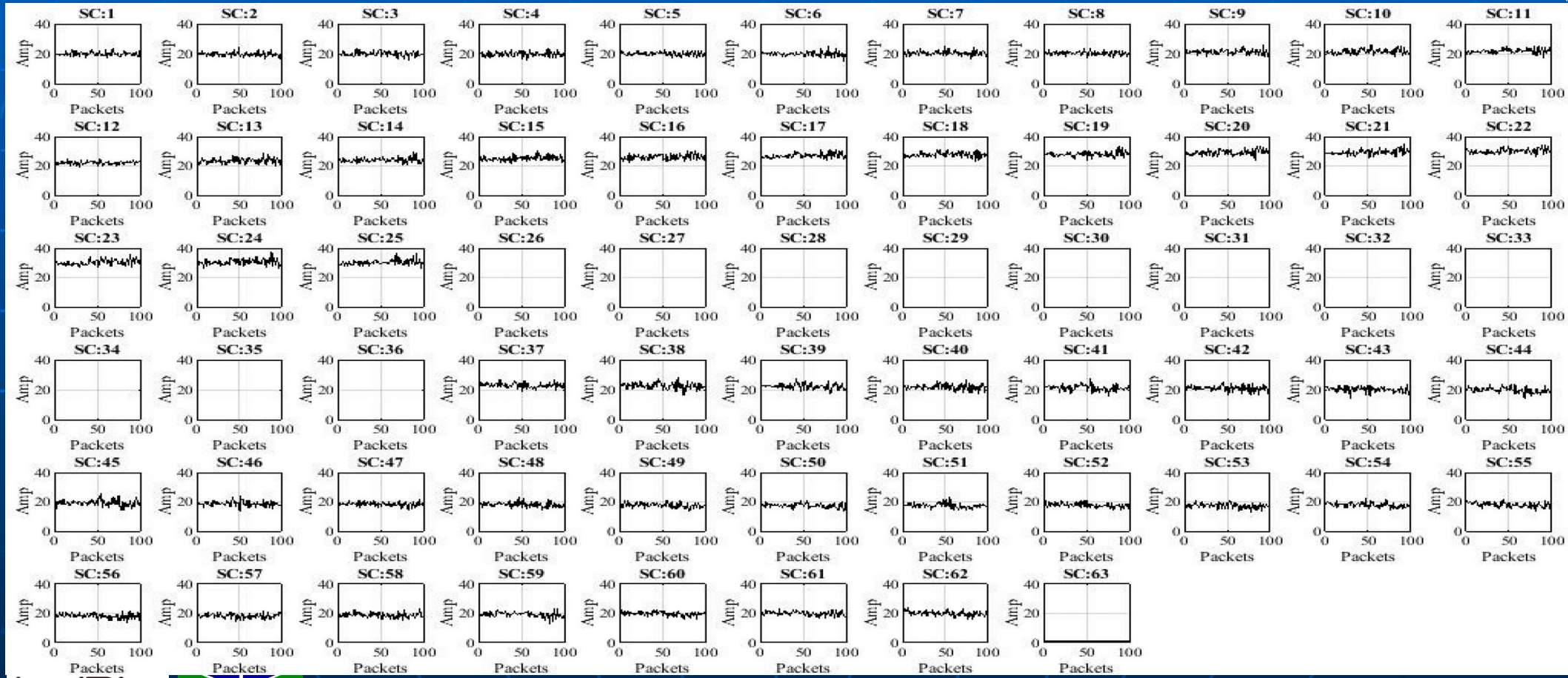


Passive Indoor Localization with WiFi Fingerprints

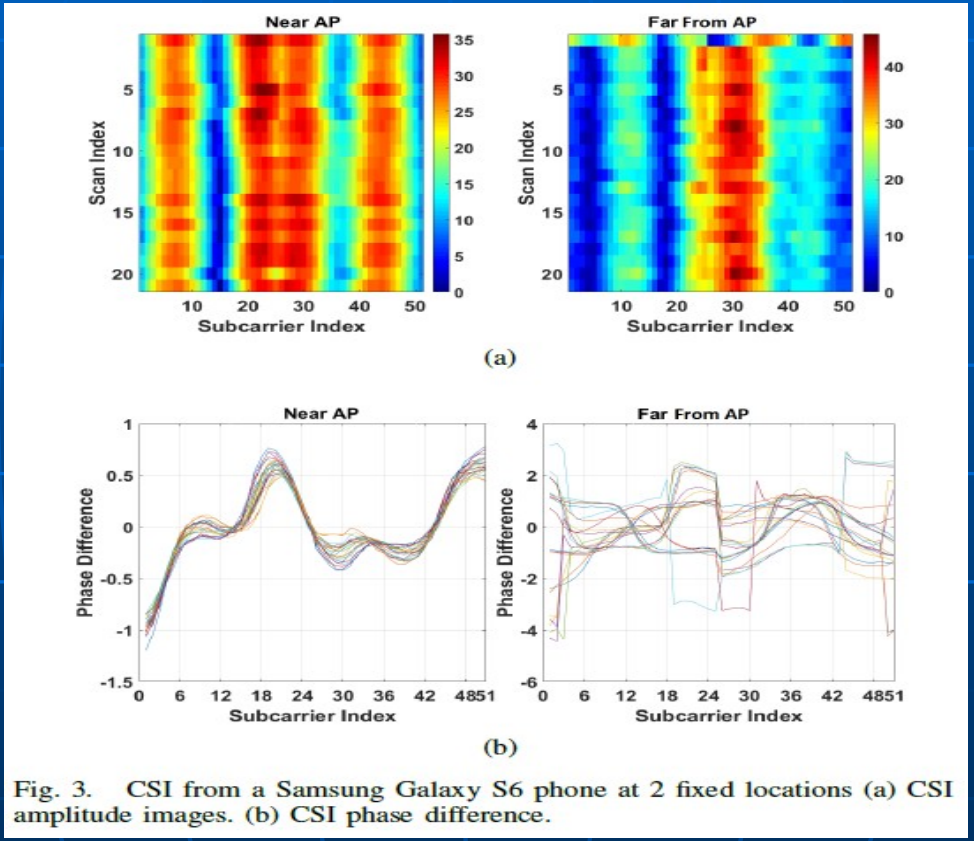


Fig. 3. CSI from a Samsung Galaxy S6 phone at 2 fixed locations (a) CSI amplitude images. (b) CSI phase difference.

Passive Indoor Localization with WiFi Fingerprints
Hoang et al., arXiv:2111.14281v1 [eess.SP] 29 Nov 2021

CRAMÉR-RAO LOWER BOUND ON LOCATION ERROR

Lemma 1. *The PDF of estimated location using RSS-only fingerprint is given by*

$$f\left(P_k|m_i\right) = \prod_{k=1}^{n_a} \frac{1}{\sqrt{2\pi}\left(\sqrt{2}\sigma_R\right)} \times \exp\left(-\frac{\left(P_k + 10\alpha\log_{10}\left(\frac{r_{ik}}{r_{lk}}\right)\right)^2}{2\left(\sqrt{2}\sigma_R\right)^2}\right), \quad (4)$$

where $P_k = P_{lk} - P_{ik}$ is the difference of the vector which is RSS measured by mobile device between i-th TP and l-th RP at the k-th AP.

Proof: Please refer to (3.5) in [13].

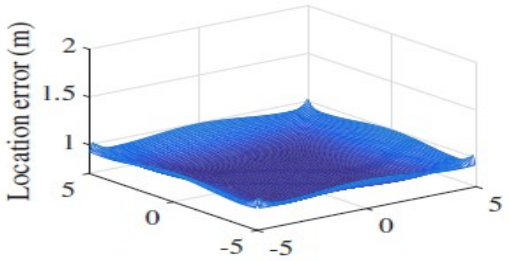
Corollary 1. *The CRLB of RSS-only localization is given by*

$$\mathrm{CRLB}\left(R\right) = \frac{1}{\alpha_R}\left[\frac{x_{sik}^2 + y_{sik}^2}{x_{sik}^2 \times y_{sik}^2 - \left(x_{sik}y_{sik}\right)^2}\right], \quad (5)$$

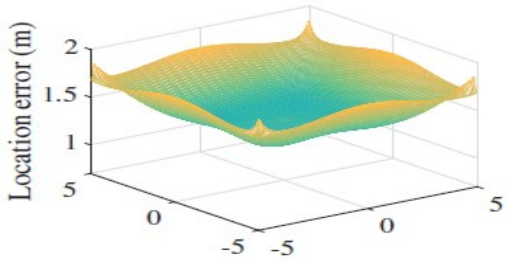
where $\alpha_R = \left(\frac{10\alpha}{\sqrt{2}\sigma_R \ln 10}\right)^2$.

Zhou et al. Hybrid RSS/CSI Fingerprint Aided Indoor Localization: A Deep Learning based Approach, IEEE Globecom 2020

CRAMÉR-RAO LOWER BOUND ON LOCATION ERROR



(a) Location error of RSS-only fingerprint localization.



(b) Location error of CSI-only fingerprint localization.

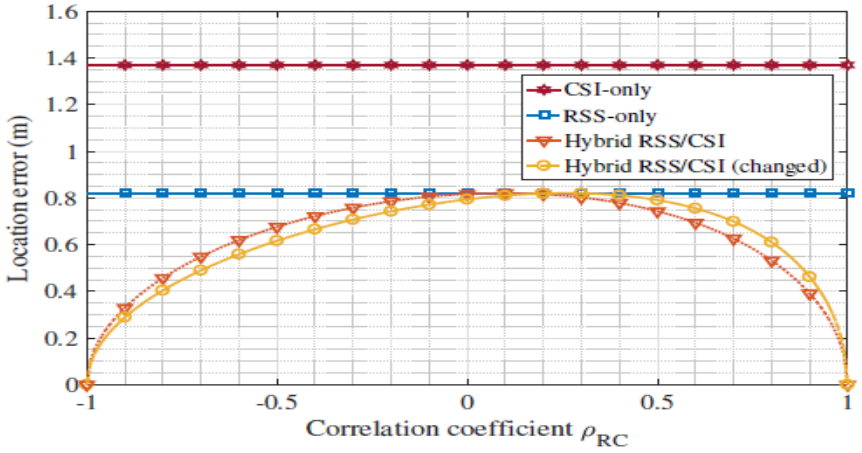


Figure 2. The location error of hybrid CSI/RSS localization with different correlation coefficient. For parameter settings, please refer to Table I.

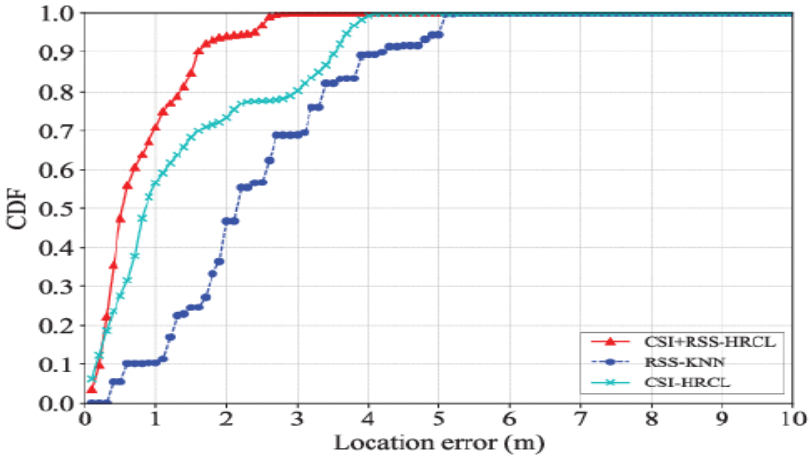
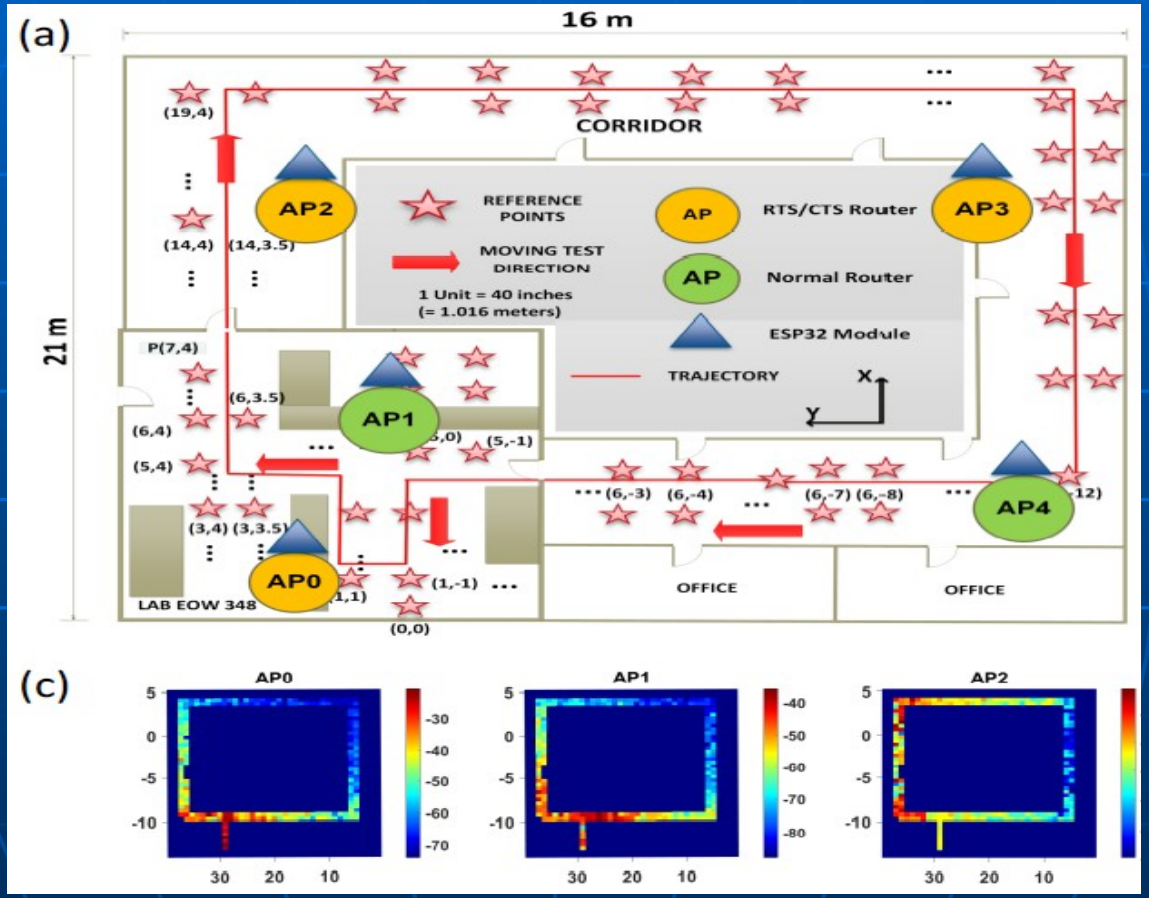


Figure 7. Location error (m) of different fingerprints.

Zhou et al. Hybrid RSS/CSI Fingerprint Aided Indoor Localization: A Deep Learning based Approach, IEEE Globecom 2020

Passive Indoor Localization with WiFi Fingerprints



Passive Indoor Localization with WiFi Fingerprints
Hoang et al., arXiv:2111.14281v1 [eess.SP] 29 Nov 2021

Open Questions

- WiFi is strongly dependent
  - on the person, attitude, cloth, metabolic rate etc.
  - change in furniture, chair position, computers, equipment
  > Multipath, Occlusion

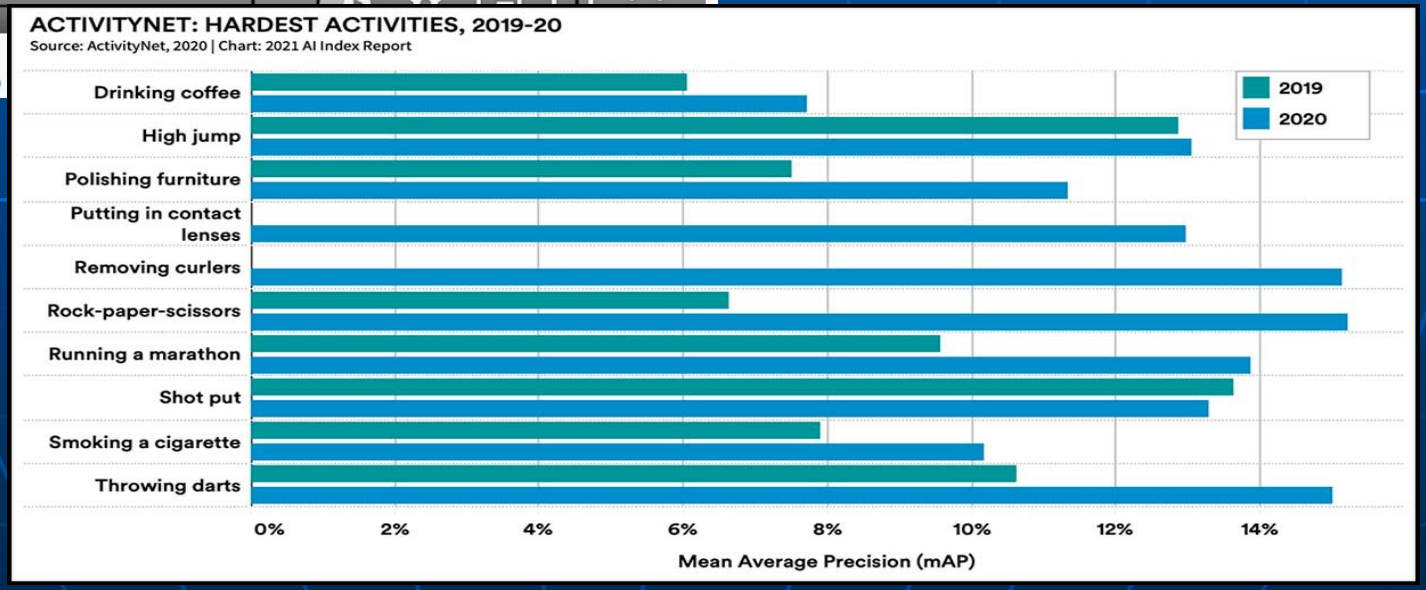
Is Frequently retraining the ANN the technical solution?

- For Climatization

The position of the occupants is often not needed

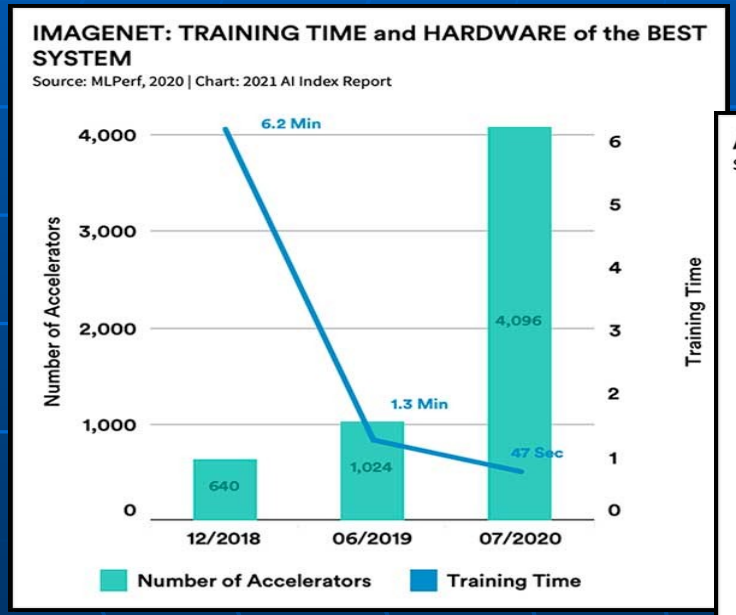
Machine Learning
Challenges & Perspectives

ActivityNet A Large-Scale Video

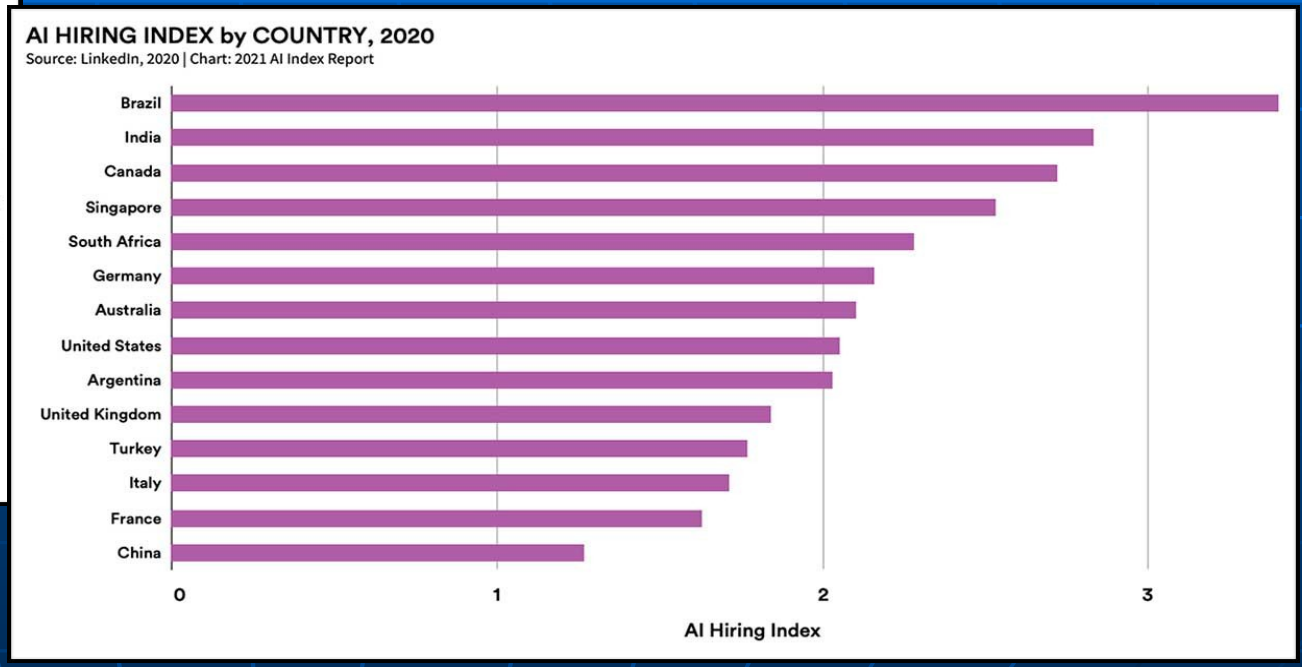


15 Graphs You Need to See to Understand AI in 2021

The 2021 AI Index provides insight into jobs, publications, diversity, and more



https://spectrum.ieee.org/tech-talk/artificial-intelligence/machine-learning/the-state-of-ai-in-15-graphs



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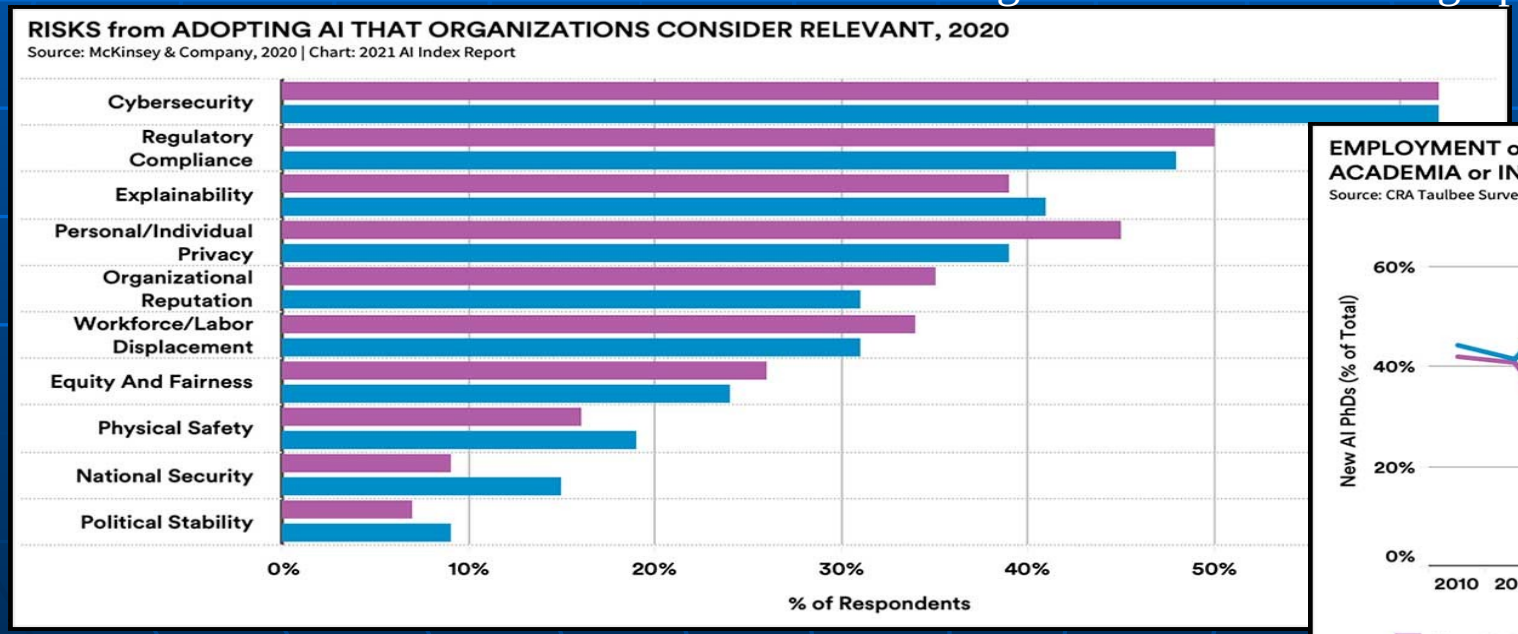
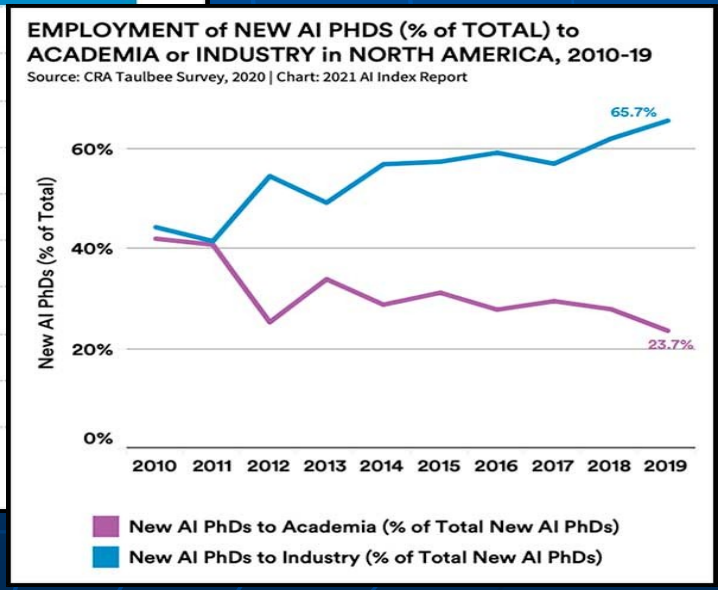
https://spectrum.ieee.org/tech-talk/artificial-intelligence/machine-learning/the-state-of-ai-in-15-graphs





AI Opportunities

- *Deep Learning*
- *Reinforcement Learning*
- *Explanation Components*

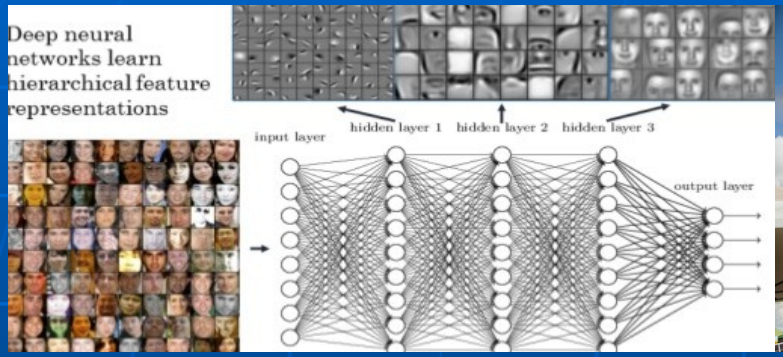
"They shouldn't allow humans to drive!"

Challanges

- *AI with emotions*
- *AI consciosness*
- *ethics in AI*
- *non-human intelligence*
- *AGI (General, Strong AI)*

Learn to Drive:
Self-Driving Car: >>1000 h
Human ~ 20 h

Super-human in one task != Intelligent!!



Thank You!

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