P A N E L

Trends on Miniaturization
(energy, heat, optimisation, connections, accuracy, sensitivity, etc.)

Chair
Petre Dini, IARIA, EU/USA
petre@iaria.org
Needs for miniaturization

- Space saving
- Material saving
- Light devices/machineries
- More handily
- Less energy consuming
- Transportability easiness
- Less computation power
- Speeder devices
- Less costly
- Less storage (space - datacenters, memories chips – data, etc.)
- Nice looking
Journey for electronic circuitry

**Domains**
Human perception (arts): Micro-sculpture, mini-books, mini-picture, ...
Entertainment (games, devices): Screens: screens, medium, small, wearable, ....
  Keyboards: medium, small, on-wrist, ...
Deployment (services): Micro-services, service composition, ....
Healthcare (surgeries): micro, nano (bio-robots), ...
Materials (devices): Macro - mini - micro - nano - pico, ...
Volume (data): Huge data, large data, raw data, compressed/fusion data, temporary data, ...

**Changes/Innovation/Challenges**
Size: Manufacturing tools, measurement tools, controlling procedures,...
Cooling/Heating: Special dedicated devices, techniques for heat dissipation, optimization, ...
Ergonomic: Hand-able, wear-able, harmless, light-weight, ..
Computation procedures: Local, Distributed, Intermittent, ...
Case study

All the photos/pictures are public in open space
Vacuum tubes (the road to electrical devices)
The road to transistors (4-decade period)
Chips (integrated circuits)
Multi-layers integrated circuits

- Multilayer PCB
  - Copper Layer
  - Dielectric
  - Copper Layer
  - Dielectric
  - Copper Layer
  - Dielectric
  - Copper Layer
  - Dielectric
  - Copper Layer

- Ultraviolet lithography
Miniatured devices
(bio, blood, hearing, glycemia, heart, eye, brain. ....)
Continuing the journey

Still going:

- Mini
- Micro
- Nano
- Pico

Stories from the road by... Kyle, Sazzadur, Sorore
Panelists

• Kyle Sundqvist, San Diego State University, USA
  ksundqvist@sdsu.edu

• Sorore Benabid, ESEO, France
  sorore.benabid@eseo.fr

• Sazzadur Chowdhury, University of Windsor, Canada
  sazzadur@uwindsor.ca
Quantum-coherent devices using superconductors at millikelvin temperatures
Kyle Sundqvist, Department of Physics, San Diego State University, San Diego, California, USA. ksundqvist@sdsu.edu

- Superconductive devices as qubits
- Readout using single-photon amplifiers at GHz frequencies
- Sources of entangled GHz photons

à How do we network quantum-coherent devices together? Use “SLH Formalism”
à Opportunities to explore new physics with entangled GHz photons, or with single-photon resolution, inside of a millikelvin cryostat.

Panelist Summary

Oxford Instruments’ Triton 400uW dilution refrigerator, being installed at SDSU
Parametrically-driven superconductive devices

Kyle Sundqvist
San Diego State University
Physics Department
ksundqvist@sdsu.edu

NetWare 2020 Congress
Panel: Trends on Miniaturization

November 2020
We are setting up a low-temperature condensed matter lab.

With access to a millikelvin dilution refrigerator at SDSU, we are preparing a platform by which to amplify photons measuring nearly to the quantum-noise limit.

These amplifiers are designed with readout of superconducting qubits in mind, but have other potential applications.

Such parametrically-driven devices based on superconducting electronics, and operate by driving the natural non-linear inductance related to Josephson junctions.

Oxford Instruments’ Triton 400 Dilution refrigerator
The only potentially active element in superconducting electronics is the **Josephson junction**.

It is formed by two superconductors which are connected by a thin layer of insulating material.

The tendency between superconductors to phase-lock across the junction gives rise to the **Josephson relations**, which depend on the phase difference across the junction, \( \phi_J = \phi_2 - \phi_1 \).
Reviewing the Josephson relations.

DC Josephson Effect:

There is a relation between the current and macroscopic phase difference across the junction:

\[ I = I_c \sin(\phi_J) \]

AC Josephson Effect:

The junction phase and voltage drop are related:

\[ V = \left( \frac{\Phi_0}{2\pi} \right) \frac{d\phi_J}{dt} \]
The DC SQUID looks like a tunable Josephson junction.

Current is the summation of parallel junctions:

\[ I = \frac{I_c}{2} \sin(\phi_{J,1}) + \frac{I_c}{2} \sin(\phi_{J,2}) \]

Circular loop imposes phase boundary condition:

\[ \phi_{J,1} + \phi_{J,2} + 2\pi \frac{\Phi_{\text{ext}}}{\Phi_0} = 2\pi n \]

Simplifying, the DC SQUID looks like a Josephson junction, but with a critical current sensitive to the external flux:

\[ I = \left[ I_c \cos(\pi \frac{\Phi_{\text{ext}}}{\Phi_0}) \right] \sin(\phi_J) \]

\[ V = \left( \frac{\Phi_0}{2\pi} \right) \frac{d\phi_J}{dt} \]
The flux-pumped SQUID acts like a flux+phase mixer.

\[ I = I_c \cos\left(\pi \frac{\Phi_{\text{ext}}}{\Phi_0}\right) \sin(\phi_J) \]

"flux" term

"phase" term

apply a driven external flux:

\[ \Phi_{\text{ext}} = \Phi_{\text{dc}} + \Phi_{\text{ac}} \cos(\omega_p t + \theta_p) \]

Series expand, as the ac flux is assumed small.

\[ \sin(\phi_J) \approx \phi_J \]

\[ \phi_J = \phi_s \sin(\omega_s t + \theta_s) \]
By frequency mixing, “idler” tones form.

<table>
<thead>
<tr>
<th>(Angular) frequency</th>
<th>Designation</th>
<th>Relation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega_1$</td>
<td>“signal”</td>
<td>$\omega_1$</td>
</tr>
<tr>
<td>$\omega_2$</td>
<td>“idler” (three-wave difference)</td>
<td>$\omega_3 - \omega_1$</td>
</tr>
<tr>
<td>$\omega_3$</td>
<td>“pump”</td>
<td>$\omega_3$</td>
</tr>
<tr>
<td>$\omega_4$</td>
<td>“idler” (three-wave sum)</td>
<td>$\omega_3 + \omega_1$</td>
</tr>
<tr>
<td>$\omega_5$</td>
<td>“idler” (four-wave difference)</td>
<td>$2\omega_3 - \omega_1$</td>
</tr>
<tr>
<td>$\omega_6$</td>
<td>“idler” (four-wave sum)</td>
<td>$2\omega_3 + \omega_1$</td>
</tr>
</tbody>
</table>
We can refer **input impedance across** the transformer, which can supply gain.

\[
\begin{pmatrix}
I_1 \\
I_2^*
\end{pmatrix} = \frac{1}{jL_j} \begin{pmatrix}
\frac{\varepsilon_0}{\omega_1} & -\frac{\varepsilon_1^*}{\omega_2} \\
\frac{\varepsilon_1}{\omega_1} & -\frac{\varepsilon_0}{\omega_2}
\end{pmatrix} \begin{pmatrix}
V_1 \\
V_2^*
\end{pmatrix}
\]
This understanding has allowed for a large gain-bandwidth, strongly-coupled lumped amplifier.
This implementation required air-bridge technology.
This produced the yet largest gain-bandwidth parametric amplifier for a lumped SQUID.
An Austrian group recently demonstrates a quantum radar prototype, using superconductive circuits.

- This group uses a Josephson parametric converter (JPC), essentially a parametric amplifier to enable this prototype.

Panelist Summary

FPGA-Based Obstacle Avoidance and Line Tracking System For Autonomous Mobile Robots
Sorore BENABID, ESEO, FRANCE sorore.benabid@eseo.fr

- Introduction & Previous work
- Robot Architecture
- Experimental Results
- Conclusion & Further work

→ Field-Programmable Gate Arrays (FPGAs)
→ Machine learning on FPGAs; Object detection; Synthesis; Real-time FPGAs; etc.
FPGA-Based Obstacle Avoidance and Line Tracking System For Autonomous Mobile Robots

Sorore BENABID\textsuperscript{1}, Loïc LATOUR\textsuperscript{2}, Solène POULAIN\textsuperscript{3}

Email: sorore.benabid@eseo.fr, loic.latour@ipsa.fr, solene.poulain@ipsa.fr
\textsuperscript{1}Department of Electronics and Automatic, ESEO
\textsuperscript{2,3}Department of Aeronautical and Aerospace Systems, IPSA
Paris, France

The Thirteenth International Conference on Advances in Circuits, Electronics and Micro-electronics
CENICS 2020
Dr Sorore Benabid

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, IA algorithms, cognitive radio, software defined radio, wireless communication systems, electronics IC design.
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

<table>
<thead>
<tr>
<th>Reference</th>
<th>Proposed architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>[2013], S. Boroumand and al., Iranian Conference on Fuzzy Systems (IFSC).</td>
<td>A fuzzy algorithm on FPGA-based mobile robot for line tracking and obstacle avoidance purposes</td>
</tr>
<tr>
<td>[2015], G. Velez and al., Journal of Real-Time Image Processing,</td>
<td>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.</td>
</tr>
<tr>
<td>[2017], A. Irwansyah and al., Journal of Parallel and Distributed Computing.</td>
<td>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</td>
</tr>
<tr>
<td>[2019], S. Benabid and al., IEEE International Midwest Symposium on Circuits and Systems (MWSCAS)</td>
<td>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.</td>
</tr>
</tbody>
</table>
Robot architecture

Embedded system architecture

Robot Specifications

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPGA Board</td>
<td>Nexys 4 DDR - Artix-7</td>
</tr>
<tr>
<td>Board Dimension</td>
<td>10.9 x 12.2 cm</td>
</tr>
<tr>
<td>Logic Slices</td>
<td>15,850</td>
</tr>
<tr>
<td>Block RAM</td>
<td>4,860 Kbits</td>
</tr>
<tr>
<td>DDR2 Memory</td>
<td>128 MiB</td>
</tr>
<tr>
<td>Operating Frequency</td>
<td>100 MHz</td>
</tr>
<tr>
<td>Power Supply</td>
<td>4.5V-5.5V</td>
</tr>
<tr>
<td>Camera</td>
<td>CMOS Image sensor</td>
</tr>
<tr>
<td>Photosensitive Matrix</td>
<td>640 x 480</td>
</tr>
<tr>
<td>Issuance formats (8)</td>
<td>RGB 565</td>
</tr>
<tr>
<td>Maximum rate</td>
<td>30 fps in VGA</td>
</tr>
<tr>
<td>Pixel height</td>
<td>3.6μm</td>
</tr>
<tr>
<td>Output format</td>
<td>VGA</td>
</tr>
<tr>
<td>DC motor</td>
<td>Decelerate motors ratio 1:48</td>
</tr>
<tr>
<td>Drive voltage</td>
<td>12V</td>
</tr>
<tr>
<td>Ultrasonic sensor</td>
<td>HC-SR04</td>
</tr>
<tr>
<td>Operating voltage</td>
<td>5 V</td>
</tr>
<tr>
<td>Operating current</td>
<td>15 mA</td>
</tr>
<tr>
<td>Range of distance</td>
<td>2 cm to 400 cm</td>
</tr>
<tr>
<td>Battery</td>
<td>EC Technology</td>
</tr>
<tr>
<td>Capacity</td>
<td>22400mAh / 82.8Wh</td>
</tr>
<tr>
<td>Entry</td>
<td>5V / 2A</td>
</tr>
<tr>
<td>Max Output</td>
<td>5V / 3.4A (AUTO)</td>
</tr>
<tr>
<td>Dimension</td>
<td>160x80x23mm</td>
</tr>
<tr>
<td>Weight</td>
<td>462g</td>
</tr>
</tbody>
</table>
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.

\[ D = \frac{T \times S}{2} \]

, 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.

The motor control using the line model

<table>
<thead>
<tr>
<th>Binary vector</th>
<th>Action on motor</th>
<th>Duty cycle (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>00111111111</td>
<td>Turn left</td>
<td>65</td>
</tr>
<tr>
<td>00011111111</td>
<td>Turn left</td>
<td>60</td>
</tr>
<tr>
<td>10001111111</td>
<td>Turn left</td>
<td>60</td>
</tr>
<tr>
<td>11000111111</td>
<td>Turn left</td>
<td>50</td>
</tr>
<tr>
<td>11100011111</td>
<td>Forward</td>
<td>50</td>
</tr>
<tr>
<td>11110001111</td>
<td>Forward</td>
<td>50</td>
</tr>
<tr>
<td>11111000111</td>
<td>Forward</td>
<td>50</td>
</tr>
<tr>
<td>11111100001</td>
<td>Turn right</td>
<td>50</td>
</tr>
<tr>
<td>11111110001</td>
<td>Turn right</td>
<td>60</td>
</tr>
<tr>
<td>11111111000</td>
<td>Turn right</td>
<td>60</td>
</tr>
<tr>
<td>11111111100</td>
<td>Turn right</td>
<td>65</td>
</tr>
</tbody>
</table>
Experimental Results

Robot Structure Design

• The structure is designed on CATIA software (Computer Aided Three-dimensional Interactive Application), developed by the french company Dassault Systemes.
• 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 synthetized 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

<table>
<thead>
<tr>
<th>Resource</th>
<th>Utilization</th>
<th>Available</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>LUT</td>
<td>1107</td>
<td>63400</td>
<td>1.75</td>
</tr>
<tr>
<td>FF</td>
<td>481</td>
<td>126800</td>
<td>0.38</td>
</tr>
<tr>
<td>BRAM</td>
<td>104</td>
<td>135</td>
<td>77.04</td>
</tr>
<tr>
<td>IO</td>
<td>73</td>
<td>210</td>
<td>34.76</td>
</tr>
<tr>
<td>BUFQ</td>
<td>5</td>
<td>32</td>
<td>15.63</td>
</tr>
<tr>
<td>MMCM</td>
<td>1</td>
<td>6</td>
<td>16.67</td>
</tr>
</tbody>
</table>

The obstacle avoidance video: https://youtu.be/tjWPfim8CQ
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.
Panel 3
Trends on Miniaturization
(energie, heat, optimisation, connections, accuracy, sensitivity, etc.)

Panelist Summary

Miniaturization Challenges and Potentials
Sazzadur Chowdhury, University of Windsor, Ontario, Canada, sazzadur@uwindsor.ca

- From Nano to Pico to Femto
- Physics, materials, and processes
- Modeling challenges (*Ab initio* (first principles) simulations)
- Diverse functionality integration
- Challenge of testing
- New applications: Computing-Life science-manufacturing, and more

- Hybrid systems made of MEMS, Nano, and Pico clusters with new synthetic materials
  - Risk, validation, and reliability challenges
  - Research and technology roadmap
Trends on Miniaturization

Sazzadur Chowdhury, PhD, PEng
Electrical and Computer Engineering
University of Windsor
Windsor, ON, N9B 3P4, Canada
e-mail: sazzadur@uwindsor.ca

NetWare 2020 Congress
November 21, 2020 to November 25, 2020 - Valencia, Spain
From Nano to Pico to Femto

- Nanotechnology – Cluster of molecules
- Picotechnology – Atomic level
- Femtotechnology – Degenerate matter

- Physical properties can be radically different in micro, nano, pico, and femto scales
- Fabrication methods are possible to realize new devices

- Nanoscale technologies are evolving but are not scalable to pico and femto devices

- Opportunity of exploiting fundamental constituents of materials and fundamental forces to develop new artificial materials and devices with unprecedented level of speed, resolution, and functionality
Physics of Miniaturation

- Physics of surface, atomic, and subatomic sciences is governed by coulombic, atomic, and nuclear forces, respectively
- In nanotechnology, structure determines the behavior
- In pico, single or composition of atoms determine the behavior
- In femto, degenerate particles determine the behavior
- Modification of the size or new building blocks of fundamental particles can result in new type of physical properties
- Orders of magnitudes better than corresponding properties of conventional molecular matter can be achieved
- New kind of excitation mechanisms instead of depending on coulombic or surface forces can be used
New Materials and Building Blocks

• Nanoscale:
  – AI designed new artificial materials with improved physical properties
  – Building Blocks: Nanotubes: SWNTs, MWNTs, nanoribbon, buckyballs / buckypapers, fullerene

• Pico/Femto scale:
  – Artificial small masses of synthetic atomic (pico) / degenerate matter (femto)
  – Building Blocks: Various shapes, such as strings, single wall femtotube (SWFT), multiwall femtotube (MWFT), femtobeams, femto membranes, etc., constructed out of nucleons (neutrons, protons and electrons)
Possible New Material Properties

- Zero friction
- Superconductivity over a large range of temperatures
- Programmable extreme dielectric strength
- Programmable extreme high magnetic intensity
- Super mirror reflectivity
- Programmable extreme stiffness
- Programmable extreme thermal conductivity
- Programmable extreme hardness
- Super transparency

Orders of magnitudes better than corresponded properties of conventional molecular matter

Source: http://www.somewhereville.com
Scientific Motivation for Femto Technology

• Three initial particles to deal with:
  • Proton
  • Neutron
  • Electron

• Fewer forces:
  • Electrostatic
  • Strong
  • Weak

• In conventional technology including micro, most common molecules exist in tens of thousands and interactions between them are very complex (e.g., Van der Waals force)

• Multi-technology cluster (nano, pico, and femto)

• Multi-domain interaction / translation / energy conversion
Processing Challenges

- Conventional fabrication or manufacturing processes comprised of deposition-lithography-etching will not be possible in pico or femto scale
- No tools are available now for pico patterning or femto patterning to realize the building blocks
- A total change in fabrication technology will be necessary
- Self-Assembly as a possible solution:
  - Particles shot at a specific force in a target geometry can assemble together due to atomic or subatomic forces to shape the geometry
  - Strong force manipulation in femto scale, while capillary force manipulation in nano or pico scale
  - Determination of appropriate self-assembly mechanism / force (coulombic, Van der Waals, Casimir, Strong) which may be case specific depending on the level of self-assembly: nano, pico, or femto will be crucial

Modeling Challenges

• New modeling techniques capable of simulating 1D, 2D or 3D materials using atomic and subatomic nuclear forces need to be developed

• Simulation of forces and interactions in the nano, pico, or femto scale geometries will require significant improvement on currently available computational platforms

• Some *Ab initio* (first principles) simulation tools are available for etching simulations, but simulation of self-assembly at nano, pico or femto scale to realize devices is a formidable challenge and no tools are available now

• Significant development is necessary

• Without proper modeling tools, these advanced devices cannot be realized

Sub-picometer resolution data from a 50 pm image of graphene
Source: Royal Society of Chemistry
Diverse Functionality Integration

- It can be anticipated that some of these new nano, pico, or femto scale structures will provide active functionality (computation, sensing, actuation) and some may just be providing passive support, surface modification, or interconnection functionality.

- Heterogeneous integration and interaction of such devices constructed out of different building blocks will pose a technological challenge.

- While multi-functional, multi-material, and multi-scale integration can realize new devices, stand alone pico-coating or femto-coating of surfaces can provide totally dramatic functionality to existing macro, micro, or nano structures.

Source: University of Windsor
Challenges of Testing

- Current test equipment does not have the capability to test complex devices made of pico or femto scale devices while some nanoscale testing capability exists.
- Without testing, such devices cannot be deployed in real world.
- Extensive research is necessary to develop testing capabilities of such devices.
- It is necessary to develop test signals (vectors) to probe these new devices and make a proper low-loss, low-noise connection to capture the response, analyse signal waveforms, noise, etc.
- It remains to be determined what kind of testing could be done on a pico or femto scale device and how to interpret those test data, e.g., how to test zero friction or super reflection, property.
- A complete new set of testing definitions and protocols need to be developed.
New Applications

• Nano-pico-femto scale devices will be able to provide information not possible with conventional microsystems technology.

• This data can provide more fundamental information in areas such as biological cell clusters, disease pathogens, material structure and behavior, etc.

• Such data can revolutionize the current technology development and solution approaches for life sciences, manufacturing, computing, printing, chemical catalysis, materials synthesis, psychology, and many other fields.

• A major challenge may be how to incorporate the new functional blocks into existing systems. For example, a femto scale degenerate material based hardness coating on a turbine impeller.

• It may take several decades to be able to incorporate the new capabilities of miniaturization to enhance the functionality of evolving devices or systems.
Conclusions

• Miniaturization will offer the potential to make devices with unprecedented functionalities
• Advanced technologies will be necessary to model, manufacture, test, validate, and integrate pico / femto systems
• Many new technology segments need to be developed
• Self-assembly techniques have the potential to lower the cost of fabrication
• Diverse global stake holders are involved
• A comprehensive roadmap is necessary to create synergy among the stakeholders