Design and Implementation of Real-Time Signal Processing Applications

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Smart Systems

…incorporate functions of **sensing, actuation, and control** in order to describe and analyze a situation, and **make decisions** based on the **available data** in a **predictive or adaptive** manner, thereby performing smart actions….

Smart Systems are everywhere
Challenges in Signal Processing Design

Framework for real-time simulations

“I have to process large data and test my simulations with streaming signals. I need a simulation testbench that can keep up with real-time data.”

Quick Innovation & modeling

“I need to find innovative algorithms and create and model a working system very quickly.”

Rapid prototyping & simulation acceleration

“I need to optimize my high-level MATLAB algorithm for speed. I then need to verify that the optimized code works the same way as the original MATLAB code.”
Motivation

- Demo
  - Android App based Edge Detection
  - Raspberry Pi based Edge Detection and Image inversion
Agenda

- Acquiring and Analyzing Signals
- Developing Signal Processing algorithms
- Deployment on Hardware
- Audio System Toolbox
Technical Computing Workflow

Access
- Files
- Software
- Hardware

Explore and Discover
- Data Analysis & Modeling
- Algorithm Development
- Application Development

Share
- Reporting and Documentation
- Outputs for Design
- Deployment

Code and Applications

MATLAB, Excel, .NET, C/C++, Java, .dll
Problem Statement

- Activity classification using motion sensors on a mobile device

- **Classification**: Walking, Running, Stairs, Rest (no motion)
Data Acquisition

- Data access via Sensors on MATLAB mobile app (Android/iOS)
  - Data to be used: Accelerometer data in three dimensions

- Acquisition process:

```matlab
>> connector on
DNS name: bgl-lravichal1.dhcp.mathworks.com
IP address: 172.18.75.174
Use this link to test the MATLAB Connector:
http://bgl-lravichal1.dhcp.mathworks.com:31415/

If the test is successful, but MATLAB Mobile cannot
your computer might have multiple IP addresses. To
the correct one, see Determining the DNS Name or IP
>> m = mobiledev

```

Table:

<table>
<thead>
<tr>
<th>Axis</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>-0.157</td>
</tr>
<tr>
<td>Y</td>
<td>8.739</td>
</tr>
<tr>
<td>Z</td>
<td>4.592</td>
</tr>
</tbody>
</table>
Algorithm Development

Data exploration to identify distinguishing features between the activities.

Fourier analysis yields dominant frequency components, but not time-frequency localization (essential for a mixture of activities).

Explore and Discover

Data Analysis & Modeling

Algorithm Development

Application Development

```
for k=1:max
    x = fft(dat)
    y = 20*log1
```
Algorithm Development

- Time and Frequency Localization
  - Frame-based Fourier spectrum
  - Spectrogram

Explore and Discover

Data Analysis & Modeling

Algorithm Development

for k=1:max
x = fft(dat)
y = 20*log1

Application Development
Algorithm Development

- Frame size of 10

- Features from accelerometer data (3-D) for each frame
  - Mean (1-D)
  - Standard Deviation (3-D)
  - Maximum (3-D)
  - Maximum of FFT magnitude (1-D)

- Three-layer neural network classifier using above features
Algorithm Development

- Training
Algorithm Development

- Classification
Algorithm Deployment

- Simulink model for deployment

![Simulink model](image-url)
Same device ... different approaches

Write code and communicate with the device

Tethered Approach

Develop a model and program the device

Embedded Approach
Algorithm Deployment

- Hardware Connectivity – Single-click deployment solution

- Use algorithm as-is and deploy on hardware of your choice e.g. Android/iOS device, Raspberry Pi, Beaglebone Black
Prototyping for product development

MATLAB algorithm

Early validation (listening tests)

Advanced prototyping or production
Prototyping for product development

**Why?**
- From *algorithm developers* to *other stakeholders*
- Human in the loop – “How does it sound?”
- Interactive tuning – “What if we changed that?”

**Existing challenges**
- Owned by “algorithm” or “DSP” engineer
- C/C++ hard and time-consuming; External libraries into MATLAB don’t work well
- Plugin API is challenging to learn
- Code not re-used for production – Wasteful
Audio System Toolbox
Design and test audio processing systems

- Libraries of audio processing algorithms and examples
- Low-latency audio streaming from and to standard audio interfaces (e.g. ASIO, CoreAudio, ALSA)
- Live-tuning of MATLAB and Simulink via UI and MIDI controls
- VST plugin generation to run on Digital Audio Workstations
Design and test audio processing systems using Audio System Toolbox

- **Desktop prototyping and listening tests**
  - **Pain:** Traditional prototyping is costly and time-consuming
  - **Solution:** Audio streaming in MATLAB and VST plugin generation

- **Custom real-time measurements**
  - **Pain:** Audio test & measurement equipment can be expensive and inflexible
  - **Solution:** Audio acquisition and unlimited custom analysis

- **Real-time audio for teaching DSP**
  - **Pain:** C/C++ and hardware kits take away time from putting signal processing into practice
  - **Solution:** Real-time audio without C/C++ or embedded kits
Plugin generation and source code generation

- PC Application
- Custom Plugin
- Custom prototyping infrastructure
- Speedgoat audio real-time target
- Embedded prototype
- …

MATLAB code

Audio System Toolbox

VST plugin

C/C++
MATLAB Coder
Simulink Coder
Simulink Real Time

Design & Validation
Prototyping & code export
Challenges in Signal Processing Design

Framework for real-time simulations
Stream processing techniques and hardware peripheral access that speed up simulation and reduce memory footprint

Quick Innovation & modeling
Pre-defined algorithms as functions and System objects for quick prototyping

Rapid prototyping & simulation acceleration
Support for C/C++ and HDL code generation that enables design continuity and faster simulation

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I need to optimize my high-level MATLAB algorithm for speed. I then need to verify that the optimized code works the same way as the original MATLAB code.
Questions?
Thank you!