Electrical and Computer Engineering School

Aeronautical Engineering School

FPGA-Based Obstacle Avoidance and Line Tracking System For Autonomous Mobile Robots

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An **Associate Professor in electronics and signal processing at Electrical** and **Computer Engineering School** (**ESEO**), in France, since **2019**. She held the same position from **2010 to 2019 at Aeronautical Engineering School (IPSA) in France**. From **2014 to 2018**, she was an **Associate Researcher** at **Sorbonne University** in System On Chip (SOC) department working on the design of a reconfigurable RF transmitter for the 5G wireless communication systems. Dr. Benabid received her **Ph.D** from the **University Paris Saclay in 2005**, on the design of sigma-delta ADC converters at the department of signal and electronic systems at **CentraleSupélec**. In **1999**, she received a **M.Sc. degree in Electronics** from the **Paris Diderot University** in France. She was born on August 11, 1974 in Algeria. She obtained an **Engineer degree in Electronics engineering** from **Setif University, Algeria, in 1995**. Her **research interests** include **embedded systems and information processing, FPGA, AI algorithms, cognitive radio, software defined radio, wireless communication systems, electronics IC design.**

Outline

- Introduction and previous works
- Robot architecture
- Experimental results
- Conclusion and perspective

Introduction & Previous work

- **Mobile robots** are expected to perform increasingly complex tasks in various application fields: space exploration, Intelligent Transport Systems (ITS), military, medicine, service robots, education, ..etc.
- The **Mobile robots use** different kinds of **sensors** to collect environmental information and a set of **actuators** for their motion and reaction to be able **to navigate** successfully in their environment.
- A **powerful and flexible device** is necessary **to control and manage the set of sensors and actuators** present on the mobile robot,
- The Field Programmable Gate Arrays (**FPGA**) are gaining popularity due to their **reconfigurability**, **parallel ability** and **real-time response** in a dynamic environment.

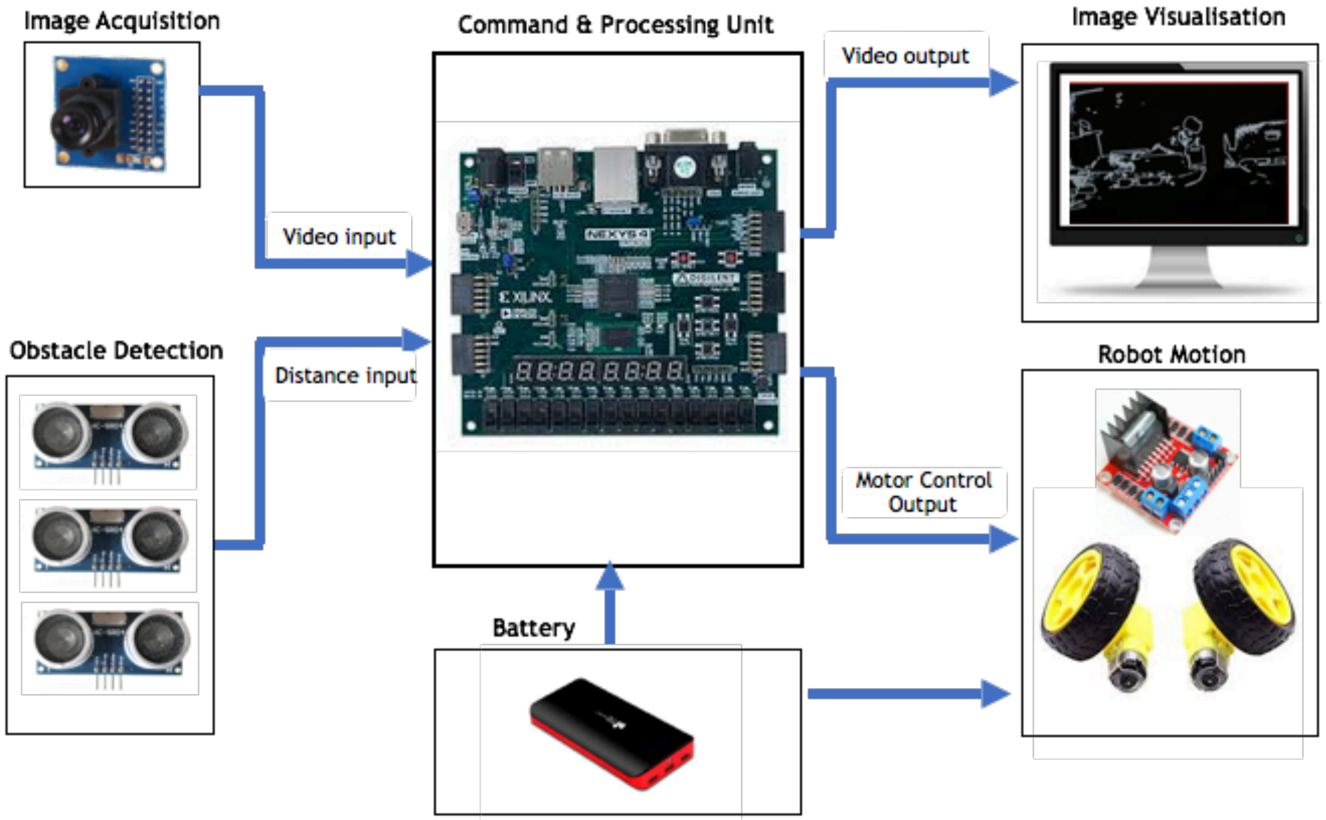
Introduction & Previous work

- Some **related work** on the FPGA-based mobile robot navigation

Reference	Proposed architecture
[2013], S. Boroumand and al., Iranian Conference on Fuzzy Systems (IFSC).	A fuzzy algorithm on FPGA-based mobile robot for line tracking and obstacle avoidance purposes
[2015], G. Velez and al., Journal of Real-Time Image Processing,	FPGA-based vision system for Advanced Driver Assistance Systems (ADAS) applications. The developed board contains a SOC composed of a programmable logic for parallel processing, and a μprocessor for serial decision making.
[2017], A. Irwansyah and al., Journal of Parallel and Distributed Computing.	An FPGA-based architecture for multi-robot tracking using multiple GigE Vision cameras. The proposed architecture was implemented comprising a multi-camera frame grabber and IP cores for image processing
[2019], S.Benabid and al., IEEE International Midwest Symposium on Circuits and Systems (MWSCAS)	An FPGA-based vision system for autonomous mobile robots. The proposed system evaluated in real-time the distance between a robot and an object or obstacle in front of it.

Robot architecture

Embedded system architecture



Robot Specifications

FPGA Board	*Nexys 4 DDR - Artix-7*
Board Dimension	10,9 x 12,2 cm
Logic Slices:	15 850
Block RAM	4,860 Kbits
DDR2 Memory	$128MiB$
Operating Frequency	$100MHz$
Power Supply	4.5V-5.5V
Camera	*CMOS Image sensor*
Photosensitive Matrix	640 x 480
Issuance formats (8)	RGB 565
Maximum rate:	30 fps in VGA
Pixel height	$3.6\mu m$
Output format	VGA
DC motor	*Decelerate motors ratio 1:48*
Drive voltage	12V
Ultrasonic sensor	*HC-SR04*
Operating voltage	5 V
Operating current	15 mA
Range of distance	2 cm to 400 cm
Battery	EC Technology
Capacity	$22400mAh$ / $82.8Wh$
Entry	$5V$ / $2A$
Max Output	$5V$ / $3.4A$ (AUTO)
Dimension	$160x80x23mm$
Weight	$462g$

Robot architecture

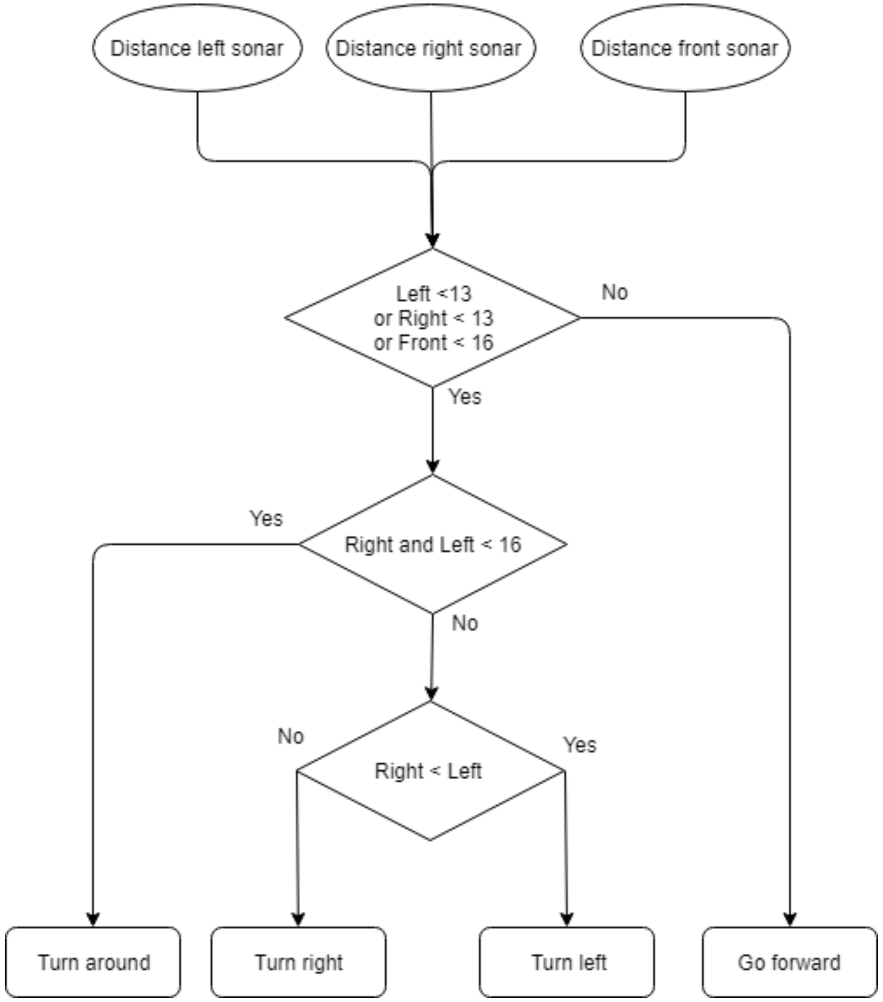
Robot Motion

The Pulse Width Modulation (**PWM**) principle is used **to control the speed of the robot**.

Obstacle Avoidance

This function was filled by 03 ultrasonic sensors placed at the front of the robot and oriented at different angles. Ultrasonic Sensors measure the distance (D) to the target object by measuring the time (T) between the transmitted and received wave.

$$D = \frac{T.S}{2}$$, S represents the sound speed

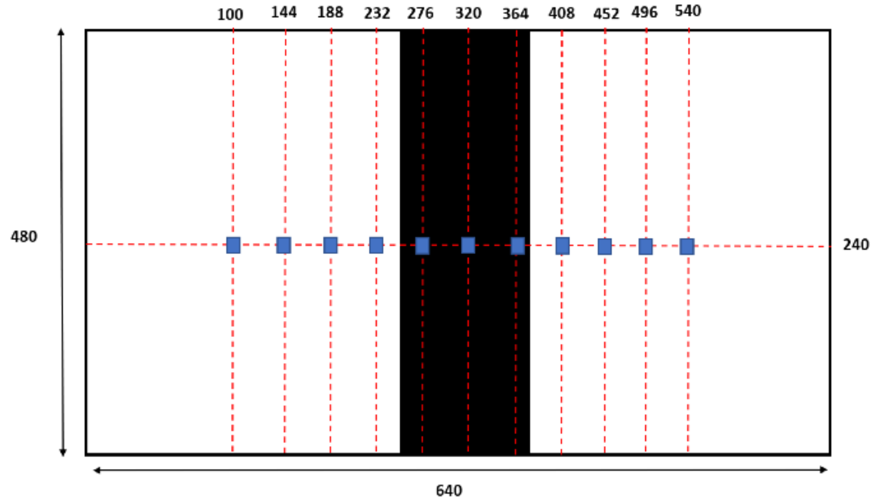


Robot architecture

Line Tracking

A single camera is used at the front of the robot. We have chosen to **track a white line on a black background** reversed by a black and white filter. We chose **11 pixels aligned horizontally, represented by an 11-bit binary vector.** Each bit of the 11-bits vector are set to ”1” (white) or to “0” (black) according to a filter threshold. **The line is modeled by 3 bits at the center of the 11-bits vector.**

Line modeling after black and white filter



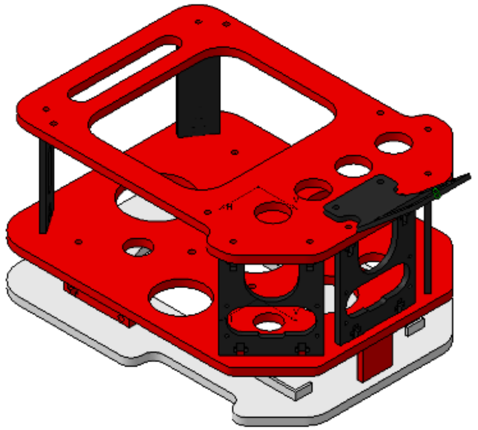
The motor control using the line model

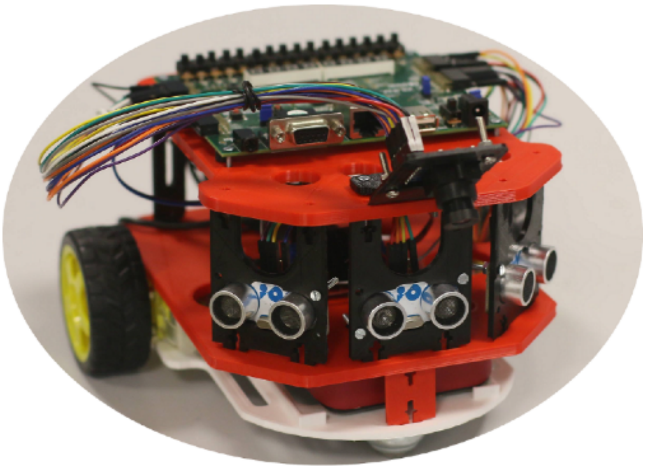
Binary vector	*Action on motor*	*Duty cycle (%)*
00111111111	Turn left	65
00011111111	Turn left	60
10001111111	Turn left	60
11000111111	Turn left	50
11100011111	Forward	50
11110001111	Forward	50
11111000111	Forward	50
11111100011	Turn right	50
11111110001	Turn right	60
11111111000	Turn right	60
11111111100	Turn right	65

Experimental Results

Robot Structure Design

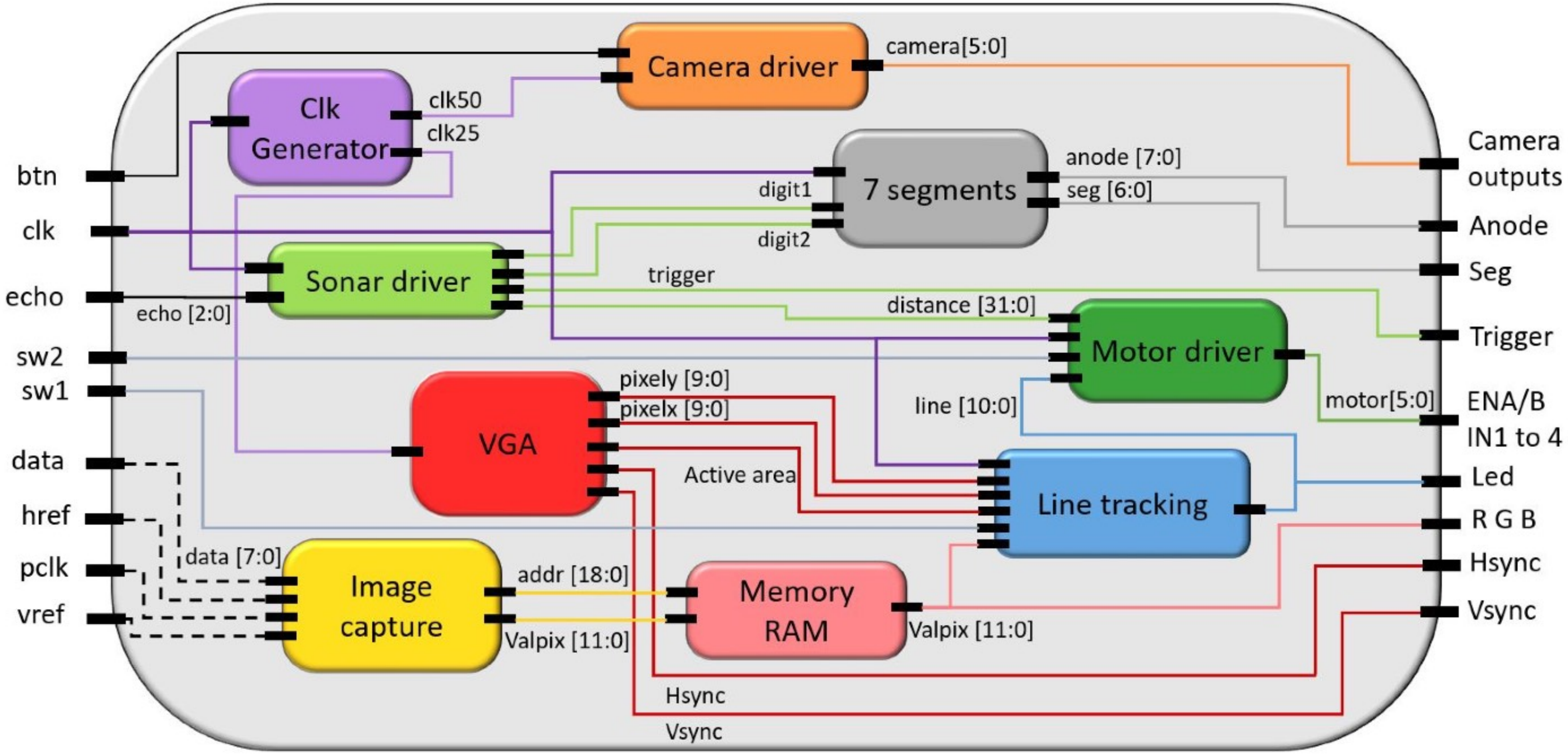
- The structure is designed on **CATIA software** (Computer Aided Three-dimensional Interactive Application), developed by the **french company Dassault Systèmes**.
- The designed structure is printed by a **3D printer** available at the laboratory of the autonomous aerial systems at **IPSA.**





Experimental Results

The proposed architecture is synthesized only on **VHDL code** : robot motion, image processing, obstacle avoidance and line tracking



Experimental Results

Black and white filter for line tracking

FPGA resource usage of the proposed system

Resource	*Utilization*	*Available*	*%*
LUT	1107	63400	1,75
FF	481	126800	0,38
BRAM	104	135	77,04
IO	73	210	34,76
BUFG	5	32	15,63
MMCM	1	6	16,67

The **obstacle avoidance video:** https://youtu.be/tjWPFtim8CQ
The **line tracking video :** https://youtu.be/SjUswlInYgM

Conclusion & Further work

- An **FPGA-based embedded system navigation** for the **mobile autonomous robots** is proposed. The proposed system can **detect and avoid the obstacles** and **track a line**.
- The whole architecture is implemented **only in VHDL code.**
- The achieved robot provides a good experimental **platform for academic environment** in collaboration with industrial partners.
- This platform will be further improved and extended for other tasks such as path planning and object recognition algorithms.
- The engineering students will learn and test **AI algorithms** for mobile robots. They will also be able to propose a new AI techniques for several applications: Intelligent Transportation Systems (ITS), medical application, environmental protection,..etc.