Educational framework using robots with vision for constructivist teaching Robotics to pre-university students

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Overview

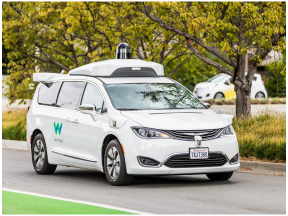
Introduction

Situation of Robotics in daily life



- Technology is becoming common in daily and industrial life.
- Appearance of robotic devices in the mass market.
- Numerous applications and existing domotic services.

Situation of Robotics in industrial life



- Automotive manufacturers and software companies (Google, Apple).
- New companies like Tesla are well positioned in this sector.
- Knowledge of using of technologies is becoming increasingly key.

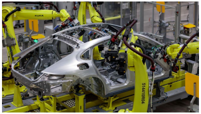
Robotics and Industrialization

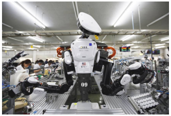
1st Industrial Revolution of 1800

Products developed by machines; the steam engine was the flagship.

2nd Industrial Revolution of the end of the 19th century

With electricity and the main new concept was the assembly line.





3rd Industrial Revolution of 1970

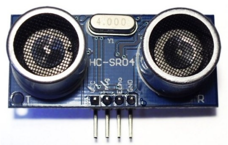
Automation with electronics; PCs and Internet incorporated in society.

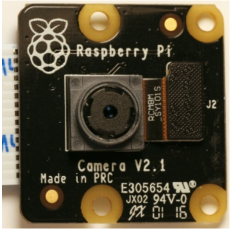
Industrialization 4.0

Integration of complex robotic systems (with vision) in factories.

Industry 4.0: Smart robots for smart factories

- They need complex sensory systems to act intelligently.
- Autonomy in complex surroundings is a deep field in Robotics.





- Vision is a branch of AI which is focused in camera-like sensor.
- For some years, sonar & laser have been more used as sensors.
- At present, camera is the most widely used sensor.
- A camera is a low-cost device but very computationally rich.

Open lines of research

- Visual perception: Biometrics, surveillance, detection (ANNs).
- 3D Reconstruction: video games, reconstruction of buildings.
- Visual self-localization in indoors places (Roomba).
- Visual attention: extract useful information in real time.
- Visual memory: to take more intelligent decisions.

AI and Robotics: the future of labour market

Half of jobs will be occupied by robots in the next 25 years

The future of employment. *U. Oxford*, 2013.
The impact of technology on jobs in the UK. *Deloitte*, 2013.

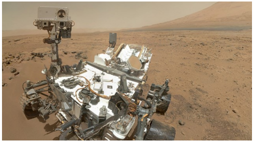
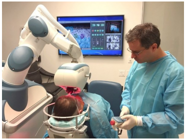
Robots will perform the work of about 800 million jobs in 2030

Report on the global economy. *McKinsey institute*, 2017.

- So young students need proper training.
- Robotics is a field where many areas converge.

Robotics as a profession



- It is essential to incorporate Robotics in education.
  - Robotics is growing in importance in pre-university education.
  - But it is fundamentally conducted in universities.
- The subject was included in the official curriculum in 15/16.
- Outside Spain: U.S., Canada, Ireland, Japan, New Zealand, etc.
- Another example: robotic competitions for teenagers.
- Even more: congresses to emphasize Robotics in Education.

Educational robotics kits

- To support this increasing presence of educational robotics.
- The existing kits focus on their use in class time.
- Cons: low complexity, *a short useful* life, low motivation (3rd & 4th).
- Students need a constant level of motivation and challenge.
- Robots with vision can help to keep a constant level of motivation.

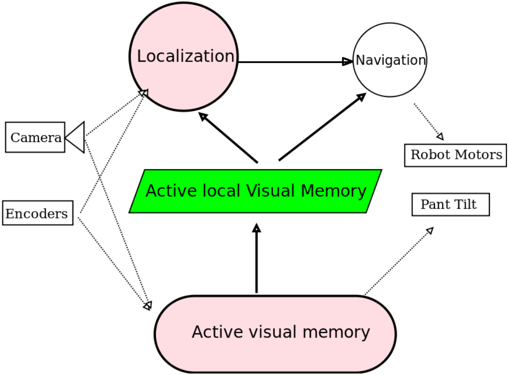
Goals of this thesis

Main topic: incorporating Robotics with vision in the class

- Design and develop an architecture for robots with vision.
  - Visual control, visual memory and visual attention system.
- Design and develop a teaching framework, integrating the above.
  - For teaching Technology and ICTs in pre-university courses.
  - Mitigating academic gap: pre-university *vs.* university training.
- Deployment in different schools and evaluation.

Robotic vision systems

Robot navigation based on attentive visual memory

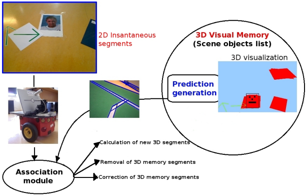


- Avoid false positives and occlusions.
- Create a robust visual memory.
- Localizate the robot with robustness.

Modules of the visual memory

The goal

Storing information about objects surrounding the robot.

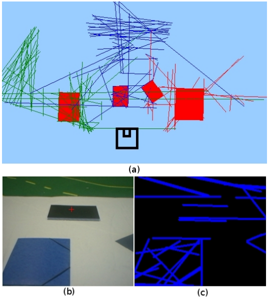


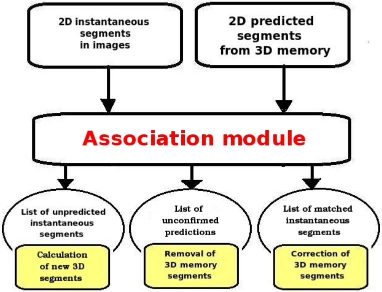
1. 2D analysis, which detects 2D segments in the image.
2. Predictions from the current visual memory 3D contents.
3. Reconstruction of 2D segments in 3D space (*ground-hypothesis*).
4. 3D memory stores their position, update or merge them.
5. Perceptual hypotheses with stored items and new predictions.

2D image processing

The goal

Extract 2D segments as a basic primitive to get object shapes.



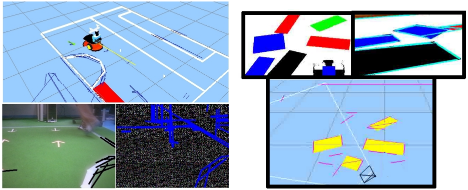


1. Each stored 3D visible object is projected on the image plane.
2. The system corroborates such segments, comparing with image ones.
3. This comparison provides three sets of segments (right fig.).

Reconstruction with 3D segments

The goal

Obtain 3D information from 2D segments/objects in the image.

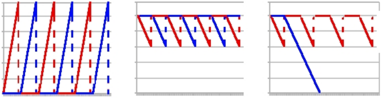


- Ground-hyp.: to estimate the 3rd dimension from a single camera.
- There are four relevant 3D coordinate systems in this approach.
- Post-processing to avoid duplicates in memory due to noise in images.
- Output: a set of observed 3D segments set on robot coord. system.

Visual attention system

The goal

Control the camera movements to track objects and explore areas.

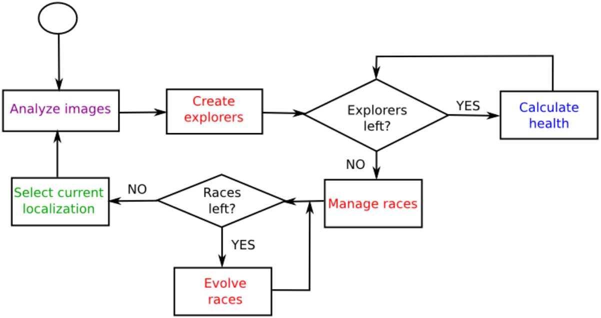

(a) (b) (c)

- *Salience*(a): grows, and vanishes when an element is visited.
  - It represents the *desire to look* at an element.
  - It is used to explore new areas looking for new objects.
  - The point with highest salience will be the next to be visited.
- *Life*(b): decreases, and grows when an element is visited.
  - It represents the health of an element.
  - It is used to forget old or disappearing elements (c).
- *P-controller*: to avoid the Pan-Tilt oscillations.
  - PTU commands can be computed using inverse kinematics.

Localization algorithm design

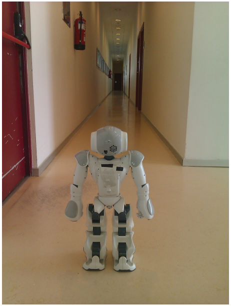
The goal

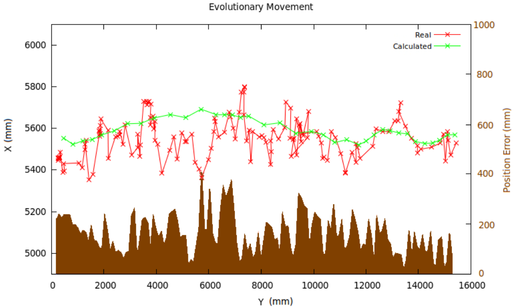
Localizate the robot inside a known environment.



- *Individuals*: Candidate solutions.
- *Races*: Population of Individuals that evolve over time using GAs.

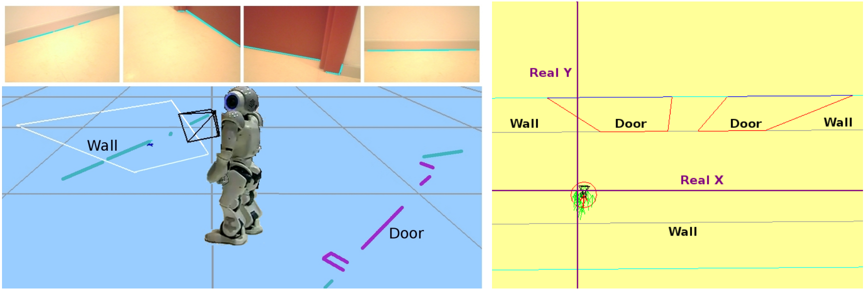
Visual localization from current image





- Real movement of the robot starting on a known position.
- The red line shows the real robot path.
- The green line shows the calculated positions.
- The brown area is the error. The average error has been 15,4 cm.

Visual localization from visual memory



- Whole system: visual memory, visual attention and visual localization.
- The robot moves its head and body to detect all segments around it.
- The average position error is below 15cm and 5 degrees.

Discussion

- Visual memory mechanism stores objects around the robot.
  - It allows to make better navigation and localization decisions.
- Overt visual attention system.
  - *Salience* dynamics let choose the most salient FOA.
- Robust evolutionary localization algorithm.
  - It keeps a population of particles to represent robot positions.
  - It deals with symmetries, grouping particles into races.

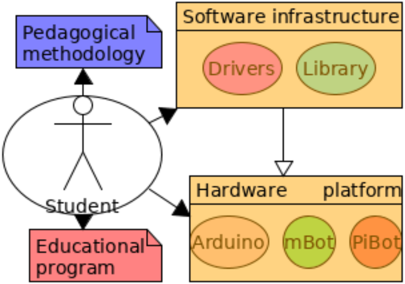
Visual memory improves localization

- Persistence: the memory deals with temporary occlusions.
- The localization is robust to recover from kidnappings.

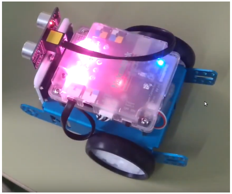
Educational framework

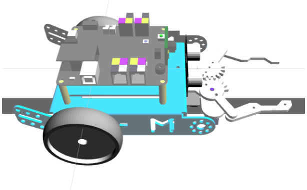
The educational framework includes:

- Hardware platforms: Arduino, mBot and PiBot.
- Software infrastructure: JdeRobot-Kids.
- Educational program for a full academic year.
- Suggested specific pedagogical methodology.



Robot based on Arduino



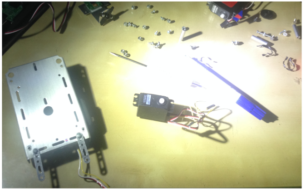
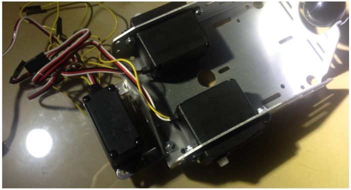
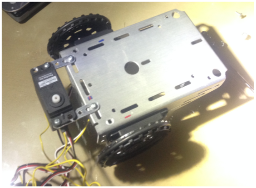
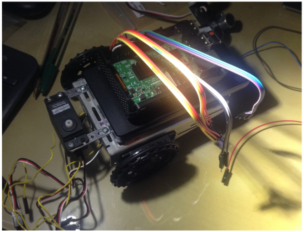
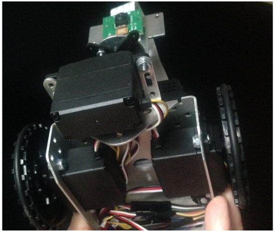


mBot has support for programming in the mBlock graphic language.

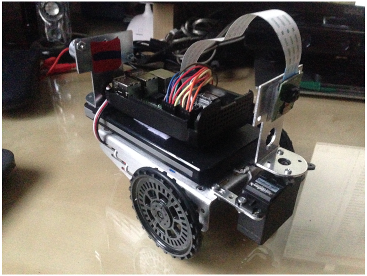
Gazebo-simulated mBot features:

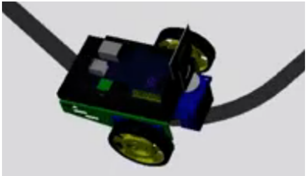
- Graphic and mechanical model and a C++ plugin were developed.
- It allows the students to program virtual IR, US and motors.
- Main problems are mitigated: economic costs and HW maintenance.

Robot based on Raspberry Pi. Assemblage of components

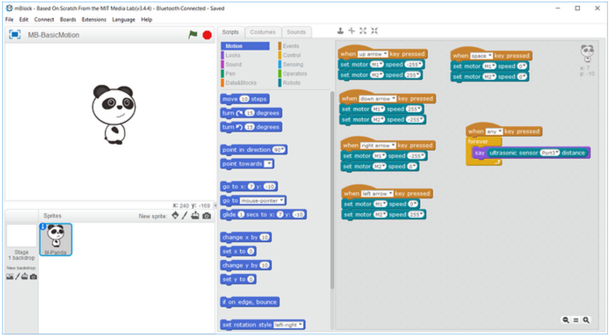

Robot based on Raspberry Pi. Features of PiBot

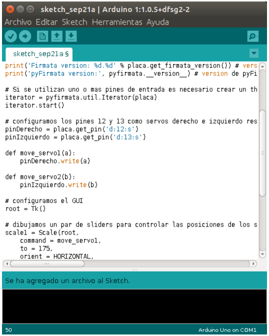




- It is a more powerful platform which permits the use of a camera.
- The computational core is a Raspberry Pi 3 controller board.
- R.Pi main features: Linux O.S., camera data bus and GPIO ports.
- Vision with the Raspberry PiCamera (Sony CMOS 8Mpx sensor).
- A Gazebo-simulated PiBot was also programmed.

Existing programming languages for Arduino-based robots





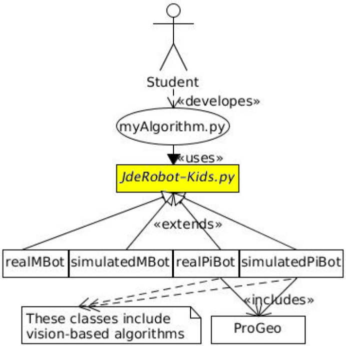
- Arduino is programmed by Arduino IDE, Scratch, or mBlock.
- Visual languages are easy to learn but less powerful.
- Non-visual languages are powerful but not easy to learn.

Using JdeRobot-Kids API and Python language

```python
import JdeRobotKids

if __name__ == "__main__":
  myJdeRobotKids = init()

  vel = 100
  while True:

    val = myJdeRobotKids.leerUltrasonido()
    print(val)
    if (val < 10):
      myJdeRobotKids.retroceder(vel)
      time.sleep(0.5)
      myJdeRobotKids.girarDerecha(vel)
      time.sleep(0.3)
    myJdeRobotKids.avanzar(vel)
    time.sleep(0.3)
```

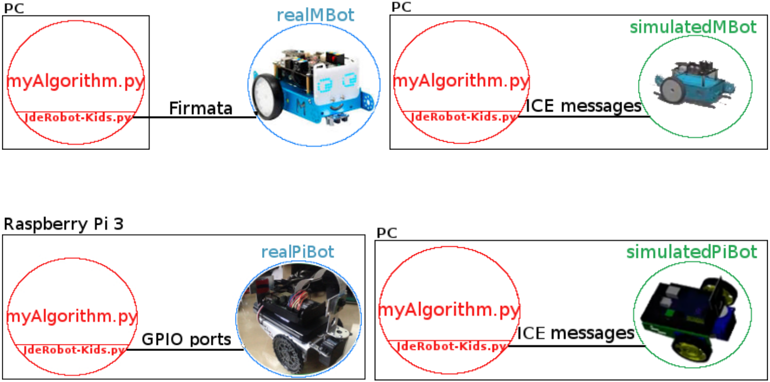
- Python: widely used and letting not to worry too much about syntax.
- JdeRobot-Kids: offers a *cooked* API allowing focus on the task.

JdeRobot-Kids library design and API methods



Acting	Sensory
mover (V, W)	leerIntensidadLuz
avanzar (V)	leerUltrasonido
retroceder (V)	leerIntensidadSonido
girarIzquierda (W)	leerPotenciometro
girarDerecha (W)	leerMandoIR
parar	dameImagen
moverServo (θ)	dameObjetoDeColor
encenderLed	dameSonarVisual
apagarLed	
escribirTexto (T)	
playTono (Fs)	

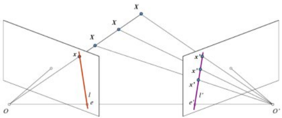
Modules for mBot and PiBot

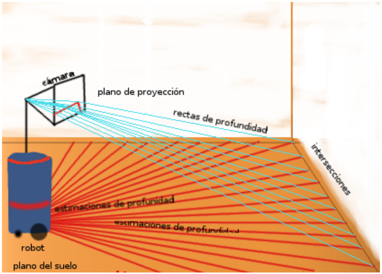


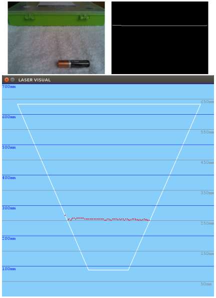
Stereo vs. single camera system

Basis

- Ground hyp.: a single camera can be used to estimate distances.
- Camera model: an ideal camera is assumed (*Pin-hole* model).







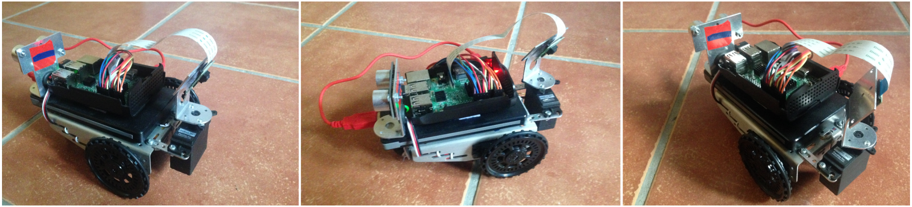
Coordinate systems transformations

Objectives

- The position of the camera needs to be calculated.
- It is defined and positioned according to its matrices $K * R * T$.
- K has been calculated using an own tool: *PiCamCalibrator*.

Camera parameters	Definitions
K (3x3)	intrinsic parameters
R (3x3)	camera rotation
T (3x1)	camera translation
X	forward shift
Y	left shift
Z	upward shift

PiBot camera rotation and translation



Next steps are needed for a complete translation of the camera:

- Robot is moving with respect to $(0, 0)$ and rotating in Z axis.
- Camera is moved along the Z axis with respect to the robot base.
  - Since it is mounted over a Pan unit (servo).
- And it is rotated in:
  - Pan axis with respect to the Z axis according to the Pan angle.
  - Tilt axis with respect to the Y axis according to the Tilt angle.
- The camera OC is translated in X and Z from the Tilt axis.

Academic program

The academic program is divided into four phases:

1. 14 sessions: Basic notions of programming using Scratch.
   - Loops, conditions, variables, etc.
2. 10 sessions: Introduction to Python language.
3. 20 sessions: Robotics practice programming sensors and actuators.
4. 10 sessions: Programming behaviors in a robot.
   - Final project that encompasses all the above.

Basics of programming

Starting to program with a visual language: Scratch

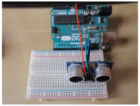
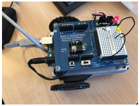
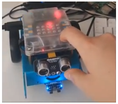
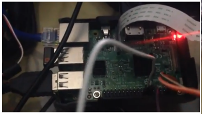
1. *Introduction to Scratch*. Designing an interactive character.
2. *Use of variables*. Developing a game.
3. *Dynamic objects (loops)*. Adding moving objects.
4. *Final project*. Adding different screens (phases).

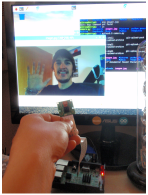
Introduction to the Python language

Focusing on keywords and syntactic issues of Python

1. Printing the numbers from 1 to 100.
2. Printing the numbers from 100 to 0.
3. Printing the even numbers between 0 and 100.
4. Printing the sum of the first 100 numbers.
5. Printing the odd numbers to 100 and how many there are.
6. Printing the numbers from 1 to another entered by keyboard.

Robotic practice activities: sensors and actuators

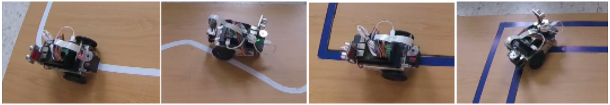







Students carry out a total of ten activities

1. Assembling different components on an Arduino board.
2. Reviewing some basic concepts of electronics.
3. Installing simple components on a protoboard on Arduino.
4. Mastering the use of the sensors and actuators in a `mBot`.
5. Mastering the use of the sensors and actuators in a `PiBot`.
6. Using a camera as a sensor and the treatment of images that it serves.

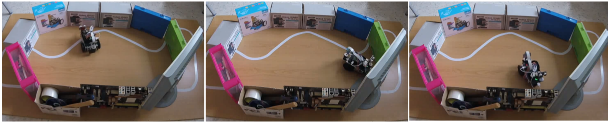
Robotic practice activities: autonomous behaviors

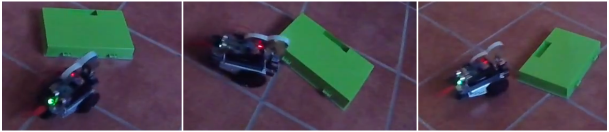


Students combine everything previously learnt in a Robotics project

- Navigation avoiding obstacles by means of ultrasounds.
- Navigation following the light.
- Sumo fight between two mBots.
- Navigation by clapping.
- Stone, paper or scissors game, using the LED array.
- Following an object using a camera sensor.
- Navigation following a line using a camera sensor.
- Navigation avoiding obstacles using a camera sensor.

Robotic practice activities: autonomous behaviors (cont.)





Constructivist methodology in robotics

Based on my experience and the on-site study in Finland

- *Constructivism*: Knowledge is in the participants.
- Students learn more when they are given the opportunity to explore.

Constructivism fits perfectly with JdeRobot-Kids

- Students can experiment with a physical device.
- They learn from them while working, thus building their knowledge.
- There is no differentiation between theoretical and practical.
- Teacher becomes a guide rather than a strict setter of norms.
- Students always work on robotics in groups to avoid being frustrated.
- Last 10' are reserved for reflection and clarifying learning.
- Students assess themselves daily by giving two grades.

Deployment

In the 2016/2017 academic year

- Curr. subjects at the Franciscanas de Montpellier Foundation.
- Extr. at the N.S.S.C. in Madrid and the Villa de Móstoles Schools.

In the 2017/2018 academic year

- It was continued in the six schools of the Foundation.
- Extracurricular subjects at the Rihondo School in Alcorcón.

2,050 students were surveyed

- Curr. (53.2%), extr. (36.2%), and specific events (10.6%).
- Nine teachers were responsible for delivering this content.

Results

Student surveys

- It was easy to learn? $> 54\%$ scored it 8-10; 26% scored it 5-7.
  - Very positive results since their initial level was very low or zero.
- $> 70\%$ reported finding Robotics very interesting (scoring 8-10).
- $> 60\%$ scored the materials received between 8-10. The rest, 5-7.
- $> 70\%$ found the practice activities performed very interesting (8-10).

Teacher surveys

- Students follow classes easily? 8/9 teachers scored it 4/4.
- They considered the academic performance of students improved.
  - 1/2 rated it 4/4. The average grade of the class improved 2 pt.
  - 1/2 rated it 3/4. The average grade improved 1 point.

Discussion

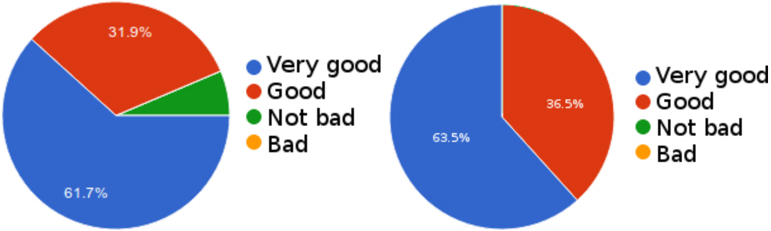


Figure: General assessment of the students and the teaching staff

- The results were satisfactory.
- The surveys show slightly different ratings curr. vs. extr. classes.
- There had been no previous use of Robotics or little use.
- After deployment all the schools embraced Robotics with enthusiasm.
  - They have also held various competitions and workshops.

Conclusions

Discussion and contributions

This research is focused on incorporating Robotics with vision in the class

- Training pre-university *new digital age students*.
- Improving existing little motivating educational Robotics kits.

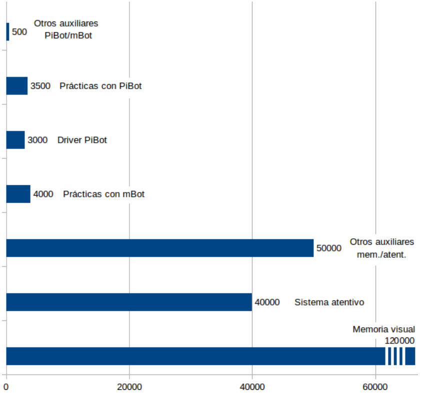
1. Design and development of architecture for robots with vision.
   - Visual memory to incorporate and abstract complex elements.
   - Attentive system to attend the surroundings.
   - Evolutive localization algorithm based on the visual memory.
2. Design and development of a complete educational framework.
   - A robotic platform based on the free HW board Raspberry Pi 3.
   - A SW infrastructure developed in Python language, JdeRobot-Kids.
   - A wide repertoire of practice activities.
   - An academic program that includes the plan of activities.

Results

More than 200,000 lines of code were implemented

The progress of this dissertation can be followed in the dedicated Wiki.

- http://jderobot.org/JulioVega_PhD



Results (cont.)

All these works are integrated into the JdeRobot robotic platform

They are under the framework of several major projects.

- *http://jderobot.org/RobotVision*
- *http://jderobot.org/VisualMemory*
- *http://kids.jderobot.org:8000*

Publications

They can be found in http://gsyc.es/jmvega/publications.html

- 2 journals
  - Julio Vega, Eduardo Perdices and José María Cañas. (2013). *Robot evolutionary localization based on attentive visual short-term memory*, pages 1268-1299. **Sensors**. ISSN: 1424-8220. Impact factor (JCR 2013): 2,048 (Q1).
  - Julio Vega, José María Cañas and Eduardo Perdices. (2012). *Local robot navigation based on an active visual short-term memory*, pages 21-30. **Journal of Physical Agents**. ISSN: 1888-0258. Impact factor (SJR 2011): 0,254 (Q3).
- 2 submitted
  - Julio Vega, José María Cañas. (2018). *PiBot: an open low-cost robotic platform with camera for STEM education*. **Journal of Educational Computing Research (JOECR)**. Under review. Impact factor (JCR 2017): 1,234 (Q3).
  - Julio Vega, José María Cañas, Fran Pérez and Aitor Martínez. (2018). *JdeRobot-Kids: Educational framework using robots with Python to pre-university students*. **ACM Transactions on Computing Education (TOCE)**. Under review. Impact factor (JCR 2016): 1,844 (Q2).
- 1 book chapter
  - Julio Vega, Eduardo Perdices and José María Cañas. (2012). *Attentive Visual Memory for Robot Localization*, pages 408-438. **Robotic Vision: Technologies for Machine Learning and Vision Applications**. Ed. IGI-GLOBAL. ISBN: 978-84-694-6730-5.
- 9 workshops & 1 poster

Future lines

1. Unifying the API for both real and simulated PiBot platforms.
2. Extending the framework to a Web-IDE to work in the cloud.
3. Developing new practical sessions with vision.
   - Materializing in the PiBot a visual attentive memory system.
4. Disseminating the developed framework.
   - Last month of July a Robotics workshop was taught at URJC.
   - A manual is being prepared to serve as a textbook for the teacher.
   - Continuing the implementation in the schools already using it.
   - New schools such as the Carpe Diem Secondary School, Fuenlabrada.
   - Collaboration with two teaching robotics companies.
   - Project with INTEF: 19 teachers & more than 400 students.
5. `PyOnArduino`: Python to Arduino converter (instead of Firmata).

The End

Thank you for your attention

Educational framework using robots with vision for constructivist teaching Robotics to pre-university students

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RT camera matrices

- A single matrix $RT(4x4)$ can be used instead of R and T.
- The RT camera matrices rotating θ in X, Y and Z axes:

$$\begin{bmatrix} 1 & 0 & 0 & X \\ 0 & cos(\theta) & sin(\theta) & Y \\ 0 & -sin(\theta) & cos(\theta) & Z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} cos(\theta) & 0 & -sin(\theta) & X \\ 0 & 1 & 0 & Y \\ sin(\theta) & 0 & cos(\theta) & Z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} cos(\theta) & -sin(\theta) & 0 & X \\ sin(\theta) & cos(\theta) & 0 & Y \\ 0 & 0 & 1 & Z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

Solis' algorithm

```
cvCvtColor (&image, IplTmp1, CV_RGB2GRAY);//to Gray
cvNormalize(IplTmp1, IplTmp1, 0, 255, CV_MINMAX);
cvSmooth(IplTmp1,IplTmp2,CV_BLUR,3,3);//Avrg filter
cvLaplace(IplTmp2, IplLaplace, 3);//Laplace
cvConvertScale(IplLaplace,IplTmp1);
cvThreshold(IplTmp1,IplTmp2,ThressValue,255,CV_THRESH_
```

- It uses a compilation of different image processing steps.
  - Normalization, Gaussian smoothing, Laplace and thresholding.
- It is surprisingly more accurate, robust, faster.
- It uses less parameters at any orientation and location...
  - ...than the widely used Hough Transform algorithm.

P-controller mechanism