Signal and Image Processing for Medical Applications

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Today’s Agenda

• MATLAB in Biomedical Research
• The MATLAB Development and Deployment Platform
• Medical Image Processing
• Signal Processing for Medical Applications
• Wrap Up, Questions and Answers
MathWorks Mission and Vision

*Accelerate innovation and discovery in engineering and science*

**MATLAB**
- A powerful, high-level language to develop algorithms, collect and analyze data, and visualize information

**Simulink**
- A graphical system to model and simulate complex systems, and implement real-time and embedded systems
MathWorks Products Drive Innovation in a Broad Range of Industries

- Aerospace and Defense
- Automotive
- **Biotech, Pharmaceutical, and Medical**
- Communications and Semiconductor
- Education
- Financial Services
- Industrial Equipment and Machinery
- Instrumentation
- **Medical Devices and Instrumentation**
Wide Product Adoption Throughout Academia

- 3,500 universities teach students and conduct research using MathWorks products.
- More than 600 textbooks have been published for education and professional use, in 19 languages.

- Biosciences
- Controls
- Signal Processing
- Image Processing
- Mechanical Engineering
- Mathematics
- Natural Sciences
- Environmental Sciences
The MathWorks Product Family

Integrated for:
- Technical computing, data analysis, and visualization
- System modeling and simulation
- Implementation of real-time embedded software

MATLAB

SIMULINK

Stateflow

Blocksets

Toolboxes

Data and Image Acquisition Cards
Instruments
Databases and Files

Code Generation
PC-Based Real-Time Systems
Desktop Applications
Automated Reports
The MathWorks Product Family

Toolboxes for modeling, analysis, and computation
Specific functionality for data analysis, modeling, design, and other capabilities

• Bioinformatics
• Statistics
• Image Processing

• Neural Networks
• Optimization
• Compiler

• Symbolic Math
• Curve Fitting
• Filter Design

• Wavelet
• Signal Processing
• Fuzzy Logic

Toolboxes

MATLAB®
Applications in Medical Imaging

Microscopy

Cytology and Pathology

Radiological Imaging

Functional Imaging

Gel and Microarray Images

Visualization and 3D Reconstruction

Multidimensional Image Processing

gel image: Alan W. Partin, M.D., Ph.D., Johns Hopkins University School of Medicine
cancer cell image: Alan W. Partin, M.D., Ph.D., Johns Hopkins University School of Medicine
pathology image: Angelo M. DeMarzo, M.D. Ph.D., Johns Hopkins University School of Medicine
Microscopy

Quantify number, area, color intensity, and shape of objects

- Automatic segmentation
- Automatic counting
- Morphometry
- Motility
- Deblurring
Radiology and Functional Imaging

- Segmentation
- Registration
- Image enhancement
- Signal reconstruction
- DICOM
- Statistical analysis
- Co-registration
- Motion correction
- Spatial normalization
Signal Processing in the Medical Industry

Analysis of PSG recordings

Hearing aid design

ECG analysis

Real-time processing of EEG, EMG, ECG, and EOG

Real-time biosignal amplifier
ECG Analysis

Acquire, filter, process, and visualize ECG signal

- Real-time data acquisition
- Easy filter design and implementation
- Diverse automatic signal processing options
- Several signal visualization options
Hearing Aid Design

Design, tune, and implement model

- Design components of system to be integrated
- Test and tune parameters on the fly
- Create real-time test bench for rapid prototyping
- Automatically generate code
- Test generated code on target
Customer Solutions: Institute for Biodiagnostics

Noninvasively Assessing Burn Injuries

The Challenge

- Develop technique to evaluate burns soon after injury to prevent irreversible tissue damage

The Solution

- Used NIR spectrometer and multiband CCD imager to measure hemoglobin levels and blood volume in shallow and deep epidermis tissue
- Used MATLAB, Signal Processing Toolbox, Wavelet Toolbox, and Image Processing Toolbox to conduct burn simulations

The Results

- Non-invasive device to measure burn severity
- Efficient test environment to support clinical trials and pursue FDA approval for new device
What can you do with MATLAB?

- Explore your data.
- Perform matrix computations (linear algebra).
- Visualize complex data to gain insight.
- Develop algorithms to solve problems.
- Build custom data analysis tools with GUIs.
- Understand how functions and algorithms work.
- Share programs, data, and results with colleagues.
- Integrate MATLAB with other software.
- Develop models to simulate sensors, systems, and processes, especially with Simulink.
MATLAB Java Interfacing

Access to the rich Java GUI building, database, and Web tools from the familiar MATLAB development platform.

- Call Java directly from MATLAB (via interpreter).
- Embed Java routines and objects in MATLAB applications.
- Exchange data between MATLAB and Java.
- Access Java API class packages and third-party Java classes.
Customer Solutions: Given Imaging

The Challenge
- Develop a minimally invasive diagnostic tool that substantially improves visual imaging of the small intestine

The Solution
- Used MathWorks tools for the feasibility study, development, and refinement phases of the image processing project

The Results
- Fast FDA approval and time-to-market
Customer Solutions: Beth Israel Deaconess

The Challenge
- Develop a safe and effective way to improve the resolution and speed of MR scans

The Solution
- Use the Image Processing Toolbox and other MathWorks products to develop a technique for accessing multiple image components simultaneously

The Results
- Faster, more informative MR scans
- Ability to experiment with new approaches
- Reduced programming time
MATLAB supports Multi-modality Imaging

- MRI
- CT
- PET
- Ultrasound
- X-Ray
- ...

MATLAB can incorporate images from several different data sources
Image Processing Toolbox

Image visualization, analysis, processing, and algorithm development

- **Key Features:**
  - Interactive image viewer
  - Image analysis functions, such as edge detection, feature measurement, and more
  - Image processing functions, such as enhancement, segmentation, morphology, and registration
  - Support for numerous image and scientific file formats, including DICOM
Image Processing Toolbox Functions

- Pixel values and statistics
- Profiles
- Intensity plots
- Edge detection
- Morphology
- Segmentation
- Background removal
- Segmentation
- Object labeling
- Feature measurements
- Image deblurring
Image Acquisition Toolbox

- **Key Features:**
  - Image and video streaming directly into MATLAB
  - Hardware detection for supported video and image acquisition devices
  - Device property configuration
  - Background image acquisition
  - Live video previewing
  - Support for multiple hardware vendors
Image Acquisition Toolbox

- Supported Image Capture Vendors
  - Matrox
  - Data Translation

- Supported Windows Video Devices
  - USB/FireWire cameras, DV camcorders, image capture boards, TV tuner cards, etc.
  - Requires:
    - Windows Driver Model (WDM) or Video For Windows (VFW) driver
    - Microsoft DirectX 9.0 or later

Visit http://www.mathworks.com/products/imaq/ for more information
Neuroimaging Case Study

Measure volume of white and gray matter in an MRI brain scan
What this Case Study Shows

- **Data Access**
  - MRI scan = set of DICOM files

- **Visualization**
  - 2D slices
  - 3D volume

- **Analysis**
  - Segmentation
    - Thresholding grayscale intensities
    - Cropping spatial dimensions
    - 3D morphological refinement
  - Volumetric measurements (density)
Data Access

- Patient examination conducted using MRI scanner
  - 3D volumetric region of head surrounding brain
  - Coronal slices acquired as individual DICOM files
- Parse DICOM files
  - Identify image series associated with patient study
- Read slice images
  - Populate XYZ matrix
- Keep track of voxel size
  - aspect ratio
Demonstration

Enough with the slides, already … let’s see some MATLAB!
DICOM Support (acquired image files)

Reading and Writing DICOM Files

The Image Processing Toolbox includes support for working with image data in Digital Imaging and Communications in Medicine (DICOM) format. The following sections describe how to:

- Read image data from a DICOM file
- Read metadata from a DICOM file
- Write image data to a DICOM file
- Write metadata to a DICOM file

To see an example that reads both the image data and metadata from a DICOM file, modifies the image data, and writes the modified data to a new DICOM file, see Example: Creating a New Series. The example shows how to use the dicomuid function to generate a DICOM unique identifier, which you need to create a new series.

Reading Image Data from a DICOM File
Visualization

- MATLAB Handle Graphics® engine
  - Display complex plots, images and surfaces
  - Manipulate display properties (color, texture, lighting)
    - Interactive mouse-based controls (camera tools)
    - MATLAB commands allow programmatic control

- OpenGL support
  - Hardware acceleration provides fast redraw
  - Reduces CPU burden
2D Visualization

Explore image data \([\text{imview}]\)
2D Visualization

Display images \texttt{[imshow]} and intensity distributions \texttt{[hist]}.
3D Visualization

- Display volume cross sections \([\text{slice, contourslice}]\)
- Display surface of interior volume \([\text{isosurface, isocap}]\)
Custom Data Analysis

Download *sliceomatic* from the MATLAB Central file exchange.
Segmentation

- Threshold by range of intensities
  - Background air, CSF & other (soft?) tissues too dark
  - Skull & other (hard?) tissues too bright
  - Custom GUI to aid parameter tuning (thresh_tool)

- Crop by spatial dimensions
  - Brain mass not too low in head

- Trim off small, residual fragments
  - Morphological opening = erosion + dilation [imopen]
  - Connected region size [bwlable, regionprops, .Area]

- Separate brain mass (white vs. gray matter)
  - Use thresh_tool to help select proper threshold level
  - Use sliceomatic to display 3D results
Outside of the Head
Surface of the Brain
Gray & White Matter
Volumetric Measurements

- \[
\text{scan\_density} = \frac{\text{head\_voxels}}{\text{total\_voxels}}
\]

- \[
\text{brain\_density} = \frac{\text{brain\_voxels}}{\text{head\_voxels}}
\]

- \[
\text{gray\_fraction} = \frac{\text{gray\_voxels}}{\text{brain\_voxels}}
\]

- \[
\text{white\_fraction} = \frac{\text{white\_voxels}}{\text{brain\_voxels}}
\]
What this Case Study Showed

With MATLAB you can:

- Work with DICOM files to facilitate patient examinations.
- Display 2D slices as images – separately or in XYZ space.
- Display 3D surfaces containing interior volume with realistic rendering.
- Perform simple to complex image processing on 2D, 3D or N-D data.
- Segment features of interest from image background and other objects.
- Quantitatively measure blob sizes to volume densities.
- Build custom data analysis tools to solve scientific imaging problems.
Why Use MATLAB for Medical Imaging?

- Verified and trusted algorithms for a wide range of image processing applications
- Ideal for exploration and learning
- More flexible and customizable than “point and click” software
- Saves time from developing and maintaining standard image processing algorithms
- Enables you to present and share results graphically, in reports and on the Web
- Multi-modality imaging capabilities
Customer Solutions: Medrad

The Challenge
- Design an MRI vascular injection pump that administers safe levels of pharmaceuticals to patients

The Solution
- Use MathWorks tools to improve the pump’s pressure sensing technology

The Result
- Design time reduced by several months
- Prestigious industry award received
- FDA approval achieved
Signal Processing Workflow

RESEARCH
- Data Acq & Import
- Data Analysis & Visualization
- Mathematical Modeling

DESIGN
- Algorithm Design & Analysis
- Environment effects
- Embedded algorithms
- System components
- System Modeling, Simulation and Partitioning

TEST
- Rapid Prototyping
- Verification, HIL Test
- Code Generation
- Embedded Software
- Embedded Hardware

IMPLEMENT

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Simulink: Model-Based Design

**RESEARCH**
- Data Acq & Import
- Data Analysis & Visualization
- Mathematical Modeling

**DESIGN**
- Algorithm Design & Analysis
- DSP, Comms, Fixed Point Blocksets
- Signal Processing & Filter Design Toolboxes
- Environment effects
- Embedded algorithms
- System components
- System Modeling, Simulation and Partitioning

**TEST**
- Verification, HIL Test
- Rapid Prototyping
- Code Generation
- Embedded Software
- Embedded Hardware

**IMPLEMENT**
- MATLAB
- Simulink
Over Half of All Embedded Software Projects are Completed Behind Schedule

- Completed Behind Schedule: 51.6%
- On Schedule: 6.7%
- Ahead of Schedule: 22.7%
- Canceled: 19.0%

Source: Software Development Times, December 2002
Venture Development Corp. data
Support and Community

- The MathWorks Connections Program
- The MathWorks Consulting Service
- The MathWorks Book Program
- The MathWorks Training Services

MATLAB CENTRAL
MATLAB Connections

More than 300 add-on products and services from partners that complement and extend MathWorks products

- Specialized third-party toolboxes for MATLAB
- Interfaces to partners' software and hardware products
- Specialized training courses and consulting services
- Turnkey systems providers that incorporate MathWorks products
Your Obstacles and Our Solutions

- Performing advanced and diverse analysis or processing requires several different tools
- A lot of time is lost coding in a low-level language instead of focusing on solving the problem
- Prototyping and testing takes too long

- MATLAB provides one environment for all types of analysis (signal, image, statistics, wavelets, etc.)
- MATLAB’s high-level language allows you to focus on the problem solving with the advanced low-level implementation already done for you
- MATLAB’s capabilities allow you to create a test bench which allows you to test, tune, and implement your design quickly
"I have used a number of commercial image processing packages over the years, and prefer the (MathWorks Image Processing) toolbox for several reasons: the wide variety of functions it provides, the user’s ability to write additional functions with minimal effort, the quality of the software, and the high level of support."

- Rafael C. Gonzalez
  University of Tennessee
From a leading textbook author ...

Released in December 2003:

“Digital Image Processing Using MATLAB”

by Gonzales, Woods, and Eddins
From a leading textbook author ...

Released in January 2004:

“Biosignal and Biomedical Image Processing
MATLAB-Based Applications”

by John L. Semmlow
Further Information

- **Product Information and Demos**
  Trials and technical literature are available at [www.mathworks.com](http://www.mathworks.com)

- **MATLAB Central**
  - File exchange and newsgroup access for MATLAB and Simulink users
  - [www.mathworks.com/matlabcentral](http://www.mathworks.com/matlabcentral)
  - Access to comp.soft-sys.matlab

[Matlab Central]