Clarke's Prediction "Laws"

 Any sufficiently advanced technology is indistinguishable from magic

Arthur Clarke

Implantable Telemetry Systems: the State of the Art and Challenges

Robert Sobot

- **Q** The short history of technology development
- **Q** Implantable technology
- **Q RF Telemetry System**
- **Q** Technology and the human body
- **Q** Closing comments

The short history of technology development

Technology waves

From the tube to IC

Evolution of the radio

Low-Power RF cc 111 *~36mm3*

Commercial

~6.6mm3

 $15KU$

82

 $\frac{1 \text{ mm}}{227}$

Courtesy Zettl Research Group, Lawrence Berkeley National Laboratory and University of California at Berkeley

 $25mm$

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Research

 \sim μ m^3

Moore's law

Moore's law

^{24th} century: Cpt. Picard's iPad mini must have... $...$ CPU with \sim 1e60 transistors \odot the human brain: \sim 1e10 neurones \odot the human body: \sim 1e27 atoms **Q** the Universe: ~1e80 atoms

Augmented technology distance

S-curves

Why the implants?

Total Artificial Heart

Aorta Venae Pulmonary Cavae Artery Right ∟eft Atrium Atrium Left Right
Ventricle Ventricle

Human Heart

File source: wikipedia.org

Why the implants?

O Human population is living longer We need medical care **O** Technology integration is inevitable

File source: wikipedia.org

Why the implants?

O Human population

We need medical care

O Technology integration

is living longer

is inevitable

Heart pump

O In 2008, 29% of ALL deaths in Canada caused by cardiovascular diseases A heart works similar to a

piston engine

Genetically modified animal

subjects are essential for research
File source: wikipedia.org

Heart pump

 PV conductance based sensor Small enough to fit in a mouse heart ! **Q** Commercially available

Heart pump

Mouse heart

Courtesy of Dr. James P. Carson.

Cardiac telemetry

Telemetry system

Telemetry system

Main challenges:

QThe system's size

...

O Multidisciplinary design

Ethical and legal issues

PV Sensor

PV sensor model

Q Linear model

- Wei's nonlinear model
- Dubois model
- **Sensor calibration**

Baan's model \blacksquare a heart can consider it stationary and distribution \blacksquare Daan s \Box H involtage calculation shows that the time–varying admittance (i.e. current variable \sim cross–sectional area *A*(*t*) in time is tied to the heart pulse (a mouse heart beets up to 700 bpm), hence in \blacksquare the second term is consider not large enough to \blacksquare first two electrodes (*ab*) and electrodes (*ac*), i.e. ∆*V* (*t*) ≈ *L*2 σ \bigcap *Rab* [−] ¹ *Rac* " considered mainly to consist of five segments stacked together. Their boundaries are defined by the inner surface of the cardiac wall and by the cardiac wall and by the equipment of potential surfaces through the electrodes (fig **1)** (about **7** x **1O-Io F.m-')** compared with **Q** (about **0.7 W.m-l)** the second term in equation (I) vanishes \sim first, even though day Therefore, the value of the median cross sectional

$$
g(t)' = \frac{1}{R(t)} = \frac{\sigma}{L} A(t) + \frac{\epsilon}{L} \frac{dA(t)}{dt}
$$

$$
g(t)'' = \omega \frac{\epsilon}{L} A(t)
$$

$$
\Delta V(t) \approx A(t) \times L
$$

$$
g(t)' = \frac{1}{R(t)} = \frac{\sigma}{L^2} V(t)
$$

$$
\Delta V(t) \approx \frac{L^2}{\sigma} \left(\frac{1}{R_{ab}} - \frac{1}{R_{ac}}\right) = \frac{L^2}{\sigma} g_b(t) = \rho L^2 g_b(t)
$$

$$
V(t) = k \rho L^2 g_b(t) + V_c
$$

gb(*t*) = ρ*L*² *gb*(*t*) (5)

 $V(t) = k \rho L^2 g_b(t) + V_c$

gb(*t*) = ρ*L*² *gb*(*t*) (5)

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*L*2

∆*V* (*t*) ≈

 $\Delta V(t) \approx$

 $\overline{}$

[−] ¹

 $\frac{1}{2}$

 $V(t) = k_0 L^2 a_b(t) + V_c$ $\ddot{}$ and $\ddot{}$ and $\ddot{}$ are $\ddot{}$ six-channel electronic electr circuit was built, both to generate the current and to generate the current and to generate the current and to measure dynamically the resistance values of the five

Rac "

and if the catheter is manufactured with several inner electrode ring pairs, then the total instantaneous several in

that is small relative to the catheter's size, as is the case of a small mouse. However, if the heart is large

=

*L*2

 $t)$

Wei's model INI keeping the other assumptions used in the linear model, Wei et al. [12] suggested the following nonlinear model, Wei et al. [12] suggested the following nonlinear model, Wei et al. [12] suggested the following non-linear m Blood conductance *g^b* can be found by definition \blacksquare *I* \overline{a} **M** *a J d* ! !*a* − " *^l E d* ! !*^l* = **. l** e ! − " *^l E d* ! !*^l* (8) \overline{V} where *I* is current (A), *V* is voltage (V), *E*! is electric field intensity (*V/m*), *J*! is current density (*A/m*²), *a* is coordinate system (*r, die reciprocal* of blood resistivity \mathcal{C} Straightforward application of Laplace's equations [∇]²*^V* = 0 and *^E*! ⁼ −∇*^V* for the case of cylindrical Straightforward application of Laplace's equations [∇]²*^V* = 0 and *^E* ∂*r* \$ **/** *<u>r</u>* ζ sin θ ∂*V* ∂θ \$ M ai's modal source M #∂²*V* \$ 1656 IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, VOL. 52, NO. 10, OCTOBER 2005

$$
V = \frac{\beta}{\left(g_{\rm inf} - g_b\right)^2} - \frac{\beta}{g_{\rm inf}^2} \qquad \text{, where} \qquad \beta = f(SV, g_{\rm inf}, g_{bmax}, g_{bmin})
$$

nonlinear analytical function for volume *V* vs. blood conductance *g^b* looks as

C Robert Sobot at Telecom-Paristech, Paris France, May 29, 2013 where the electrical conductivity and permittivity and permittivity and permittivity *and* permittivity and permittivity respectively. The permittivity and permittivity and permittivity and permittivity and permittivity o β ² [−] ^β (*g*inf − *gb*) UNIVERSITY CANADA CALIFA CALIBRATION CORODOCT SODOT at Telecom-Paristech, Paris France, May 29, 2013

*g*2

8

Dubois' model surrounding international builds upon the existing knowledge by the existing knowledge by the existing knowled

$$
V = -\pi L \left[\frac{d^2}{4} - \frac{\beta \pi^2 d^2 (d^2 - L^2) (\Delta \sigma + j\omega \Delta \varepsilon)^2}{16L^2 (Y - Y_{\text{inf}})^2} \right], \text{where}
$$

$$
Y_{\text{inf}} = \frac{\pi d (d^2 - L^2) (\sigma_b + j\omega \varepsilon_b)}{4L\sqrt{a_0^2 + d^2/4}}
$$

 $\mathbf{Western}$

Models comparison

Sensor calibration

Main challenge:

PV measurement is relative

Sensor insertion

Main challenge:

 $C.L.$ YV et, ZUU C.L. Wei, 2009

(b) carotid, and illustrations of possible (c) longitudinal and (d) radial deviations sertion a σ necessary to examine the effects of myocardium by including the effects of myocardium by inclusions of m Catheter insertion and mechanical bending

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⇒ Vol = γ Vol = γ Vol = γ Vol = γ

System Architecture

System architecture

Main challenges: System's size

estern

BAR

- Power source
- Transmission losses

System architecture

Main challenges:

3D design size

System architecture

← PWR

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78 79

*< *4*

 P_1 \bigvee P_2

Energy Harvesting *\$!" Line - implanted*

!#

%&'"(')+,*

0/

Energy harvesting sources

Energy harvesting sources

Thermoelectric - Peltier

A variety of mechanical designs for bioimplantable biofuel cells have been described in a literature spanning at least half a century \mathcal{I}_1 number of physical, electronic, and electronic, and electronic, and electronic, and electrochemical factors

Methods Section and as shown in Figures 1, 2, and 3, the novel

a classic half-open, two-chamber design [19,34,35], sized and

internal and load impedances; and environmental conditions in Λ inrational cell Λ Piezo vibrational cell

silicon wafer. PICS-Micro glass-fuel cell

Glucose Bio-fuel cell

glucose and oxygen, naturally occur mixed in physiological in physiological in physiological in physiological i
The contract of physiological in physiological in physiological in physiological in physiological in physiolog

space surrounding the human brain, and analyze the impact of

such a fuel cell on glucose and oxygen homeostasis.

Results and Discussion

Main challenges: **O** Modelling **Simulation tools O** Manufacturing and packaging

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 70035×10^{7}

Main challenges:

- **Q** Power transmission losses
- **Q**The subject's movement
- **@** Maximum allowed power

PV sensor interface

Main challenges:

Sensor specific Q Power consumption **O** Manufacturing and packaging

Biocompatible packaging

Main challenges:

O Hostile environment **Antenna integration O** Manufacturing **O** Multidisciplinary

Human Body and Technology of

Multidisciplinary research

Multidisciplinary research

Utah microarray

NeuroNexus Technologies

IMI Intelligent Medical Implants

IMI Intelligent Medical Implants

Prof. Miguel Nicolelis, Duke University

Mr. Jessie Sullivan, Prof. Todd Kuiken, Northwestern Medical School, Chicago

Photograph by Mark Thiessen

eHealth

eHealth

Our future anatomy?

- **Q** direct brain to sound, video, radio, and gps interface
- **Q** the inner ear language translator
- bi-directional brain to brain and machine interface
- **a** artificial limbs, titanium skeleton, ...

Closing comments

Intensive research, created opportunities:

- ultra-low volume size RFIC
- **O** processing algorithms
- **3D IC packaging**
- **Q** power scavenging
- **O** bio-battery
- **O** heat management
- **Q** complexity
- **O** self-repair

...

Implantable Systems Laboratory

Kyle, Gail, Kyle, Kaidi, Shawon, Sneha, Sorin, and myself (Lijun and Abdul not present)

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