SENSOR AND TRANSDUCER ELECTRONICS

FIRAT YAZICI OGLU
CATRENE WORKSHOP - 2014
HEALTH & WELLNESS - TODAY

Purpose

Medical

Remote Monitoring & Treatment

Mode of Payment

Reimbursed

Out of Pocket

Commercial

Worried Well
Quantified Self
Fitness
Sports

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HEALTH & WELLNESS - TRENDS

* Rock Health Report – connected health sensors

Reimbursed
Out of Pocket
Remote Monitoring & Treatment
Curative
Hypertension
Preventive
Weight Management
Stress
Hypertension
Dehydration
Personal Safety

Worried Well
Quantified Self
Fitness
Sports

PATCHES
WRISTBANDS
GLASSES & HEADSETS
SHOES

USER ACCEPTANCE

driven by
Comfort
Functionality
Cost
WEARABLE & IMPLANTABLE MEDICAL DEVICES

Low-Power

Miniature

Sensor Electronics
TRENDS – SENSOR INTERFACE DESIGN

Already Happening (10Y): Miniaturizing
- Smart
- Low-Power Design
- Miniaturization

Recently Started (2Y-): Multi-Modal Systems
- Multi-Sensor Interfaces
- Sensor Fusion

Third Wave (Now -): Adaptive Systems
- Personalized
- Situation Aware

Low-Power Design Techniques
- Mixed Signal Designs
- Adaptive Architectures
- Holistic Design Approaches
- New Sensing Paradigms
- Context Aware
- Wearable Devices
WORLD IS ANALOG
(INTER)FACE IT!

Physical Sensors
- Temperature: °C
- Acceleration: mg
- Pressure: Pa
- Rotation: °/h
- Flow: m³/h

Medical Sensors
- EOG
- EMG
- GSR
- EEG
- ECG
- Bio-Impedance
- PPG

Analog

Signal Conditioning
Capacitive instrumentation amplifiers using sub-threshold transistors are resistors.

Chopper modulation using DC servo feedback.
RESEARCH ENABLED POWER EFFICIENT INSTRUMENTATION AMPLIFIERS

Utilizing Pseudo Resistors
Chopper Modulated
Other Types
Off-the-Shelf IAs (3-amp)

Research Enables new IA architectures

Digital compensation techniques – like chopper modulation – increased resolution

\[ NEF = K \frac{V_{in,rms}}{\sqrt{\frac{\pi}{2} \times BW}} \sqrt{I_{total}} \]
LOW-POWER DESIGN TECHNIQUES
NEW INTERESTS: LOW-VOLTAGE & MIXED SIGNAL DESIGN

Maximum Power Point Tracking

Voltage Up-conversion

Voltage Regulation

Solar  Vibration  Thermal  RF

Extremely low-power levels 1uW – 100uW

Floating supply analog blocks and Ultra-Low-Voltage Analog Increasing end-to-end system efficiency. Also facilitates low-voltage mixed signal design.

Power Inefficient blocks
LOW-POWER DESIGN TECHNIQUES
NEW INTERESTS: LOW-VOLTAGE & MIXED SIGNAL DESIGN

Mixed Signal Instrumentation Amplifier
Design Operating from 0.5V Supply Voltage

Comparator Based Analog Architectures can operating from 0.35V
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Mixed-Signal Designs

Multi-Sensor Interfacing

Analog

Digital

Algorithms
More analog blocks are appearing in digital MCU’s.

Medical Applications requires even more analog.
MIXED SIGNAL DESIGNS
AREA OF ANALOG IS A CONCERN

Total Area:
7mm x 7mm

Analog Area:
Dominated by SD ADCs

Digital Area:
Dominated by SRAM
Fill factor of digital area is very low
ADAPTIVE SYSTEMS WE ARE DIFFERENT!

GENETICS

LIFESTYLE

Patient A

Patient B

Patient C

Patient D

Patient E
ADAPTIVE SYSTEMS
EACH DAY IS DIFFERENT
CONTEXT AWARE SYSTEMS

Mood
Activity Level

Adaptive Systems

Accuracy/Resolution
Resource Allocation
Feature Definition
Classification

Subject Specific Signal Features
Health Conditions
Combining a small processor with a large one more efficient task partitioning can be done.

Software automatically moves workload between processors.

Always On Voice Recognition – adaptive resource utilization

VAD STAGE 0: No voice detected
VAD STAGE 1: Voice detected
VAD STAGE 2: Keyword detected

- Always listen mode
- Keyword spotting
- Host wakes
- Audio buffer to host & ASR Assist mode

OK Audience, play some jazz
Listen
Ready
Playing
ADAPTIVE SYSTEMS
PERSONALIZING SIGNAL ANALYSIS

Training (one-time / infrequent)

Training data and labels → Trainer

Detection (real-time)

Classifier model

Classifier (E.g. Support Vector Machine)

Real-time physiological data

Feature Extractor → Test vector

Nonseizure Vector
Seizure Vector

Decision boundary (derived from “support vectors”)

1st Principal Component of Feature Vector

2nd Principal Component of Feature Vector
HW-SW Co-Design

- Analog
- HW
- SW
- Digital
- Algorithms
HOLISTIC DESIGN
CO-DESIGN ANALOG READOUT, ADC, AND ALGORITHMS FOR HRV ANALYSIS

Digital Assisted Adaptive Sampling

Analog Signal Processing

Coarse-Fine Algorithms
ADAPTIVE SAMPLING ADC & DATA COMPRESSION

The diagram illustrates the process of adaptive sampling and data compression. It shows an ECG waveform and the components involved in the system:

- ECG input
- 11-bit SAR ADC
- Activity Detector (AD)
- Δx/Δt
- Thresholds
- 1-bit Flash A/D

The system samples at 1024 Hz with a sample rate of 64 Hz and achieves a compression ratio of 1:6.
ANALOG SIGNAL PROCESSING AND FEATURE EXTRACTION

Band-Power Based Feature Extraction

Band-Power Based Beat Detection
HARDWARE ORIENTED ALGORITHM DEVELOPMENT

Knowing that there is a power efficiency “coarse” algorithm, then the fine (and power hungry) algorithm can make use of fine algorithm to reduce power dissipation.
BENEFITS OF HOLISTIC DESIGN

Power Dissipation (µW)

2500
2000
1500
1000
500
0

Conventional DSP

Analogue Assisted DSP

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<th>Continuous ECG Signal</th>
<th>Activity Based Sampled ECG Signal</th>
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<td>ANALOG</td>
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<td>DSP (µP)</td>
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CONCLUSIONS

- There has been a important trend on low-power sensor interface design for healthcare application (last 10Y)

- The importance of multi-sensor interfaces is increasing tremendously for wearable wellness devices – analog area is becoming a concern

- Emerging design trends: HW-SW, Analog-Digital Co-design

- Emerging application trends: situation adaptive and personalized systems can improve signal analysis accuracy and reduce power dissipation significantly