Nonlinear physics in Cameroon, Omnipresent chaos and Bio-inspired electronic oscillators

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PHYSICS MATTERS Colloquia Series

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I- Introductory facts on nonlinear physics in Cameroon

I-1- Definition of nonlinear physics (soliton and chaos)

I-2- Introduction of nonlinear physics in Cameroon

I-3- Some facts on research on solitons in Cameroon

I-4-Some facts on the development of chaos research in Cameroon

I-5- Present reseach topics of LAMSEBP

II- Omnipresent chaos

II-1- Quantifiers of chaos, routes to chaos and its manipulation

II-2- Omnipresence of chaos

II-3- Some chaos applications

III- Bio-inspired electronic oscillators

III-1- Biological oscillators and objective of their mimicking

III-2- Principles to design bio-inspired electronic oscillators and examples

III-3- Heart pump toys and flying bird toys

Audience: an undergraduate student will understand. Delicate task

Part I

Introductory facts on nonlinear phyics in Cameroon

I-1- Definition of nonlinear physics (soliton and chaos)

I-2- Introduction of nonlinear physics in Cameroon

I-3- Some facts on research on solitons in Cameroon

I-4-Some facts on the development of chaos research in Cameroon

I-5- Present research topics of LAMSEBP

I- Introductory facts on nonlinear physics in Cameroon

I-1- Definition of nonlinear systems (soliton and chaos)

- **Nonlinear systems:**

- A systems in a state where the response to an input is not proportional to the input,
- Present in different scientific and technological fields,
- Governed by nonlinear differential/partial differential/discrete equations. (presence of terms with power greater than 1 or complex function of the unknown)

- Dominated by many striking and complex structures or responses: among which Solitons and Chaos

Solitons: Nonlinear waves with particular characteristics:

- spatial localization,
- propagation with constant velocity and shape,
- conservation of identity after a collision with other waves.

Two main groups:

- Topological solitons: amplitude independent of the velocity. Exist as a defect in a physical system (Fluxons in Josephson junctions, dislocations in crystals, domain walls in ferroelectric and ferromagnetic systems, etc.).
- Non topological solitons : amplitude depends on velocity. Can not exist with velocity equal to zero.

Chaos: A dynamical system (depending on time) is said to be **chaotic** when it is **deterministic (without any disordered interactions), but its temporal behavior is unpredictable and extremely sensitive to initial conditions**.

Nonlinearity and at least three dimensionality

Spatial chaos and spatiotemporal chaos exist

Examples below

Nonlinear physics specifically chaos is strongly impacting research in physics and in other fields so that some people think it will have the same consequences as the quantum mechanics did at the beginning of 20th century.

I- Introductory facts on nonlinear physics in Cameroon

I-2- Introduction of nonlinear physics in Cameroon

- 1988 : introduction of nonlinear physics in Cameroon by Professor Kofane.
- Three students already engaged in PhD on the study of wood elastic, viscoelastic and plastic properties

- Providence: new scientific leader of the group under the supervision of a department professor.
- New research topics on solitons dynamics and applications:

a- Effects of the discrete nature of materials on the propagation of solitons (domain walls and dislocations) in ferroelectric materials and mechanical structures.

b- Solitons in monoatomic and diatomic lattices

c- Mathematical solutions of some nonlinear partial differential equations having solitons as solutions.

- Striking consequence: three PhD thesis defended the same date with 6 articles +1 article + 1 article published in outstanding journals by APS, IOP-UK, Elsevier, Journal of the Nordic countries academies of sciences.

- Thus a good starting point that was followed by some of Professor Kofane's former students and I have been privileged enough with my contribution in terms of supervision of PhD thesis , and publication of research articles , opening of new research topics

I- Introductory facts on nonlinear physics in Cameroon

I-2- Introduction of nonlinear physics in Cameroon

- Nonlinear physics or nonlinear dynamics or nonlinear science is by very far the most prolific research topic in Cameroon with possibly more than 1000 articles and more than 200 PhD thesis supervised.

- Most of the former PhD students are doing well in different universities all around the world: In each of the 10 State Universities in Cameroon, Central African Republic, Gabon, Chad, Bostwana, Senegal, USA, Germany, Austria, etc,

- Strong collaborations with many research groups all over the World.

- Strong support from the Abdus Salam International Centre for Theoretical Physics (where a good number of former PhD students were associate members)

I- Introductory facts on nonlinear physics in Cameroon

I-3- Some facts on research on solitons in Cameroon

Research on solitons in Cameroon :

- What are the conditions to have a soliton in a physical/biological/optical/electrical system?
- How a soliton propagation is affected by internal irregularities and external excitations?
- How solitons affect the properties and the functional role of a physical/biological/optical/electrical or technological system?
- How to generate very short size solitons?

Etc.

Media used for the study

Media used for the investigations:

- Condensed matter physics or solid state physics,
- Surface science,
- Electrical transmission lines with semiconducting and superconducting components,
- Optical fibres,
- Biological lattices/long chain biomolecules,
- Hydrodynamics,
- Etc,

I- Introductory facts on nonlinear physics in Cameroon

I-4-Some facts on the development of chaos research in Cameroon

- Before 1995 : The contributions of Cameroon in nonlinear physics were almost all on research on soliton dynamics.

- Search for nonlinear systems where one could conduct experimental investigation along with theoretical investigation in Cameroon.

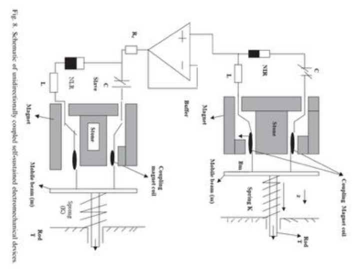
- A shift on research on Chaos came in 1995 after three research stays conducted by at ICTP.

- Lucky enough by been invited to ICTP for conferences in 1994 and 1995 and then got the ICTP associateship in 1995 and equipment grant later from TWAS.

Chaos research thus got its impetus in Cameroon with theoretical and experimental works.

I- Introductory facts on nonlinear physics in Cameroon

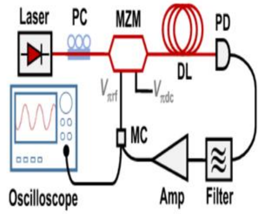
I-5- Present research topics of LAMSEBP



LAMSEBP present research activities

a- Theoretical and experimental studies of the dynamics and synchronization of nonlinear Macro/micro electromechanical actuators for:

- new actuation devices for industrial processes ,
- home devices (mixers, sieves/screens)
- electric energy harvesting



b- Theoretical and experimental studies of complex dynamics of optoelectronic devices

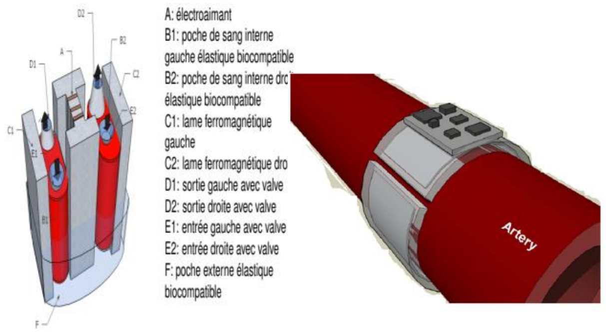
- semiconductor lasers powered by self-sustained electronic oscillators for optical chaos cryptography,
- optoelectronic oscillators having nonlinear electronic component in their electric part for the generation of special optical and electric signals for telecommunications.

c- Theoretical and experimental investigations of chaos synchronization for chaos cryptography in

- electronic circuits,
- discrete equations

d- Bio-inspired devices:

- Self-sustained electronic models for artificial heart pacemakers and artificial neurons,
- Electromechanical models for artificial ventricles,
- Electromechanical models for artificial pancreas based on mathematical models of the couple glucose-insulin



g- Solitons dynamics:

- Condensed matter physics understanding of how short topological waves propagate in ferroelectric, superconducting and biological systems.
- Extension to blood waves and sand dunes motion in deserts

Part II

Omnipresent chaos

II-1- Quantifiers of chaos, routes to chaos and its manipulation

II-2- Omnipresence of chaos

II-3- Some chaos applications

II- Omnipresent chaos

II-1- Quantifiers of chaos, routes to chaos and chaos manipulation

- How to prove the existence of chaos in a system?

Several quantifiers but the main efficient:

Lyapunov exponent: It measures how the trajectory diverge when there is the change in the initial conditions.

Calculated from the data of the numerical simulation or data from the measurement or observations.

Positive when there is chaos. Negative for periodic state

Frequency spectrum analysis: Broad for chaos and concentrated on particular frequencies when order.

Looking at the time evolution of a system, can we predict that chaos is coming?

I- Omnipresent chaos

II-1- Quantifiers of chaos, routes to chaos and chaos manipulation

* Intermittent route to chaos (Pommeau-Manneville scenario)

For a given value of the control parameter, the regular behavior is mixed from time to time with some intervals of chaotic time variation. As the control parameter increases, the number of chaotic intervals increases, leading place finally to full chaos at some critical value of the control parameters.

* Period doubling route or Feigenbaum scenario

- When the control parameter has a value in the interval [P1, P2[, the system is a periodic state of period T (an event A appears after T)
- When the control parameter has a value in the interval [P2, P3[, the system is a periodic state of period 2T (an event A appears after 2T)
- When the control parameter has a value in the interval [P3, P4[, the system is a periodic state of period 4T (an event A appears after 4T)

Continualy, we do the time at which the event A will appear is no more predictable when the control parameter attains a critical value Pn. The event A appears now in a disordered manner as other events.

- Quasiperiodic route to chaos (De Ruelle –Takens- Newhouse scenario)

- When the control parameter has a value in the interval [P1, P2[, the system is a periodic state of period T (an event A appears after T)
- When the control parameter has a value in the interval [P2, P3[, the system is a almost of period state with two incommensurate periods T1 and T2,
- When the control parameter takes a value Pc+epsilon, the chaos takes place.

- Sudden transition to chaos

When the control parameter has a value less than Pc, the system is a periodic state of period T (an event A appears after T). But just when the control parameter takes a value Pc+epsilon, the chaos takes place.

Manipulation of chaos: How? Control and synchronization

I- Omnipresent chaos

II-1- Quantifiers of chaos, routes to chaos and chaos manipulation

Chaos control methods developed using mathematical models, numerical simulation and experiment

- a chaotic state to periodic state,
- a periodic state to a chaotic state (anti-control of chaos)

Development of methods for the synchronization of chaotic systems (X=master, Y=slave)

Put in place an appropriate coupling such that two chaotic systems X and Y starting with different initial conditions will synchronize

Complete synchronization Y =X

Generalized synchronization Y=h(X)

Delayed synchronization Y=h(X(t-T)) with T>0, Y tracks a past state of X.
(slave tracks the unpredictable random past state of the master)

Anticipated synchronization Y=h(X(t-T)) with T<0, Y forecasts the dynamics of X.

(slave passes to the unpredictable ramdom state where the master will pass later)

Phase synchronization: phases Φi or frequencies ωi become locked while the amplitudes remain highly uncorrelated.

Phase synchronization with ratio n : m

$$|n\Phi_1 - m\Phi_2| < constant \quad or \quad n\omega_1 - m\omega_2 = 0$$

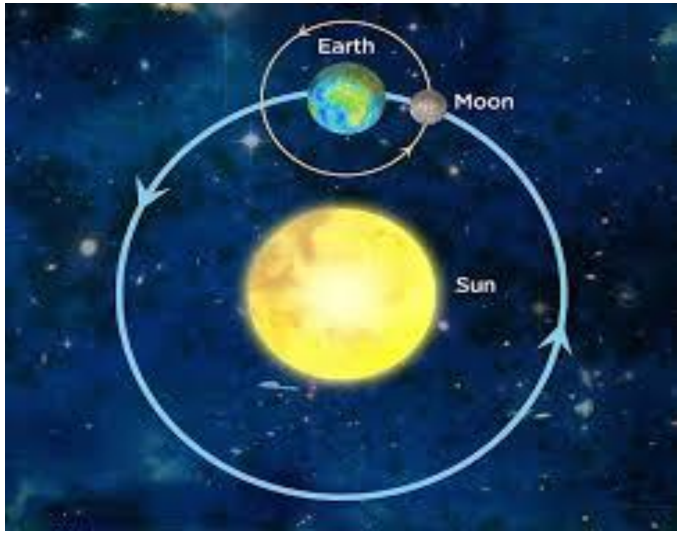
II- Omnipresent chaos

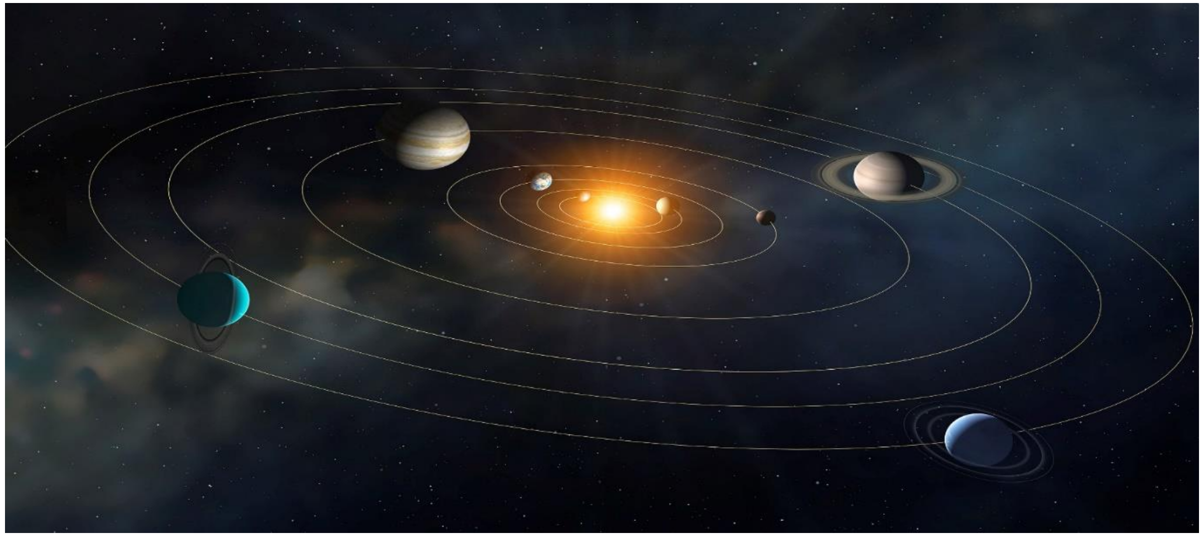
II-2- Omnipresence of chaos

- **Chaos theory started with the three-body problem**: Three masses interacting through gravitational forces

-Example: Sun, Earth and Moon (assumed as isolated from the rest of the universe).

-Then extension to the whole planets of the solar system.





Question: Is the solar system stable (stable trajectories of each planet) or one day one of the planets will hit another planet or flies out of the solar system?

- At the end of the 19th century, Poincaré demonstrated that the trajectory of each body in the three-body system may evolve chaotically. *Henri Poincaré: Méthodes Nouvelles de la Mécanique Céleste, Vol.3, Gauthier-Villars (Paris, 1899)*
- Recent simulations: the planets trajectories in the whole solar system are chaotic so that it is not possible to predict their actual position for time range of 60 millions of years. Difficult to verify considering the large range of time. *Jacques Laskar ; La stabilité du Système solaire, dans : Amy Dahan Dalmedico, Jean-Luc Chabert & Karine Chemla (sous la direction de) ; Chaos & déterminisme, Points Sciences, Le Seuil (1992); G.J. Sussman & J. Wisdom ; Chaotic evolution of the solar system, Science **257** (1992), 56-6*

II- Omnipresent chaos

II-2- Omnipresence of chaos

- **Deterministic chaos in electronic circuits**: In 1961, using analog electronic components, Yoshisuke Ueda (PhD student) found random or disordered behaviors in electronic systems. But his supervisor doubted on the results and they were published only in 1970

Abraham, Ralph H.; Ueda, Yoshisuke, eds. (2000). The Chaos Avant-Garde: Memoirs of the Early Days of Chaos Theory, World Scientific Series on Nonlinear Science Series A. Vol. 39. World Scientific.

Deterministic chaos in meteorology: In 1961, Lorenz and two women collaborators of MIT, USA,

- complex meteorological spatiotemporal equations - set 12 coupled nonlinear differential equations

  - set of 3 coupled nonlinear differential equations.

Numerical simulation: two observations

- No order in the data sequence over large period of time for some values of the coefficients.
- And sensitivity to initial conditions

(Instead of beginning the simulation with the initial data that give the first sequence, they used a new set written on the paper by the printer. The computer worked with 6-digit precision, but the printout rounded variables off to a 3-digit number, so a value like 0.506127 printed as 0.506).

Debates with colleagues: Something wrong with the functioning of the computer? No

Demonstration of the random variations of the horizontal and vertical temperatures gradients, and other meteorological dynamical variables

Lorenz, Edward N. (1963). "Deterministic non-periodic flow". Journal of the Atmospheric Sciences. ***20*** *(2): 130–141.*

The first confirmation of chaos in computer simulation

Most cited reference in chaos theory

II- Omnipresent chaos

II-2- Omnipresence of chaos

Deterministic chaos in population dynamics

- 1976: Robert May and the logistic equation

$$X_{i+1} = rX_i(1 - X_i)$$

Link between the density of biological population at the generation i to that of the next generation i+1.

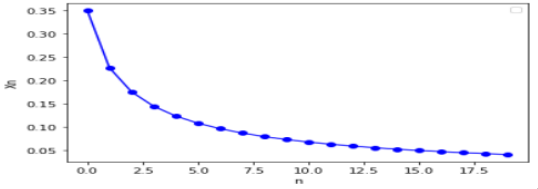
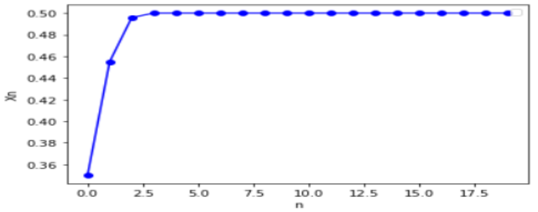
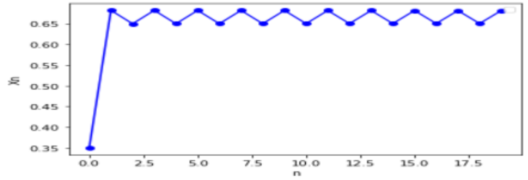
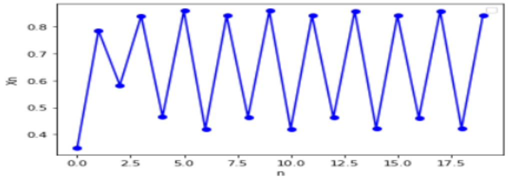
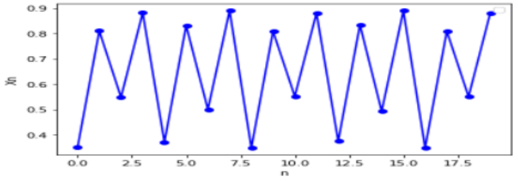
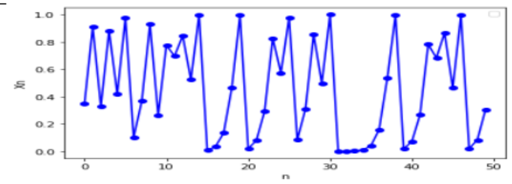
r= proportional to the birth rate.

It shows chaos for a birth rate r>3.57.

Meaning a random variation of the density of the population over time.

R. May, "Simple Mathematical Models with Very Complicated Dynamics", Nature 261, 459 (1976).

Table shows the intervals of the birth rate and the types of variation exhibited by the density versus the generation

Interval of the control parameter	Density variation versus the generation
$r \in [0;1]$ **Decrease of the population**	
$r \in [1;2]$ **Increase of the population till a constant stationary value depending the value of the birth rate**	
$r \in [2;3]$ **Increase of the population till a stationary state where it varies periodically with a period T**	
$r \in [3;3.45]$ **Increase of the population till a stationary state where it varies periodically with a period 2T**	
$r \in [3.45;3.57]$ **Increase of the population till a stationary state where it varies periodically with a period 4T**	
$r \in [3.57,4]$ **Increase of the population till a stationary state where it varies randomly or chaotically**	

Experimental demonstrations:

- *Denis et al, "Transitions in population dynamics: equilibria to periodic to aperiodic cycles", J. Animal Ecology 66, 704 (1997)*
- *Becky et al, "Experimental demonstration of chaos in a microbial foodweb", Nature 435, 1226 (2005).*

Chaos is now found in almost all scientific fields (natural sciences, economics, social sciences)

II- Omnipresent chaos

II-2- Omnipresence of chaos

Chaos in biological sciences

Degn et al., Chaos in Biological Systems, Vol.138, Springer Science and Business Media (2013).

A series of contribution demonstrating from models and experiment the presence of chaos in different subfields of biology

See also the examples of brain and heart below

Chaos in chemistry and biochemistry

Field and Gyogyi, Chaos in chemistry and biochemistry, World Scientific (Singapore, 1993)

Experimental observations and theoretical interpretation of chaos in chemical and biochemical systems such as Belousov-Zhabotinsky reaction, surface reactions, electrochemical reactions, enzyme reactions,

Chaos in economics and finance

Guegan, Chaos in economics and finance, Annual Reviews of Control 33, 89 (2009)

-Chaos theory indicates what is seen as random data in market movements are in fact the signature of deterministic chaos.

- Nonlinear mathematical models have been developed coupling the price index, the bank interest rate and the investment demand. They provide results data similar to real market data

Chaos in social sciences

Kiel and Elliot, Chaos theory in the social sciences: foundations and applications, University of Michigan Press (Ann Arbor, 1997)

Chaos theory has also been used to explain phenomena in Political Sciences and Sociology

cooperation between individuals, cultural conflicts, language competition, education performances

II- Omnipresent chaos

II-2- Omnipresence of chaos

Cardiac arrhythmias are chaotic : demonstrations through in vivo experiment and data from patients

Glass et al,, Nonlinear dynamics, chaos and complex cardiac arrhythmias, Proc. Roy. Soc.A 413, 9 (1987)
(in vivo experiment on wounded chicken heart by stimulating with electric electrodes like the natural pacemaker. The heart is wounded to form ectopic focus: this gives arrhythmias which is analysed)

It was also demonstrated that:

- **Normal electroencephalograms are chaotic**
- **Epilepsy is characterized by the presence of order with rhythmic EEG patterns.**

Sackellares et al., Epilepsy: when chaos fails, in Chaos in Brain? Pp,=. 112-133, World Scientific (2000)

Observations made in scalp and intercranial EEG recordings from patients with epileptic seizures of frontal and mesial temporal origin.

Da Silva et al,, Epilepsies as dynamical diseases of brain systems: basic models of the transition between normal and epileptic activity, Epilepsia 44, 72 (2003) Mathematical models probing the transitions from chaos (normal functioning) to synchronous oscillations (epilepsy)

The mathematical models also suggest methods to forecast the apparition of the epilepsy
Schiff, Forcasting brain storm, Nature Medicine 4, 1117 (1998).

What about chaos applications?

II- Omnipresent chaos

I-3- Some applications of chaos

- **Thanks to the possibility to synchronize two chaotic systems, chaos cryptography is possible**

Messages: text, image, audio, audio-video

- High security because of the large size of the keys: initial conditions, parameters of the chaotic systems (differential equations)
- Can be associated with the classical cryptography methods

Text encryption/ ASCII transformation

(a)

I received the M.S. degree in Telecommunication from the National Institute of Science and Technology of Abeche, Chad, in 2019; where I am currently pursuing a PhD thesis on discrete chaotic systems and their application in cryptography.

(b)

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Figure 10: Plain-text (a) and ciphered text (b)

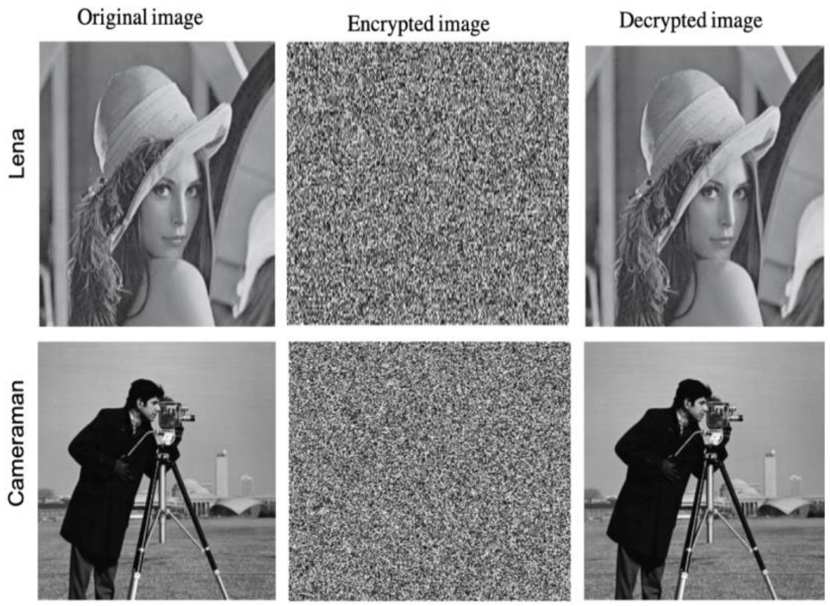


Figure 13: Results of images encryption and decryption processes

Image encryption:
Pixels transformation for encryption

Scheme for chaos cryptography:

- At the emission, the message is encrypted in an appropriate way with the first chaotic signal and sent in the transmission channel
- At the reception, one uses another chaotic signal synchronized to the one at the emission to decrypt the message

Cameroonian specialists on chaos: Theoretical and experimental development of chaos cryptography methods for different channels of transmission

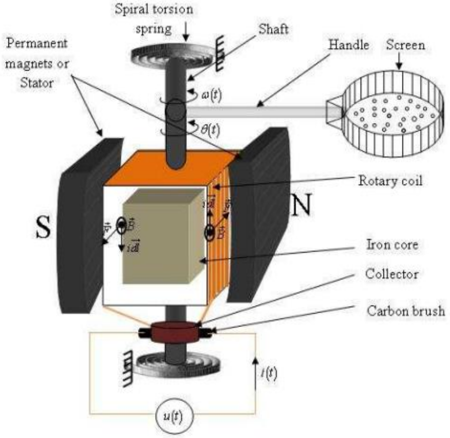
II- Omnipresent chaos

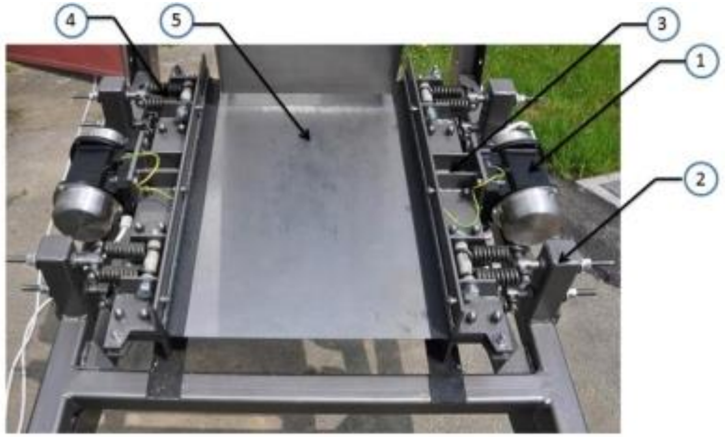
I-3- Some applications of chaos

- Chaotic mixers and sieves: 90% reduction of the operation time and 92% reduction of electric energy consumption

Reason: the random motion of the mechanical actuators of the mixers and sieves enhances the mixing and sieving processes and avoid aggregation





In our group: **- Fabrication of models of mixers and sieves (able to generate normal and chaotic behaviors)**
- Modification of the electrical circuit of the existing mixers/sieves by adding new nonlinear components to generate chaos

What about chaos in human body and chaos therapy?

II- Omnipresent chaos

I-3- Some applications of chaos

Garfinkel et al., Controlling cardiac chaos, Science 257, 1230 (1992)
The strategy of chaos control was used to stabilize cardiac arrhythmias induced by the drug ouabain in rabbit ventricle.

Arrhythmias can be controlled by the administration of electrical stimuli to the heart at irregular times determined by chaos theory, the arrhythmia is converted to periodic beating

- **Anti- control of chaos in the brain for epilepsy therapy:** By applying small electrical stimuli as prescribed by the control method in chaos theory.

Schiff et al, Controlling chaos in the brain, Nature 370, 615 (1994).
In vitro experiment was conducted with success on a hippocampal slice of rat brain for the control of the chaotic bursting states in the brain into periodic states, and the anti-control of the periodic state into chaos.

The mathematical models also suggest methods to forecast the apparition of the epilepsy
Schiff, Forcasting brain storm, Nature Medicine 4, 1117 (1998).

Part III

Bio-inspired electronic oscillators

III-1- Biological oscillators and objective of their mimicking

III-2- Principles to design bio-inspired electronic oscillators and examples

III-3- Heart pump toys and flying bird toys

III- Bio-inspired electronic oscillators

III-1- Biological oscillators and objectives of micmiking biological oscillators

- **Biological oscillators:**
  - belong to the class of self-sustained oscillators (oscillations due to internal regulation: inhibitory feedback, delay)
  - present some special features: pulse-like behaviour, relaxation oscillations, bursting-like oscillations, chaotic signals, bursting chaotic dynamics.

- **These special behaviours describe biological phenomena such as:**

- Cardiac rhythms,
- Breathing oscillations,
- Neuronal firing signals,
- Vasomotion (blood vessels internal oscillations to facilitate the blood flow),
- Menstrual cycle,
- Circadian regulation (wake and sleep),
- Etc,

- **Leading to waves when coupling between several units is considered,**
  - vibration of heart cavities (ventricle and auricles),
  - millipeds motion,
  - coordination of neural activities,

Why mimicking biological oscillators ?

- Development of new methods to predict the behaviors of biological oscillators under some special conditions affecting the natural biological oscillator (by varying some parameters of the models, one can see the signatures of some diseases and compare with the biological observations),
- Development of bio-inspired artificial organs (artificial pacemakers, electronic part of the artificial heart, artificial neurons, artificial muscle,….),
- Use of the new electronic circuits to power some devices such as actuators for special technological purposes

How to mimic artificially biological oscillators ?

III- Bio-inspired electronic oscillators

III-2- Principles to design bio-inspired electronic oscillators and examples

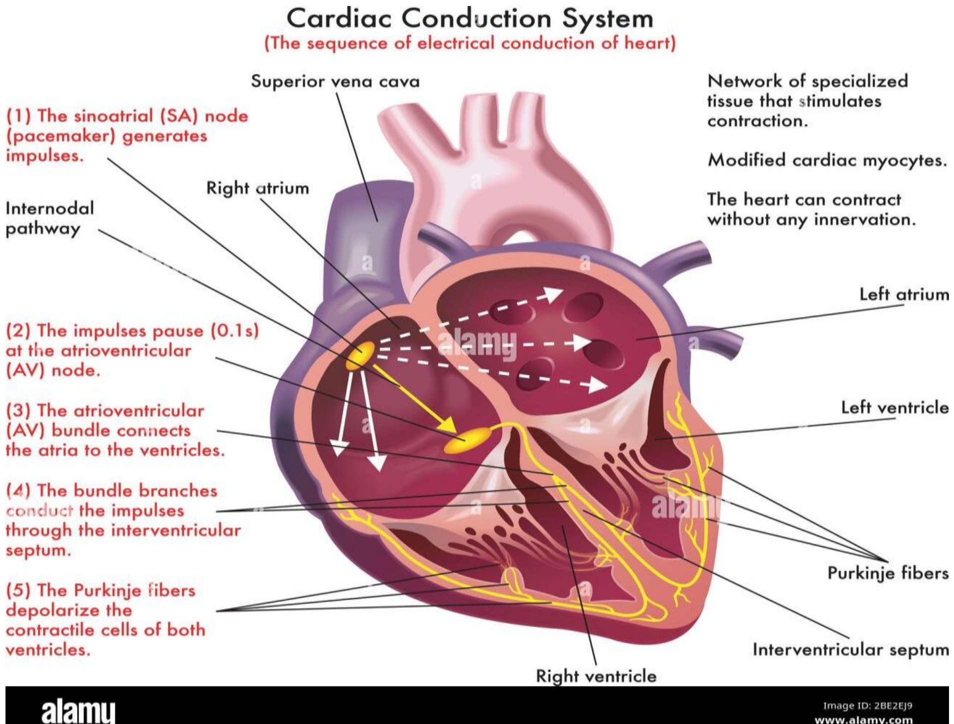
- First development of mathematical differential equations whose solutions present shapes similar to that of the biological oscillators
- Building of analog/discrete electronic circuits **or** microcontroller production of the special behaviours generated by biological oscillators

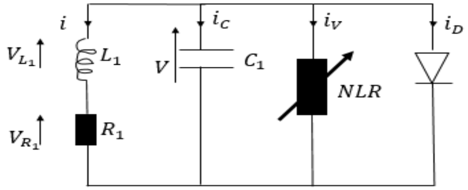
A- Bio-inspired electronic oscillator for heart pacemaker

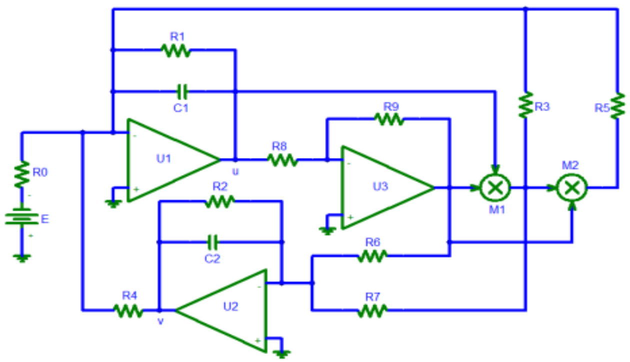
Electric circuit of the heart= Sino-atrial node, Atrioventricular node (secondary node), the bundles of Purkinje fibres distributed on the ventricles.

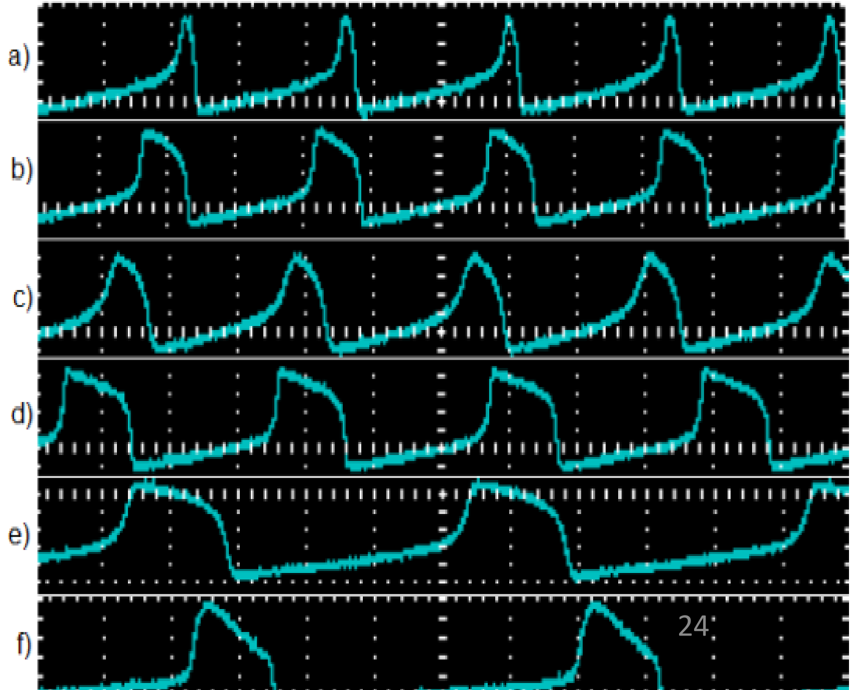
The sino-atrial and atrioventricular nodes generate self-sustained electric pulses (various mathematical models)

In our group, we are constructing some of such models and the electronic circuits to micmic those models









III- Bio-inspired electronic oscillators

III-2- Principles to design bio-inspired electronic oscillators and examples

B- Microcontroller simulators of spiking and bursting signal of the neuron (bio-inspired neuron)

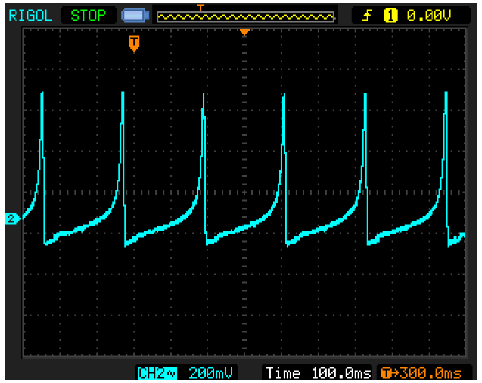
Coding the discretized version of the differential equations inside the microcontroller to generate the corresponding signal at the output,

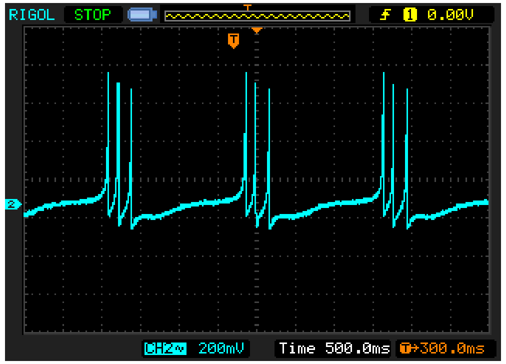
More appropriate solution since one can easily insert the control methods using sensors

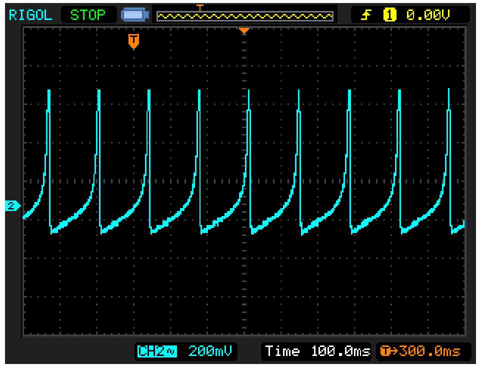
Example of the Hindmarh-Rose oscillator for a single neuron

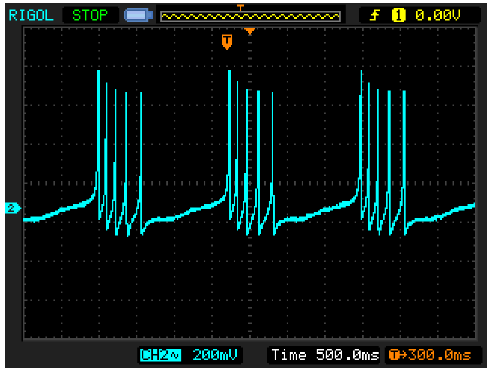
$$\begin{cases} \dot{x} = y - ax^3 - bx^2 + I - z \\ \dot{y} = c - dx^2 - y \\ \dot{z} = r\left[s(x - x_1) - z\right] \end{cases}$$

Simulating in a microcontroller, it delivers the pulse like electric signal and the bursting like electric signal as the natural neuron









An ensemble of these equations coupled in an appropriate way can be simulated in the microcontroller to generate the electrical activities of an ensemble of neurons = artificial network of neurons for some neuronal diseases: tetraplegia, blindess, deafness

What else after artificial pacemaker and neurons? Heart pump toy and Flying bird toy

III- Bio-inspired electronic oscillators

III-3- Projects on heart pump toys and bird flying toys

A- Bio-inspired pump from the heart natural pump

- Understand the electromechanical working principles of the heart pump,

- Propose new models electromechanical toys imitating the functioning of one ventricle, two ventricles or four cavities (two auricles and two ventricles).

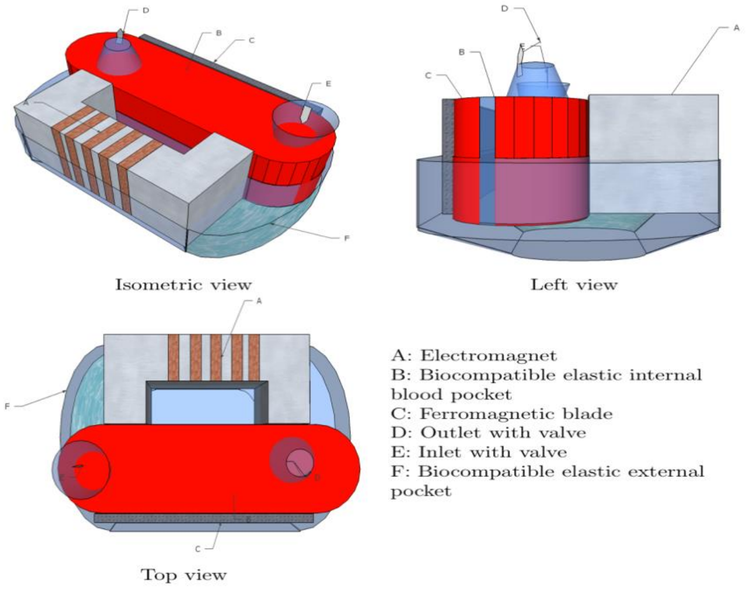


Figure 10: Basic cardiac assist device.

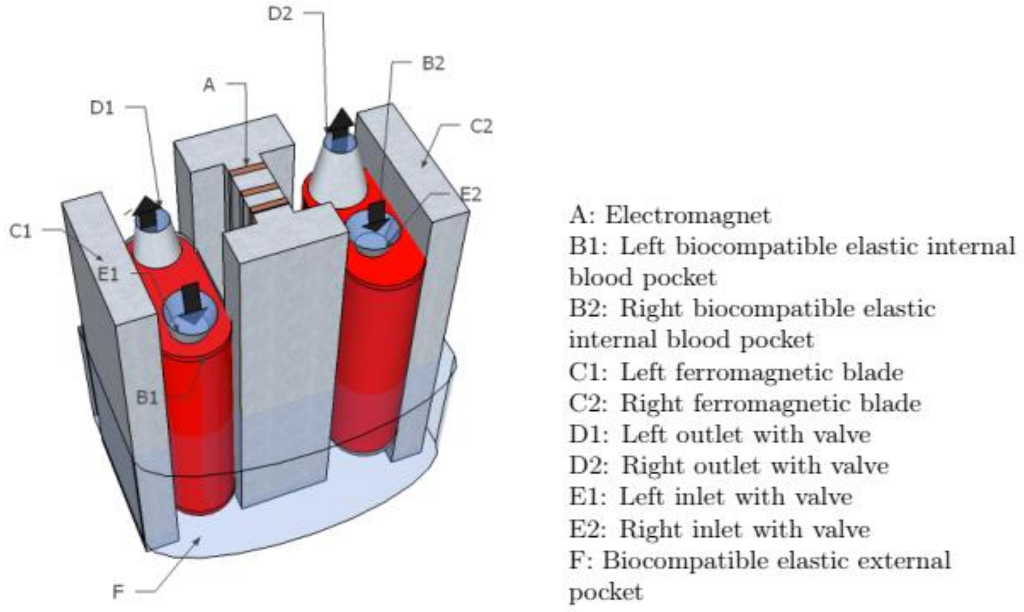


Figure 44: Isometric view of biventricular assist device (total artificial heart) model.

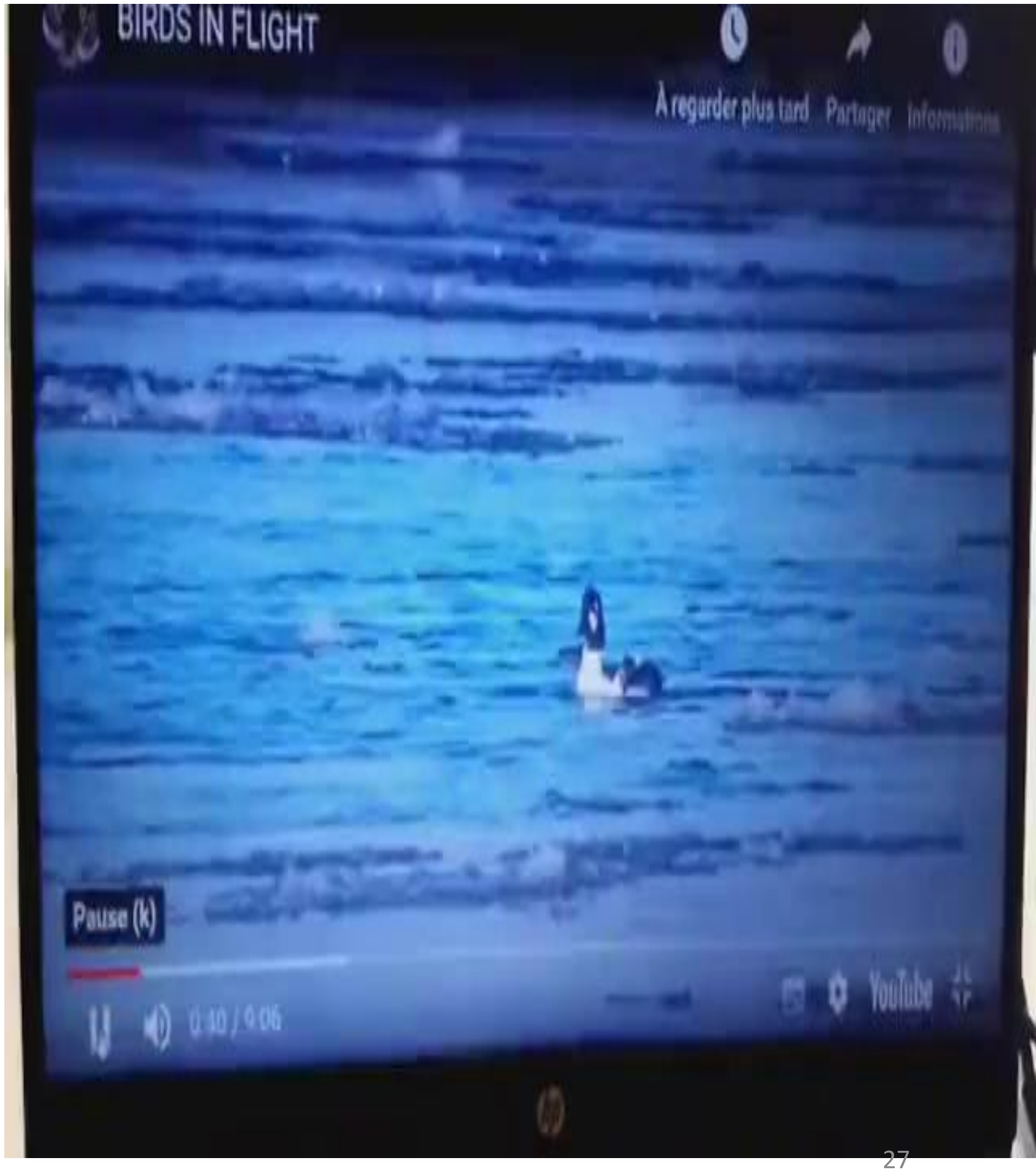
Examples of a mono-cavity and bi-cavity pump fabricated and studied in our research group powered by electric signal generated from a pacemaker model

III- Bio-inspired electronic oscillators

III-3- Projects on heart pump toys and bird flying toys

B- Bionics of birds flight

- Understand the physics/mechanics of bird flight
- Design electromechanical toys imitating the different birds flight modes



Different bird flight modes under imitation in our group and many research groups around the World

- Take-off (with acceleration) and landing (with slowing down)
- flapping mode
- gliding mode
- hovering or stationary mode
- backwards mode

<u>The next generation of warriors and spies ?</u>

- No particular research results from the Cameroonians have been presented here.

- We are preparing a very important scientific event in Cameroon on 2026 where many research will be presented.

- Contact us or wait for the information online.

Thank you

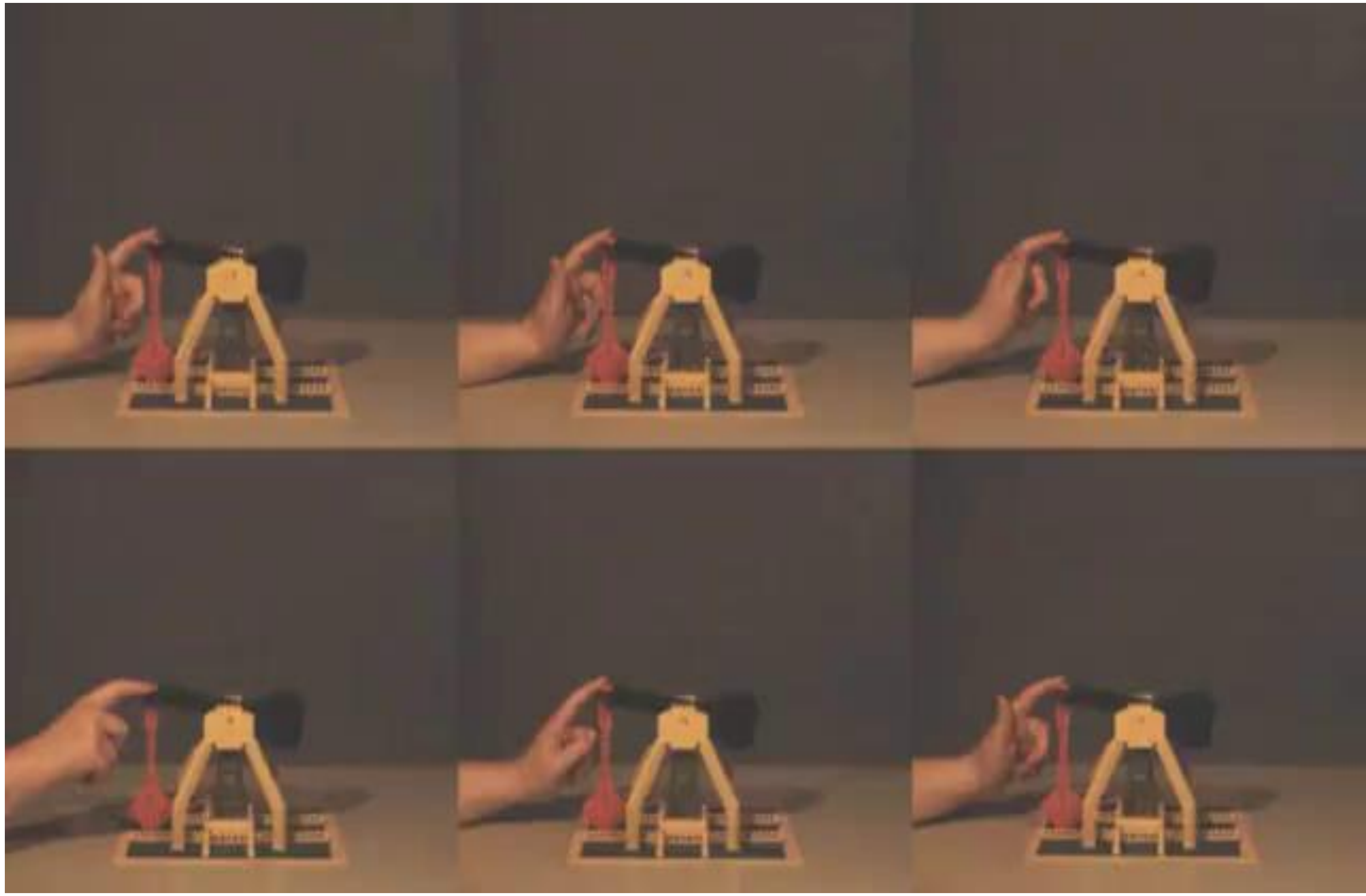
I- Omnipresent chaos

I-1- Definition of chaos and its omnipresence

- Definition: A dynamical system (depeding on time) is said to be **chaotic** when it is **deterministic (without any disordered interactions), but its temporal behavior is unpredictable and extremely sensitive to initial conditions**.

Nonlinearity and at least three dimensionality

Example of the effects of initial conditions on the motion of a double-pendulum system set in motion several times with almost the same initial conditions



Tiny differences in initial conditions

- small error in eye positioning
- small differences in moving the finger,
- blood pressure variation on the finger

- Similar movements during the first seconds
- Differences in the movements appear later despite the initial conditions are almost the same

I- Omnipresent chaos

I-1- Definition of chaos and its omnipresence

Chaos in biological sciences

Experiments and numerical simulation demonstration of chaos in several biological systems

Degn et al., Chaos in Biological Systems, Vol.138, Springer Science and Business Media (2013).

A series of contribution demonstrating from models and experiment the presence of chaos in different subfields of biology

See the examples of brain and heart in section I-5.

Chaos in chemistry and biochemistry

Experimental observations and theoretical interpretation of chaos in chemical and biochemical systems.

Examples: Belousov-Zhabotinsky reaction, surface reactions, electrochemical reactions, enzyme reactions,

Field and Gyogyi, Chaos in chemistry and biochemistry, World Scientific (Singapore, 1993)

Belousov-Zhabotinsly reaction:

Inputs: mixture of Potassium bromate, Cerium sulfate, malonic acid, citric acid (all in dilute surfuric acid)

Outputs or products: Bromure (concentration x), bromic acid (y), cerium 4 (z). See the equation

$$\begin{cases} \dot{x} = k_1 a y - k_2 x y + k_{3,4} a x - 2k_5 x^2 \\ \dot{y} = -k_1 a y - k_2 x y + \nu k_6 z \\ \dot{z} = k_{3,4} a x - k_6 z \end{cases}$$

Behaviors: varying the bromate concentation (a): One observes:

- The cerium 4 periodically transforms to cerium 2 and back leading change of colors from yellow to colorless (vice-versa).
- For some values of the bromate concentration (a), chaotic oscillations of the concentrations leading to random changes of colors.

ki and nu are chemical kinetic parameters

I- Omnipresent chaos

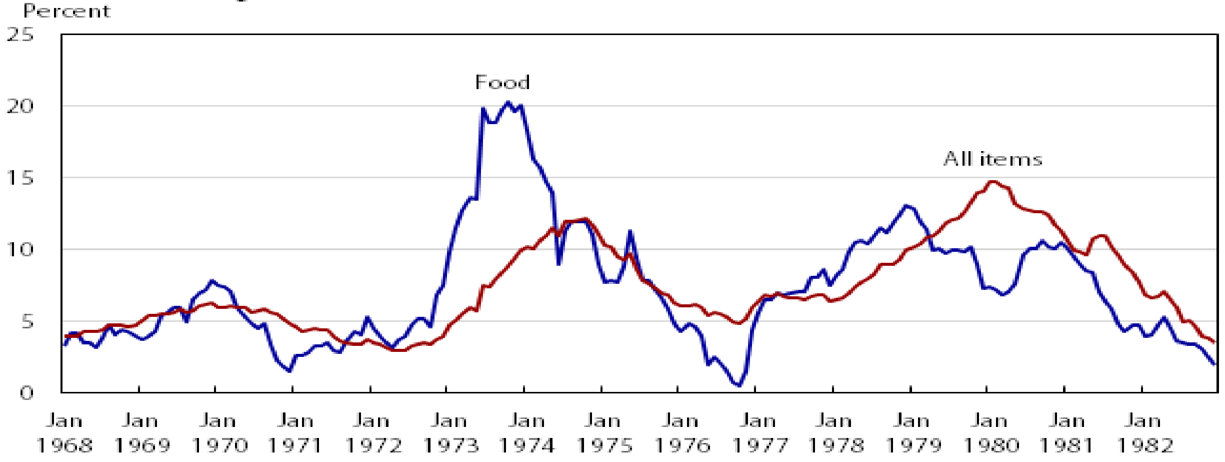
I-1- Definition of chaos and its omnipresence

Chaos in finance and social sciences

- Chaos theory indicates what is seen as random data in market movements are in fact the signature of deterministic chaos. Nonlinear mathematical models have been developed coupling the price index, the bank interest rate and the investment demand. They provide results data similar to real market data.

$$\begin{cases} \dot{x} = z + (y - a)x, \\ \dot{y} = 1 - by - x^2, \\ \dot{z} = -x - cz. \end{cases}$$

Figure 7. Consumer Price Indexes for food and all items, 12-month percent change, 1968–1982



Source: U.S. Bureau of Labor Statistics.

x=Interest rate, y=Investment demand, z=price index,
a=saving amount, b=cost per investment,
c= elasticity of the demand of commercial markets

Varying the saving amount, a variation similar to the one presented in the figure can be obtained

- Chaos theory has also been used to explain phenomena in Political Sciences, and Sociology

Kiel and Elliot, Chaos theory in the social sciences: foundations and applications, University of Michigan Press (Ann Arbor, 1997)

Guegan, Chaos in economics and finance, Annual Reviews of Control 33, 89 (2009)

With its omnipresence, some scientists think that in the future, chaos will impact of the development of fundamental and applied sciences as did the Quantum mechanics since the beginning of the 20th century.

<u>**But how to be sure that what is observed in a system is really the deterministic chaos?**</u>

Valentinuzzi, IEEE Pulse 8, 74 (2017): Cardiac pacemakers: a multiauthored breakthrough technology

S. McKeller, "Artificial hearts: the allure and ambivalence of a controversial medical technology", John Hopkins University Press, Baltimore (2018)

Ozden et al., Phys. Rev.Lett 93, 158102 (2004): coupling of an electronic circuit with a neuron leads to a wide range of dynamical behaviors

Zhang and Chen, Chaos, Solitons and Fractals 36, 144 (2008)
Kalayci et al,, Math. Probl. Engineering 2021, 6615856 (2021)
Tcheutchoua Fossi and Woafo, Commun. Nonl. Sci. Numer. Simulation 18, 209 (2013)
Tsapla Fotsa and Woafo, Chaos, Solitons and Fractals 93, 48 (2016)
Tcheutchoua Fossi and Woafo, J. Sound Vibration 329, 3507 (2010)
A. F. Zahedi and V. Babitsky, J. Sound Vibration 380, 78 (2016)
M. Zhang et al., Shock and Vibration 2021, ID 8830428 (2021)

B. Nana et al., Chaotic synchronization with experimental application to secure communications, CNSNS 14, 2266 (2009)

- **Direction of air streams**: Chaotic control of the direction of air streams in air conditioners to provide useful fluctuations for the comfort of humans

Aihara K, Katayama R. Chaos engineering in Japan. Communications of the ACM 1995;38(11):103–7

* **Chaotic dishwashers:** By changing the conventional dishwasher nozzle design from a one-link structure to a two-link structure where the center of the gravity in the smaller second link is slightly different from the center of its rotation, movement of the nozzle changes from periodic to chaotic rather than quasiperiodic (double pendulum as in the video). cover homogeneously a wider area and achieve better washing performance than do periodic ones in the conventional one-link dishwasher

Nomura H, Naito E, Wakami N, Kondo S, Aihara K. Analyses of chaotic behavior of a 2-link nozzle in a dishwasher. Proc. of JapanU.S.A. Symposium on Flexible Automation 1994:231-4

See our references:

- *Abobda and Woafo, Ferromagnetic mass fixed on a spring and subjected to an electromagnet powered by self-sustained oscillators, Eur, Phys. J. Special Topics 223, 2885 (2014)*
- *Abobda and Woafo, Modeling, mathematical and numerical studies of a new biventricular model for artificial heart powered by an electromagnet subjected to sinusoidal and square voltages, Int. J. Artificial Life Research 5, 26 (2015).*
- *Fonkou et al., Dynamic Behavior of Pacemaker Models Subjected to Arterial Pressure Excitation Simulator: Theoretical and Experimental Study by Microcontroller, Braz. J. Physics 51, 1448 (2021).*

$dx/dt = \sigma(y-x)$ x=intensity of the heated fluid movement,

$dy/dt= rx-y-xz$ y= horizontal temperature gradient

$dzdt = xy-bz$ z= vertical temperature gradient

σ= Prandtl number=ratio between the fluid momentum and heat quantity

r= ratio between the Rayleigh number and the critical Rayleigh number (Rayleigh number characterized the heat transfer inside in the fluid)

b= typical size of the system

x, y and z vary randomly

0- CAMEROON AND ITS UNIVERSITY SYSTEM

- A country located in the Central Africa Region between 2 and 13 degree above the equator.

- Africa in miniature
  - Extension in latitudes= almost all the African climatic regimes and vegetation: steppes (arid lands with isolated isles of trees) in the northern part, Savanas in the centre, dense forests in the south.
  - Many ethnic groups, some found in other parts of Africa.
  - Various species of animals.
- Borders: Nigeria, Tchad, Central African Republic, Congo Brazzaville, Gabon, Equatorial Guinea, Atlantic sea
- 475 000 km^2
- 28 millions inhabitants.

•Contact with Europeans: 1435 by Portuguese explorers,

then Spanish explorers (1492) who found a river full of a type of fish they call Cameroes/Camerones. Rio dos Cameroes/Camerones

=CAMEROON.

•German in 1864: war Kamerun-Germany from 1864-1911 (47 years): german colony

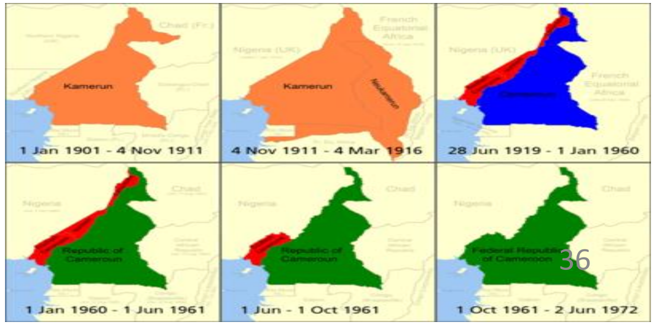
After the 1st World war: 4/5 administered by France and 1/5 by England.

•War Cameroun-France from 1955-1971 (16 years).

•Independence: 1st January 1960

•Capital city: Yaounde

•Football



What about the university system and Lamsebp?

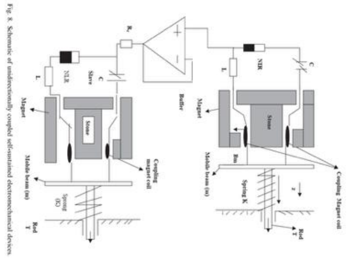
- University system

- 12 State universities with specialized engineering schools and Faculties disseminated over different cities (about 80 000 students for most universities)
- Various private and confessional universities and university schools (functioning under the academic patronage of State universities)

LAMSEBP present research activities

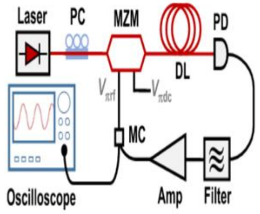
a- Theoretical and experimental studies of Macro/micro electromechanical actuators and energy harvesters:

- Theoretical and experimental characterization of their nonlinear dynamics (intrinsic or introduced nonlinear components),
- Investigation of the synchronization of two or large number of such actuators coupled in different configurations



b- Theoretical and experimental studies of optoelectronic devices

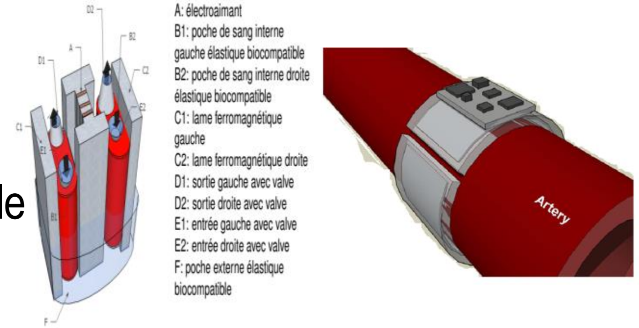
- Complex dynamics of semiconductor lasers powered by self-sustained electronic oscillators for optical chaos cryptography,
- Complex dynamics of optoelectronic oscillators having nonlinear electronic component in their electric part for the generation of special optical and electric signals for telecommunications.



c- Theoretical and experimental investigations of chaos synchronization for chaos cryptography

d- Bio-inspired devices:

- Self-sustained electronic models for artificial heart pacemakers,
- Electromechanical models for artificial ventricles,
- Electromechanical models for artificial pancreas based on mathematical models of the couple glucose-insulin



e- Control of vibration using electromechanical actuators under different types of control strategy

f- General research on nonlinear dynamical systems

Nonlinear system with heredity , chaotic mixers and sieves/screens