Hum-Power Controller for Powered Wheelchairs

Neural Engineering Lab

GEORGE MASON UNIVERSITY

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MS Thesis Defense

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George Mason University
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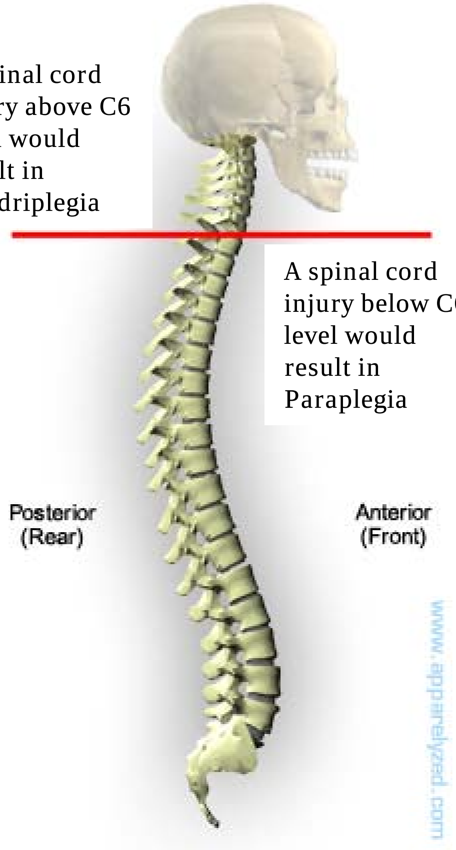
Overview

- Why This Approach?
- Preliminary Research & Projects
- Methods
- Test Results
- Potential Improvements

Statistics

- Wheelchair users worldwide:
  - about 200 millions
- In the U.S.A. every year:
  - roughly 11000 spinal cord injury
  - 47 percent leading to quadriplegia

A spinal cord injury above C6 level would result in Quadriplegia



A spinal cord injury below C6 level would result in Paraplegia

Source: http://www.apparelyzed.com/paralysis.html

In most cases power chairs do not entirely fulfill their needs!

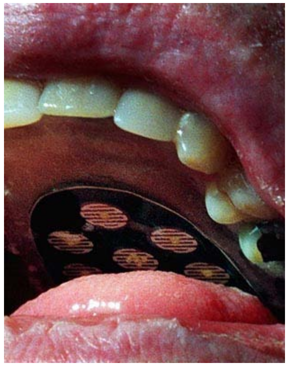
Source: National Spinal Cord Injury Statistical Center, NSCISC Annual Statistical Report, 2007

Available technologies

Joystics
81%

Head/Chin Control
9%

Sip-n-Puff
6%



Others
4%

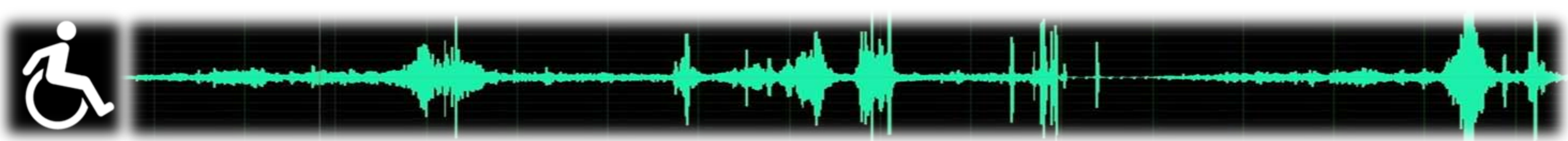
Source: http://atwiki.assistivetech.net/index.php/Alternative_wheelchair_control

Desired objectives

- Introduce control mechanism that does not require physical movement of the patients.
- Implement smooth control capability for precise maneuvers.
- Embed self-guidance & positioning system for indoor/outdoor navigation.
- Interface with the “Smart Home/Building”.

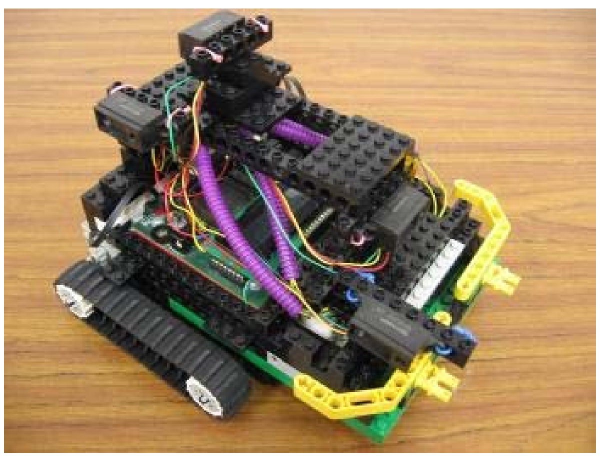
Preliminary research time-line

Features	Parking Robot	The Neurot	Mini Chair	Hum-Power Controller
Speech Recognition	✗	*Yes* *Training Required*	*Yes* *Training Required*	*Yes* *<u>No</u> Training Required*
Smooth Control	✗	✗	✗	*Yes* *Humming Controlled*
Autonomous Operation	*Yes* *IR Sensors*	✗	*Yes* *Ultrasonic Sensors*	*Yes* *<u>Not</u> Implemented*
Wireless Communication	✗	*Yes* *Bluetooth*	*Yes* *Bluetooth*	✗



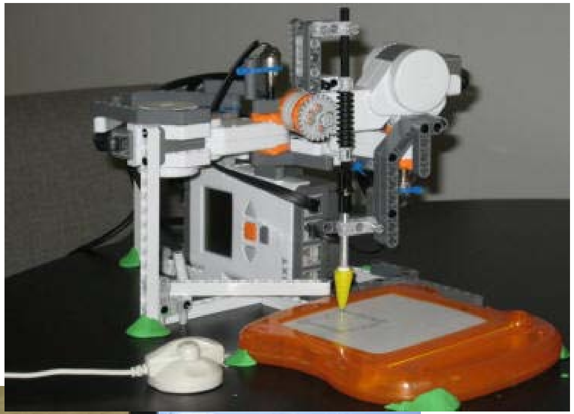
Preliminary results on obstacle avoidance

- Parallel Parking Robot
  - Designed on LEGO® and Handyboard platform
  - Using Sharp IR Sensors



Preliminary work on speech recognition in our lab

- The Neurot
  - Designed on LEGO Mindstorm® NXT® platform.
  - Speech Recognition through comparison of Mel-frequency cepstrum.
- The Mini-Chair
  - Designed on LEGO Mindstorm® NXT® platform.
  - Speech Recognition through Windows Speech SDK 5.1



Source: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=04388572

Speech recognition process of the Neurot

Training Sets

Circle

1	2	3	…	15

Square

1	2	3	…	15

Triangle

1	2	3	…	15

Comparison of Recorded Command

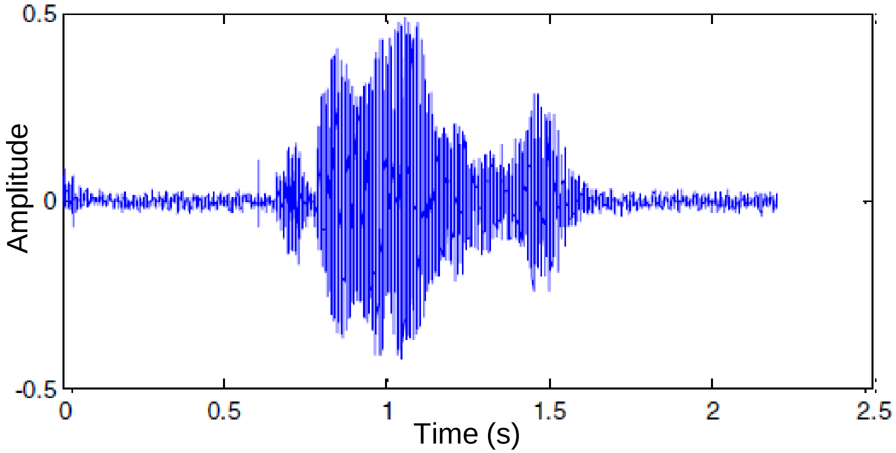
Recorded Command		Test set 1	Test set 2	Test set 3	…	Test set 15
	Circle	✓	×	×	…	✓
	Square	×	×	✓	…	×
	Triangle	×	✓	×	…	×

Final Poll

	# of Matches	Final Decision
Circle	10	✓ (67%)
Square	3	×
Triangle	1	×
No Selection	1	×

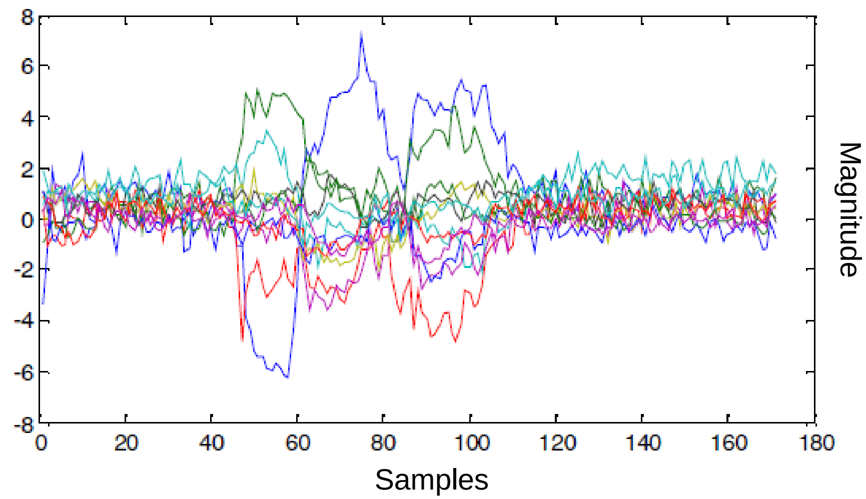
Source: Nik, H.G.; Gutt, G.M.; Peixoto, N., "Voice Recognition Algorithm for Portable Assistive Devices," Sensors, 2007 IEEE

Mel-frequency cepstrum coefficients used to classify words and voice



Recorded Voice

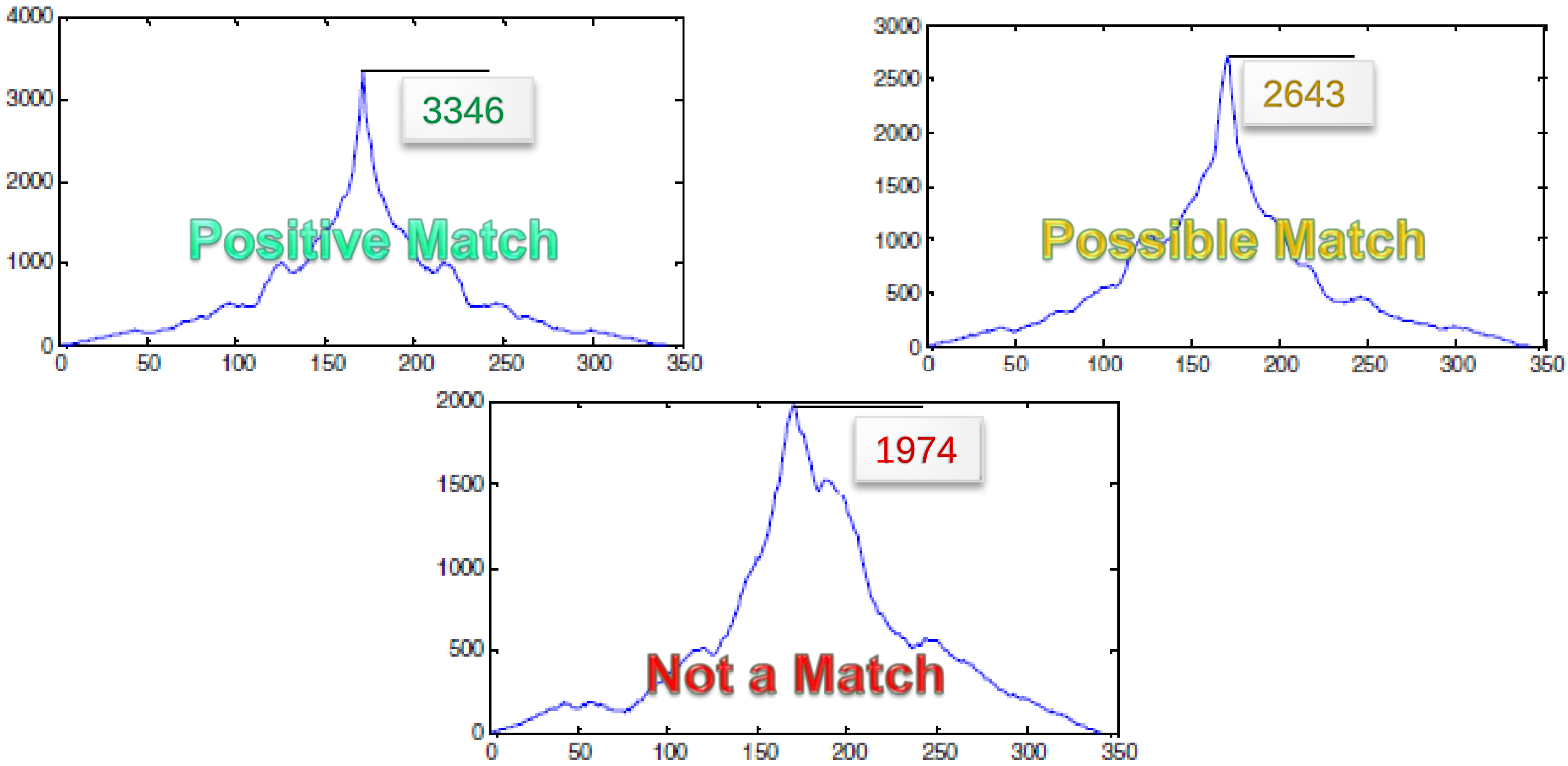
Calculated 12 MFCCs



$$m = 1127.01048 \log_e (1 + {}^{f}/_{700})$$

Source: Nik, H.G.; Gutt, G.M.; Peixoto, N., "Voice Recognition Algorithm for Portable Assistive Devices," Sensors, 2007 IEEE

Comparison of mel-frequency cepstrum coefficient amplitudes

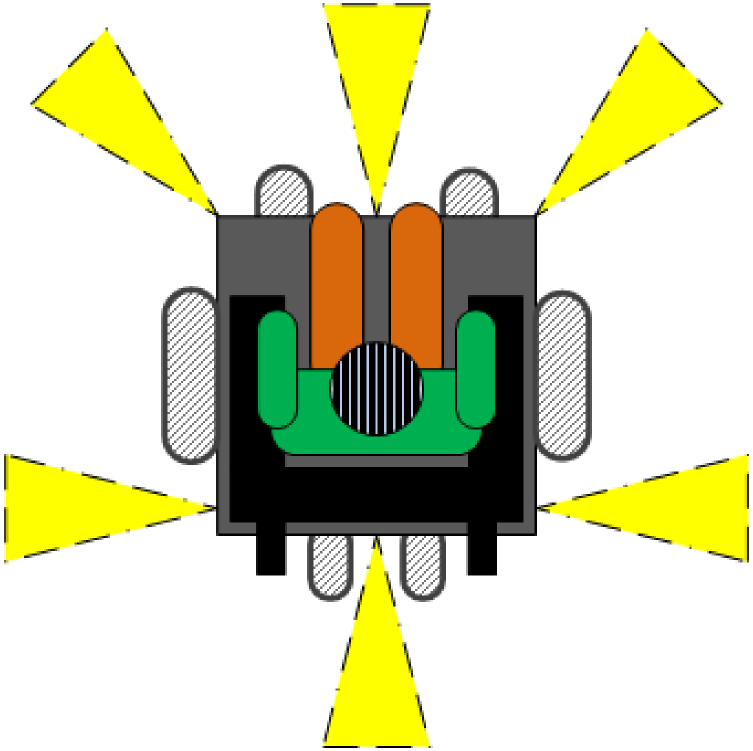


Source: Nik, H.G.; Gutt, G.M.; Peixoto, N., "Voice Recognition Algorithm for Portable Assistive Devices," Sensors, 2007 IEEE

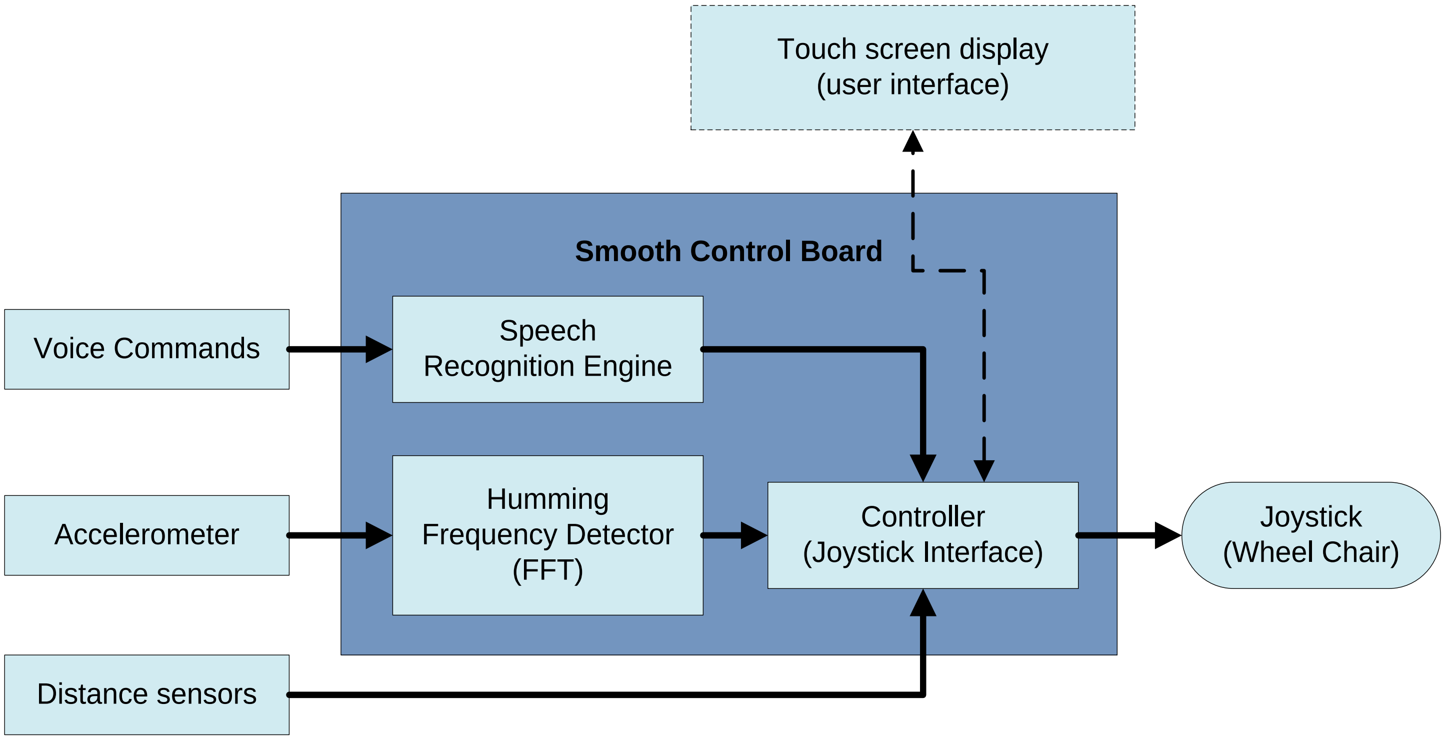
Preliminary results on speech recognition

Proposed design solutions

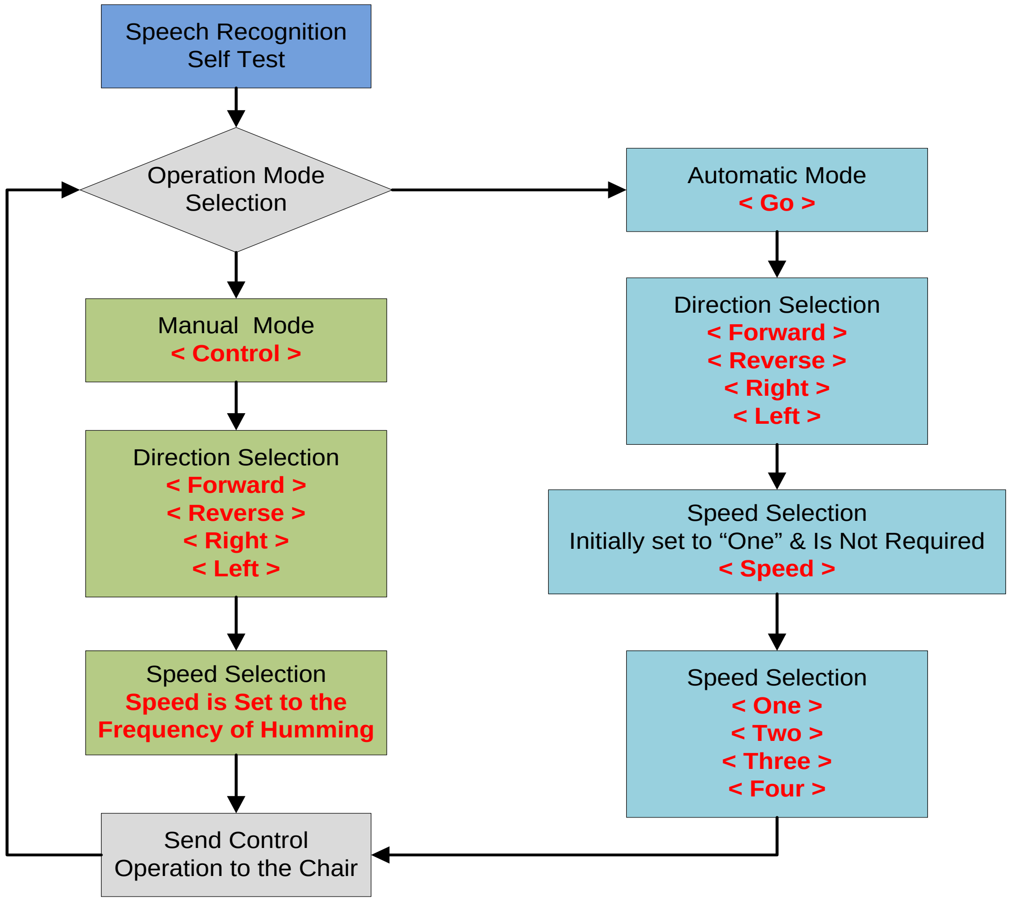
- Speech Recognition
  - Enables complete control of the power chair for all users
- Humming Control
  - Detection of humming frequency of the user through an accelerometer for precise speed control
- Distance Sensors
  - Obstacle avoidance
  - Automatic control



Block diagram of the Hum-Power Controller

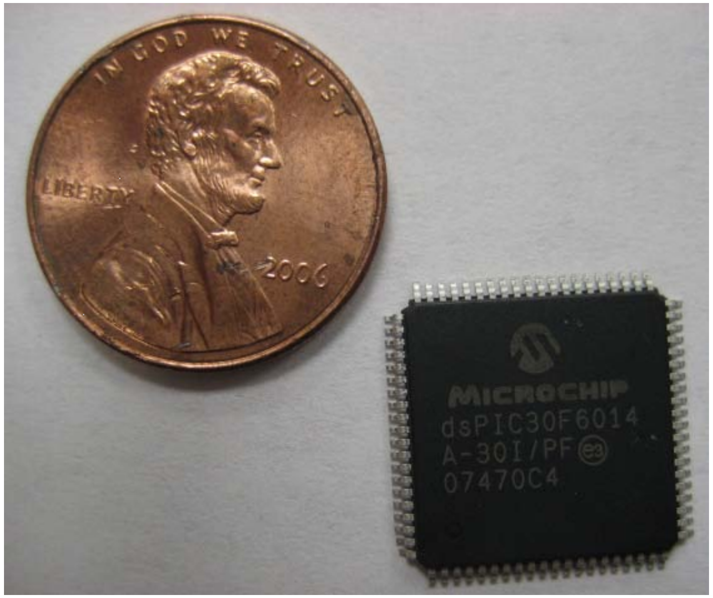


Flowchart of algorithm implemented



Digital signal processor (DSP)

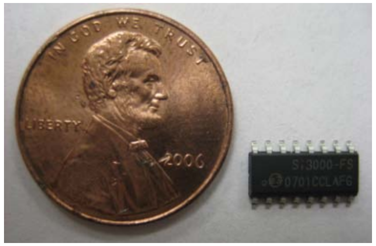
- Microchip™ dsPIC30F6014/A
  - High-Performance Modified 16-bit RISC CPU
  - In-Circuit Serial Programming™ (ICSP™)
  - Wide operating voltage range (2.5V to 5.5V)
  - 16x 12-bit Analog-to-Digital Converter
  - 2x UART, 2x SPI, 1x I2C Digital Communication Peripherals

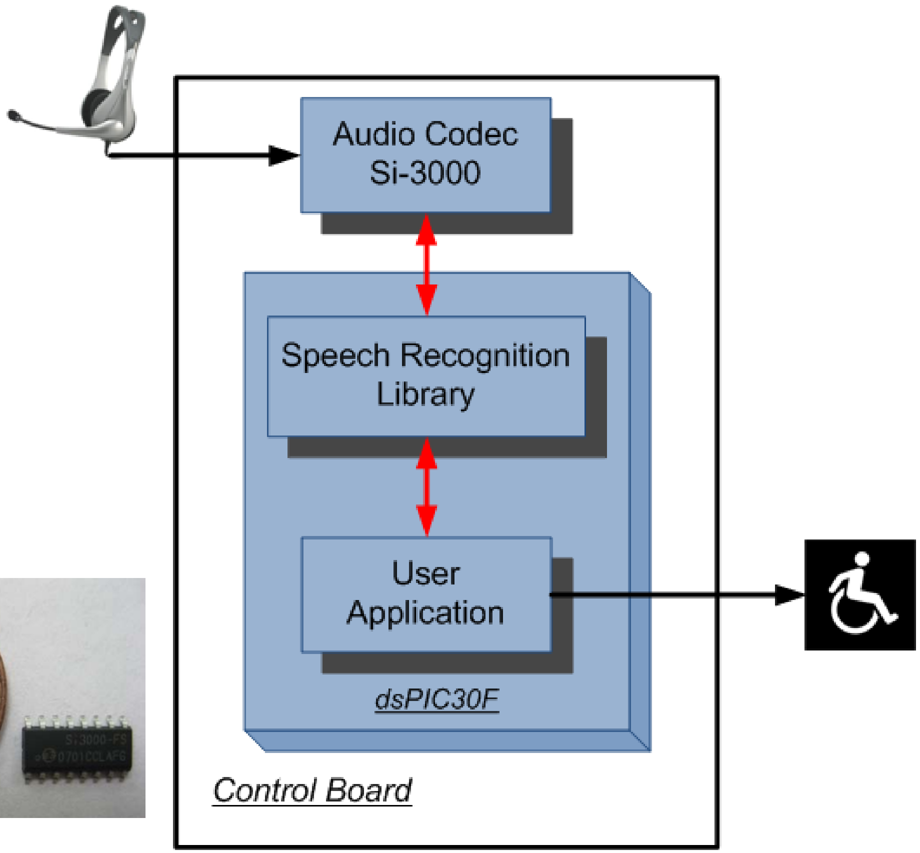


  - 68 input/output pins

Speech recognition software

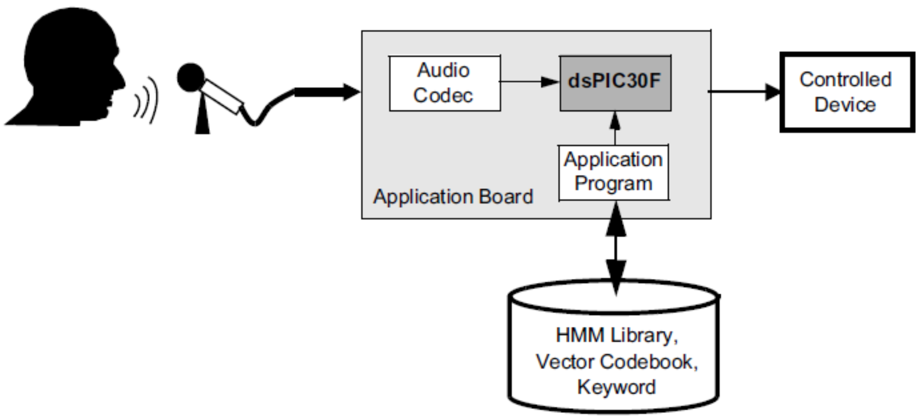
- US English language support.
- Speaker-independent recognition of isolated words.
- Hidden-Markov Model based recognition system.
- Recognition time < 500 msec.
- Optional system self-test using a predefined keyword.
- Sampling Interface:
  - Si-3000 Audio Codec operating at 12.0 kHz





Overview of speech recognition

- dsPIC30F Speech Recognition Library & Word Library Builder:
  - Provided by Microchip Inc.
  - Pre-trained by a demographic cross-section of male and female US English speakers.
  - Generates word recognition features for the Vector Codebook and the Hidden Markov Model (HMM) data files.

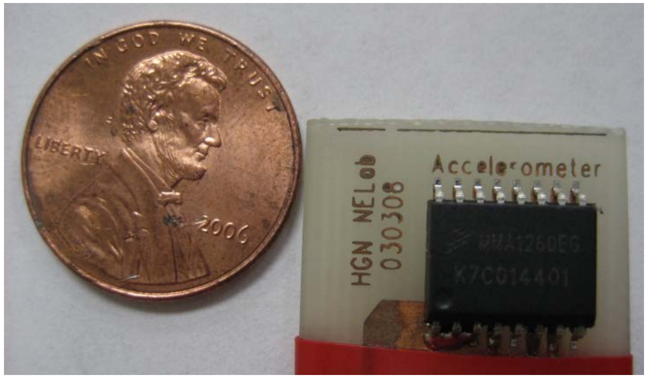


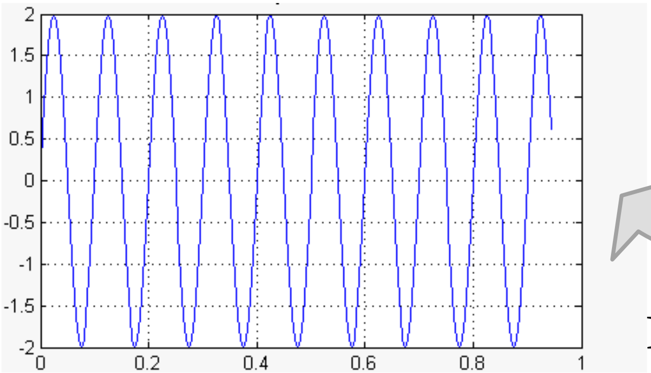
  - Frame-by-frame analysis basis using RASTA-PLP algorithm
  - Quantized into feature vectors of sound characteristics & compared against a vector codebook

Source: dsPIC30F Speech Recognition Library Users Guide

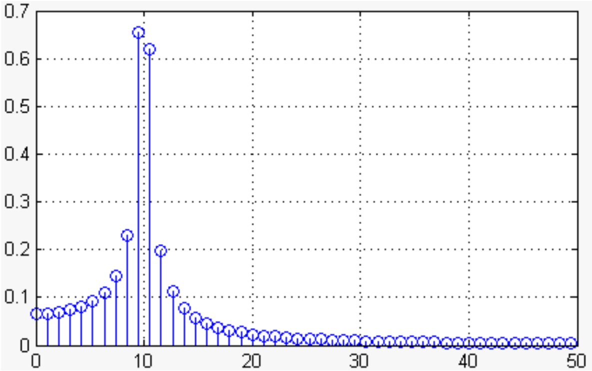
Humming detection

- Using MMA1260EG placed against the users throat
  - Low G Micromachined Accelerometer
  - Z-axis sensitivity
  - Good for Vibration Monitoring and Recording





Record Vibration



Determine Frequency

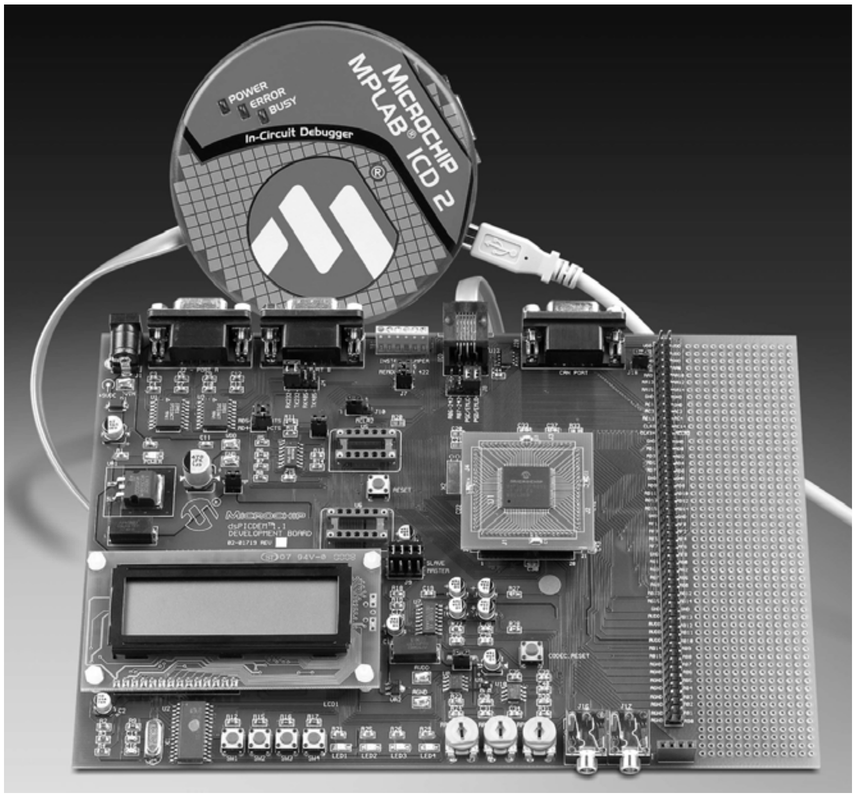
FFT for frequency of humming detection

- The FFT's Radix
  - Size of an FFT decomposition
- Decimation-In-Time (DIT)
  - Decomposed using DFT's of even and odd points
- Bit Reversal
  - MSB's become LSB's
- Twiddle Factors
  - To combine results from a previous stage to form inputs to the next stage
- In Place FFT

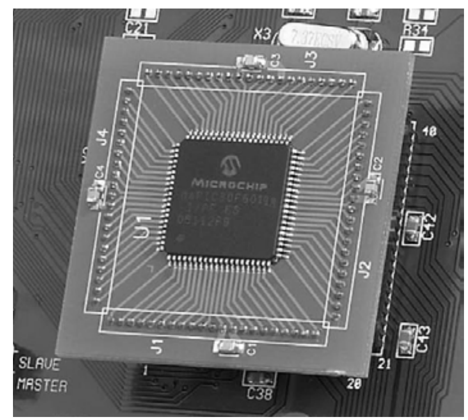
Sample numbers in normal order		Sample numbers after bit reversal	
Decimal	*Binary*	*Decimal*	*Binary*
0	0000	0	0000
1	0001	8	1000
2	0010	4	0100
3	0011	12	1100
4	0100	2	0010
5	0101	10	1010
6	0110	6	0100
7	0111	14	1110
8	1000	1	0001
9	1001	9	1001
10	1010	5	0101
11	1011	13	1101
12	1100	3	0011
13	1101	11	1011
14	1110	7	0111
15	1111	15	1111

Source: http://www.dspguide.com/ch12/2.htm

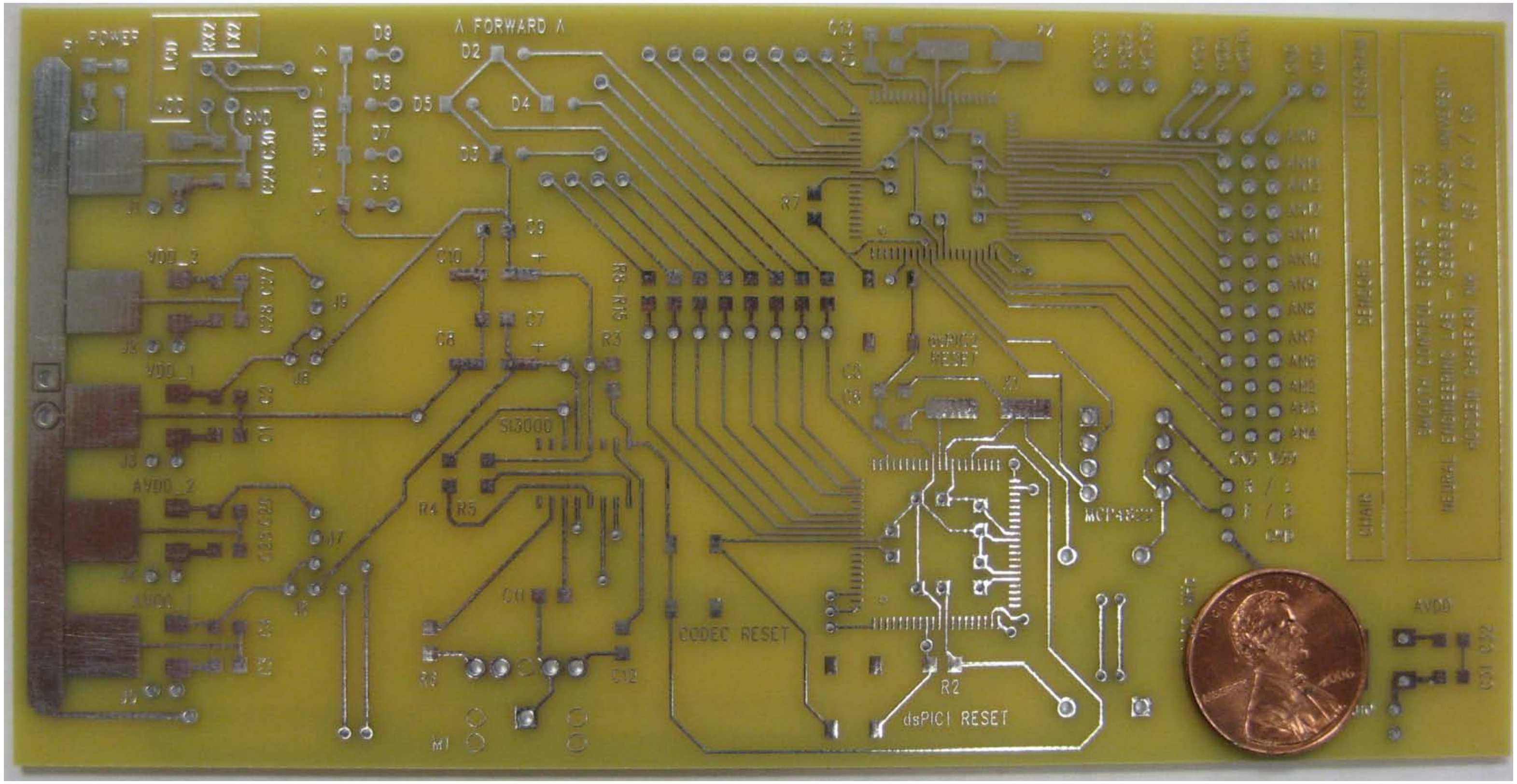
dsPICDEM Plus with MPLAB ICD2



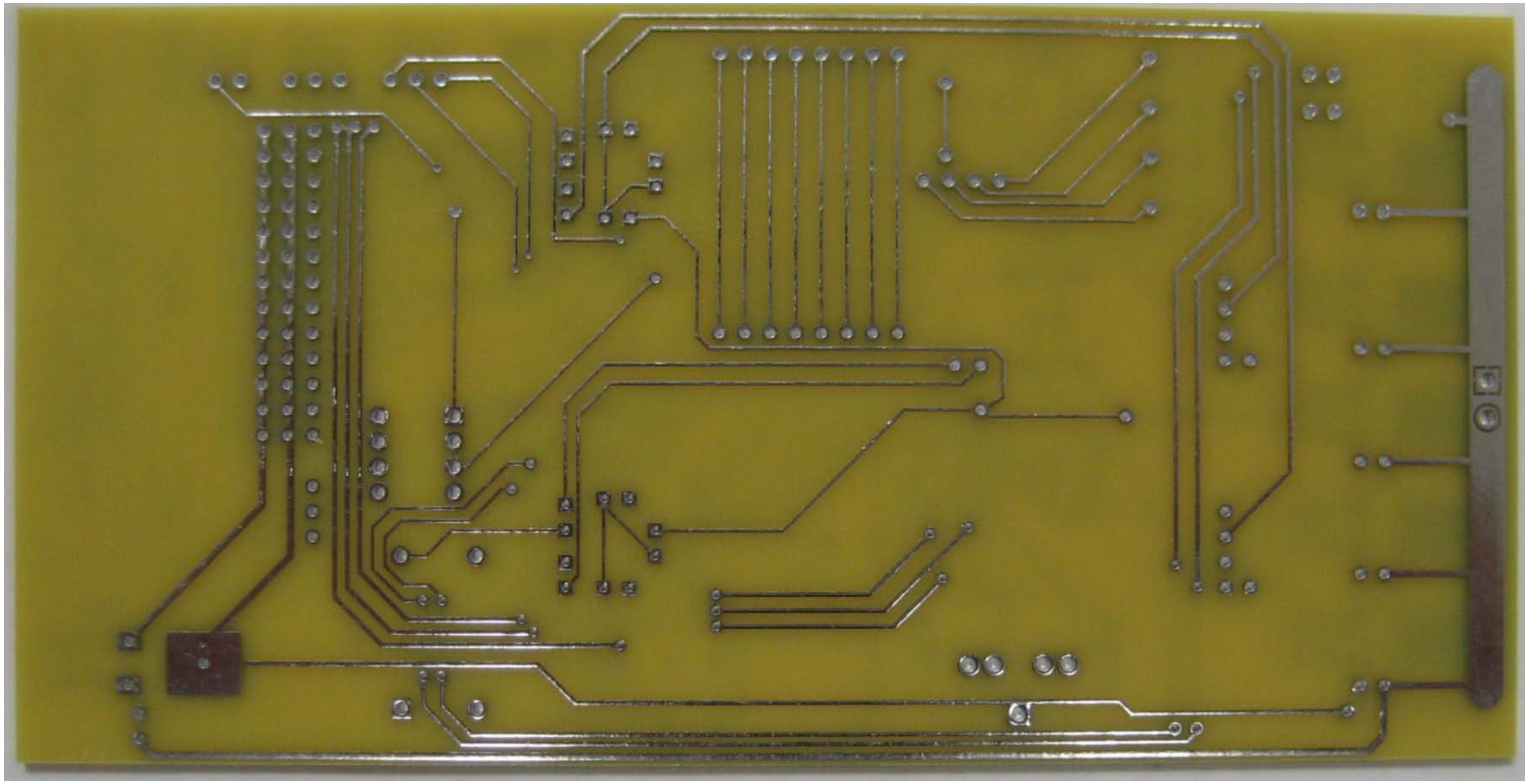
- Algorithms were first tested in evaluation boards
- Preliminary design was then fabricated on a two layer PCB.



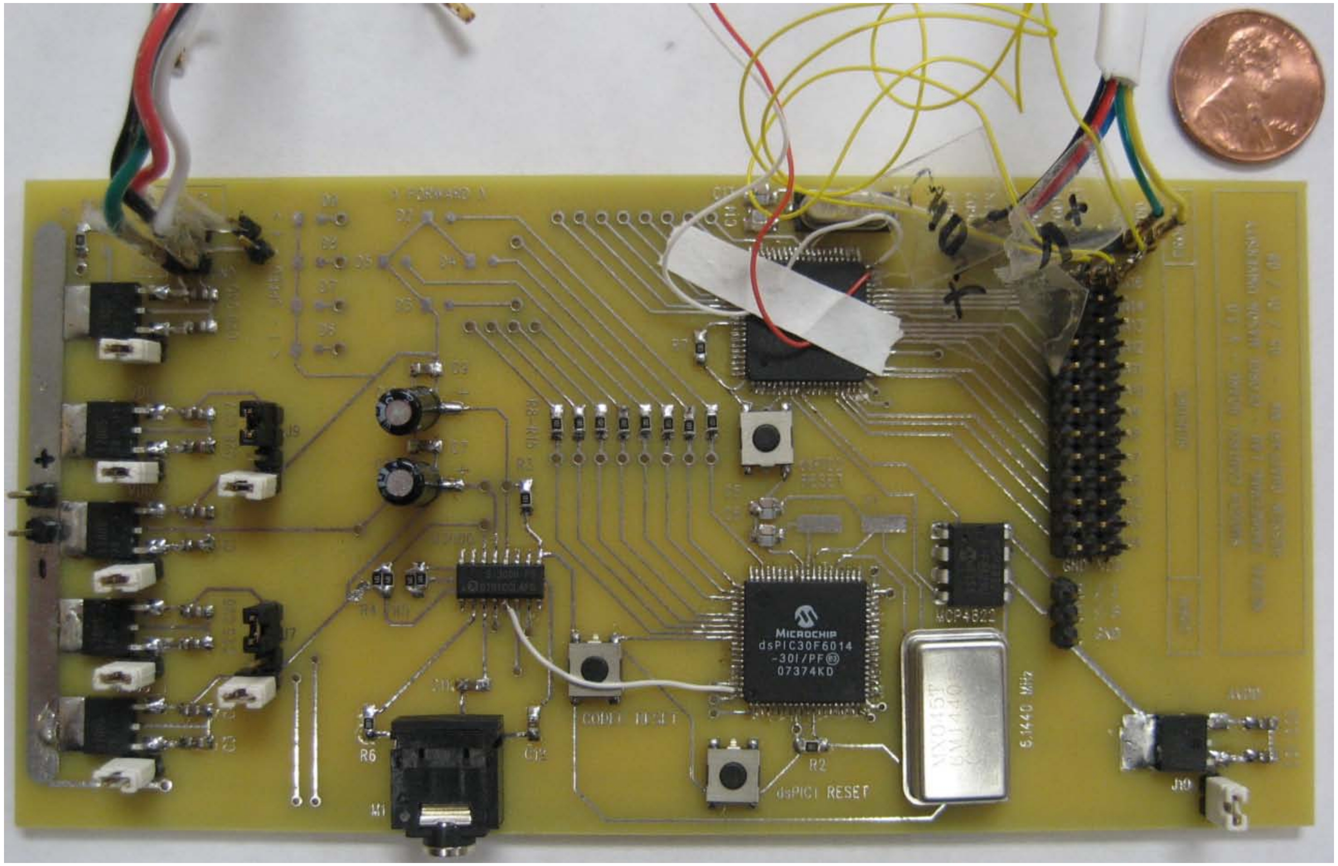
The Hum-Power Controller (front)



The Hum-Power Controller (back)



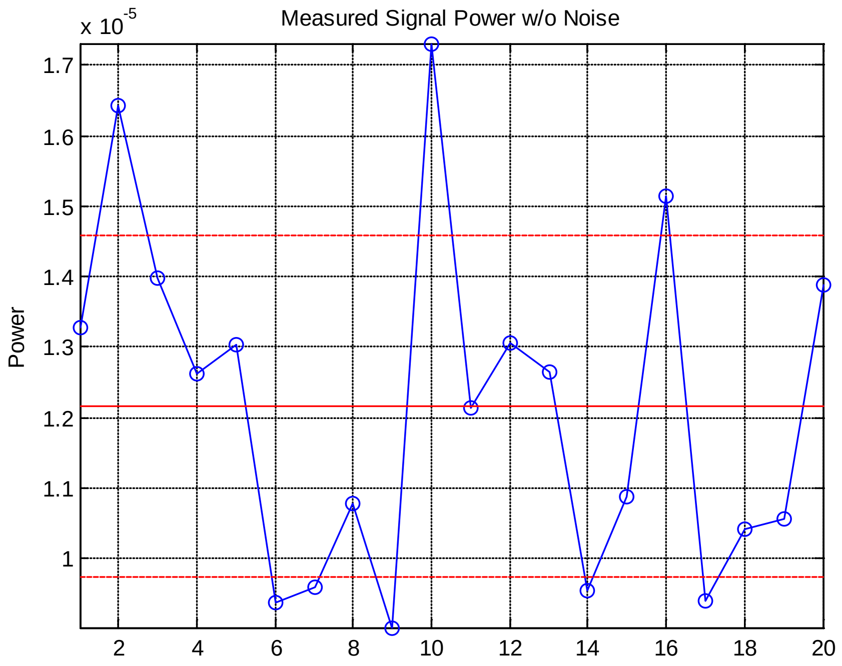
Hum-Power Controller’s working prototype



Ambient noise test

- Recorded & stored 20 “Stop” commands without any added noise.
  - Each 4 seconds long using MATLAB
- Prepared a White Gaussian Noise Source.
  - Located 2 feet away from the microphone with variable volume level
- Signal analysis was performed.
  - Using a separate PC running MATLAB
  - Measured and calculated signal-to-noise ratio

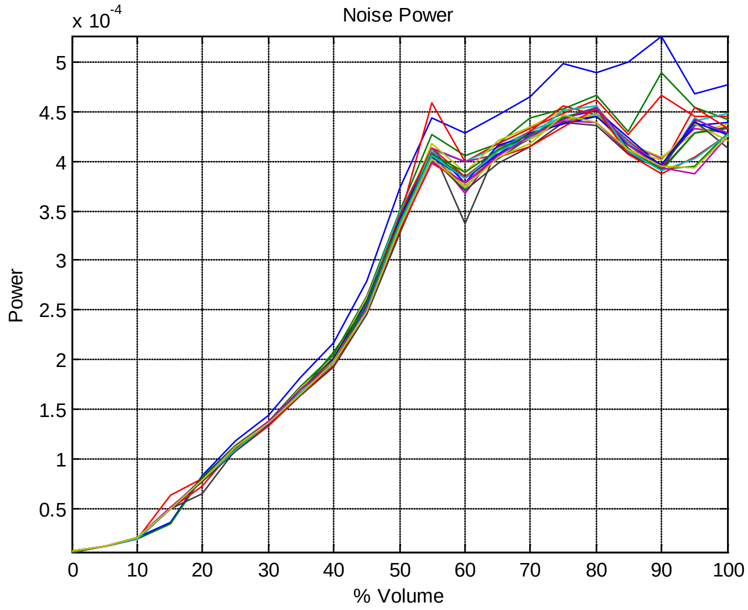
Measured signal power without added noise

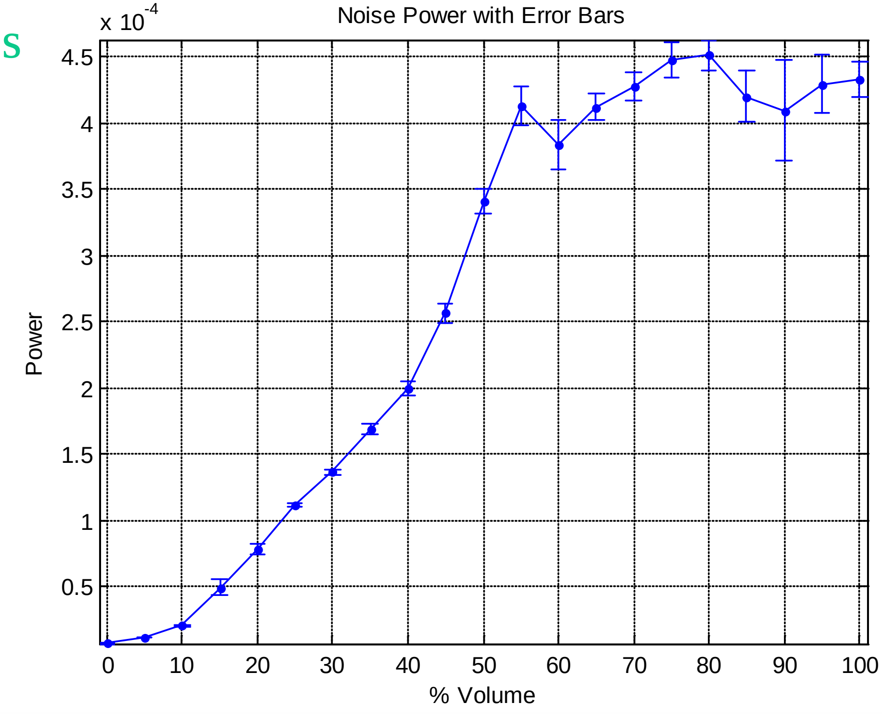


- Command “Stop” repeated 20 times
  - Signal power without added noise is measured
  - 4 seconds recorded for each instance using MATLAB

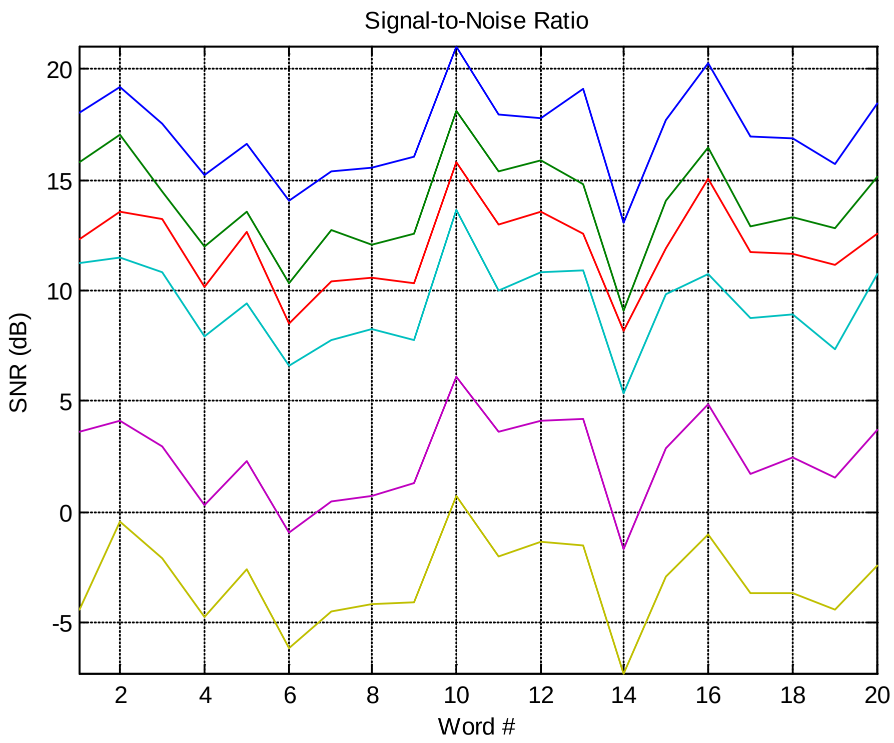
Noise source power profile

- Power Profile for the Noise Source at Different Intensity Levels
  - Average over 20 “Stop” commands

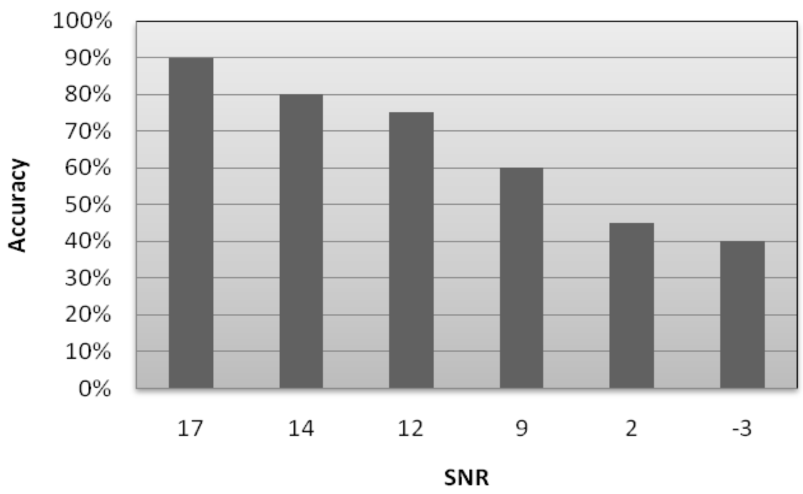




Ambient noise test results



- 20 "Stop" Commands Tested for Recognition Accuracy
  - Using 6 different noise levels
  - Accuracy out of 20 tries for each SNR



Field test results

Prototype specifications

- Speech Recognition enabled
- Humming Detection enabled
- 4 wire interface with MK5™ joystick
  - 2x for 5 Volts power and ground
  - 2x for speed/direction of movement
- 13x input/output ports for analog/digital sensor
  - Used for distance sensors

- Automatic Mode
  - Starts with [GO] command
  - Accepts [Direction] commands
  - Adjustable speed with [Speed] command
- Manual Mode
  - Starts with [Control] command
  - Accepts [Direction] commands
  - Speed change according to the frequency of humming

Problems encountered

- Lack of detailed product sheets for power wheelchair controllers
- Interfacing with the joystick
- Speech recognition engine compatibility with dsPIC30F6014A

Potential improvements

- Possible add-ons for the Current Platform:
  - Addition of distance sensors
    - Obstacle avoidance
    - Automatic cruise control
  - Touch screen interface
    - Currently available without user inputs
  - Accommodating more voice commands
    - Tilt up/down etc.
- New Platform using Windows Powered PDAs:
  - Better Speech Recognition Engines (more accurate)
  - Faster Processor
  - Wireless communication
    - Indoor guidance systems such as Ekahau
    - Easy connection to Smart Home/Buildings
    - Outdoor guidance systems using GPS

Acknowledgements

- Dr. Nathalia Peixoto
  - Thesis Director & Advisor
- East Coast Rehab LLC.
  - Donation of the Powered Wheelchair

Questions … ?

Relative spectral transform - perceptual linear prediction (RASTA-PLP)

- RASTA:
  - A technique that applies a band-pass filter to the energy in each frequency sub-band.
  - Used to smooth short-term noise variations and to remove any constant offset resulting from static spectral coloration.
- PLP:
  - Originally proposed by Hynek Hermansky
  - Warping spectra to minimize the differences between speakers while preserving the important speech informationq

Source: Hermansky, H., Morgan, N., Bayya, A, and Kohn, P. "Rasta-PLP Speech Analysis" ICSI Technical Report TR-91-069, Berkeley, California

Bill of Material (1st Prototype)

Item	Quantity	Purpose	Unit Price (US $)
DSPIC30F6014	1	Microcontroller for Speech Recognition	$ 17.25
DSPIC30F6014A	1	Microcontroller for Humming Processing	$ 10.98
MMA1260EG	1	Micromachined Accelerometer	$ 14.00
MCP4822	1	Digital to Analog Converter	$ 3.00
Si3000	1	Voice Band Codec	$ 2.38
MC7805	3	Voltage Regulator	$ 0.55
6M1440	1	Oscillator for Si300	$ 3.00
JWT 7.3728	2	SMD Microprocessor Crystals	$ 0.83
Microphone Jack	1	Microphone Jack	$ 0.50
Push Button	3	Rest Buttons	$ 0.25
LED	9	Indicators	$ 0.20
Resistor	15	General	$ 0.05
Capacitor	32	General	$ 0.05