Innovation Week on Renewable Energy Systems

MONITORING ,FAULT DETECTION & CONTROL IN R.E.S THE WIND TURBINE CASE AN APPROACH

NOUSIAS STAVROS

ELECTRICAL & COMPUTER ENGINEER

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Goals

- The study of characteristic
- Electrical Signal reception
- Sampling
- DSP
- ADuC7026 Microcontroller Programming with C
- Compination of the above so as to determine:
- **The condition of a system**
- Use of Keil Uvision development environment
- System simulation

Wind Turbine Construction(1)



Wind Turbine Construction(2)

- Moving Parts
- DC Generator Gearbox
- Vibration Generation
- Vibration Patterns
- Proper Operation
- Data
- Prediction Capability

<u>Goal</u>

Collecting, Storing Processing Vibration Data

Piezoelectric Transducers

- Turning Pressure to Electrical Signal
- Use as sensors
- **Structure** Function







Σχήμα 2.2

Διαδικασία πόλωσης:

(a) Πριν την πόλωση οι περιοχές έχουν τυχαίο προσανατολισμό.

(b) Ένα ηλεκτρικό πεδίο συνεχούς ρεύματος πολύ μεγάλης έντασης χρησιμοποιείται για την πόλωση.
 (c) Μετά την απομάκρυνση του πεδίου παραμένει εναπομείνουσα πόλωση



Data Collection



Μονοπάτι σήματος του σηστήματος.

- Αισθητήρας
- Καλώδιο
- conditioner/ενισχυτής σήματος
- Αναλογικό βαθυπερατό φίλτρο
- A/D μετατροπέας ψηφιοποιητής
 Run-time ανάλυση και απεικόνιση
- Αποθήκευση δεδομένων
- **Sampling**
- **Shannon Theorem**
- Aliasing
- **Filters**
- Oversampling



Σκήμα 3.5

Σφάλματα Aliasing παρατηρούμενα στο πεδίο του κρόνου . Ρυθμός δειγματοληφίας =1 kS/s, Συκνότητα σήματος=900 Hz.



Dxήμα 3.6 Aάθη Aliasing όπως φαίνονται στο πεδίο της συκνότητας sample rate =1 kS/S signal frequency =900 Hz.

Fourier Transforms

- Frequency Analysis
- DFT
- **Fast Fourier Transform (FFT)**
- **FFT** Algorithm
- Reverse FFT





$$F(k) = \sum_{n=0}^{N-1} f(n) W_N^Q$$

$$W_N^Q = e^{-j\frac{2\pi Q}{N}}$$

$$Q = \left\{ \left\lfloor \frac{k \cdot 2^{Stage}}{N} \right\rfloor \right\}_{bit-reversed} \text{ (twindle factor)}$$

$$0 \le k \le \frac{N-1}{2}$$

$$1 \le Stage \le \log_2(N)$$

Fourier Transforms(2)

$$X(m\Delta f) = \Delta t \sum_{n=0}^{N-1} x(n\Delta t) e^{-j2\pi \cdot m \cdot \Delta f \cdot n \cdot \Delta t}$$
$$m = 0, 1, 2, 3, \dots, (N-1)$$
DFT

$$\Delta f = \frac{1}{N\Delta t}$$

Nyquist frequency refers to m=(N/2). [(N/2)+1] frequency elements are useful data [(N/2)-1] frequency components are non-useful data and represent negative frequency components (Euler's formula)

Leakage – Windowing



Σκήμα 3.16

Αποτελέσματα time-window κατα την ανάλυση ημιτονοειδούς σήματος με διάταξη ανάλυσης FFT κρησιμοποιοώντας rectangular παράθυρο

(Α) Ακέραιος αριθμός περιόδων , καμία ασινέκεια.

(B) και (C) Όκι ακέραιος αριθμός περιόδων με διαφορετικές σκέσεις φάσης παράγοντας διαφορετική ασυνέκεια όταν τα άκρα ενώνονται σε βρόγκο.



Στο παρακάτω διάγραμμα παρουσιάζονται κάποια σημαντικά παράθυρα:

Rectangular window	w(n) = 1		
Hann window	$w(n) = 0.5 \left(1 - \cos\left(\frac{2\pi n}{N-1}\right) \right)$	$w_0(n) = 0.5 \left(1 + \cos\left(\frac{2\pi n}{N-1}\right)\right)$	
Hamming window	$w(n) = 0.54 - 0.46 \cos\left(\frac{2\pi n}{N-1}\right)$	$w_0(n) \stackrel{\text{def}}{=} w \left(n + \frac{N-1}{2} \right)$ $= 0.54 + 0.46 \cos\left(\frac{2\pi n}{N-1}\right)$	The window is optimized to minimize the maximum (nearest) side lobe, giving it a height of about one-fifth that of the Hann window, a raised cosine with simpler coefficients.



Vibration Analysis

- **Condition Monitoring**
- Changes in Frequency Spectrum
- Spectrum Interpretation & diagnosis



Σκήμα 3.21

Ανάλιναη τάσης εξελιδης (trend analysis) σε μία συνολική μέτρηση και σε ένα μόνο εύρος (A) Φάσμα συκούτητας δόνησης μετρούμενο βάση της τακύτητας για ένα καβότιο τακυτήτων μετά την εγκατάσταση. Να σημειωθεί το μεγάλο τλάνος του συκοστοκού στουειώου τον 480 Hz που κοιριομενί στο φάσμα αναφοράς (B)Το φάσμα συκούτητας δόνησης μετρούμενο βάση της τακύτητας τριος μήνες μετά. Να σημειωθεί η αύξηση στο συκοστικό στουείοι των 121 Hz το αποίο αναποτοεί στην τακύτητα του άζουα στην έζοδο του καβατιστικ (ΟΚαμπύλες που συγκρίνουν την αύξηση στο συκοιστικό στουείο του 121 Hz. Η αύξηση στη συνολυκή τακύτητα στο εύρος από 10 μέτρι 1000 Hz δείνειτ ένα αναπυτοσέιτρικο σφάλμα.



Σκήμα 3.22

Φάσμα επιτάκινσης ρουλεμάν τύπου journal σε φυγοκεντρικό συμπιεστή.

(A) Συμπιεστής σε καλή κατάσταση. Πριν την παύση λεπουργίας του το μοτίβο της δόνησης είναι φυσιολογικό με μερικές απρονικές της περιστροφικής τακύτητας του συμπιεστή και θόρυβο στις υψηλές συκνότητες λόγω έμφυτων αναταράζεων (B) Συμπιεστής με καλαρότητα στις ρουλειρών (journal bearings).



Σχήμα 3.23

Ανάλυση φάσματος δόνησης μετρούμενης στα ρουλεμάν τύπου journal μιας αντλίας ,που απεικονίζει συκιστικά στουκεία λόγω στροβιλισμού λαδιού στο 42% της περιστροφικής τακύτητας.

Spectrum Interpretation & diagnosis(1)

Παλινδρωμίζουσες

Μηχανές

- **Gamma** Subharmonic Elements
- Low harmonics of the rotating speed
- **Harmonics of the transmission Line**
- Higher Harmonics of the rotating speed

Nature of fault	Frequency of dominant vibration, Hz = rpm/60	Direction	Remarks
Rotating members out of balance	$1 \times rpm$	Radial	A common cause of excess vibration in machinery
Misalignment and bent shaft	Usually 1 × rpm Often 2 × rpm Sometimes 3 and 4 × rpm	Radial and axial	A common fault
Damaged rolling element bearings (ball, roller, etc.)	Impact rates for the individual bearing component Also vibrations at high frequencies (2 to 60 kHz) often related to radial resonances in bearings	Radial and axial	Uneven vibration levels, often with shocks Impact Rates f (Hz): For Outer Race Defect $f(Hz) = \frac{n}{2} f_r \left(1 - \frac{BD}{PD} \cos \beta\right)$ For Inner Race Defect BALL DIA (BD) $f(Hz) = \frac{n}{2} f_r \left(1 + \frac{BD}{PD} \cos \beta\right)$ For Ball Defect $f(Hz) = \frac{PD}{BD} f_r \left[1 - \left(\frac{BD}{PD} \cos \beta\right)^2\right]$ n = number of balls or rollers $f_r =$ relative rps between inner and outer races
Journal bearings loose in housing	Subharmonics of shaft rpm, exactly ½ or ½ × rpm	Primarily radial	Looseness may only develop at operating speed and temperature (e.g., turbomachines)

Spectrum Interpretation & diagnosis(2)

Oil-film whirl or whip in journal bearings	Slightly less than half shaft speed (42 to 48 percent)	Primarily radial	Applicable to high-speed (e.g., turbo) machines
Hysteresis whirl	Shaft critical speed	Primarily radial	Vibrations excited when passing through critical shaft speed are maintained at higher shaft speeds. Can sometimes be cured by tightening the rotor components.
Damaged or worn gears	Tooth-meshing frequencies (shaft rpm × number of teeth) and harmonics	Radial and axial	Sidebands around tooth-meshing frequencies indicate modulation (e.g., eccentricity) at frequency corresponding to sideband spacings. Normally only detectable with very narrow- band analysis and cepstrum analysis.
Mechanical looseness	$2 \times rpm$		Also sub- and interharmonics, as for loose journal bearings
Faulty belt drive	1, 2, 3, and $4 \times rpm$ of belt	Radial	The precise problem can usually be identified visually with the help of a stroboscope
Unbalanced reciprocating forces and couples	1 × rpm and/or multiples for higher-order unbalance	Primarily radial	
Increased turbulence	Blade & vane passing frequencies and harmonics	Radial and axial	An increased level indicates increased turbulence
Electrically induced vibrations	1×rpm or 2 times line frequency	Radial and axial	Should disappear when power is turned off

Reprocating Engines

Static eccentricity	2×line frequency and components at $\omega \times [nR_s(1-s)/p \pm k_1]$	Radial	Can result from poor internal alignment, bearing wear, or from local stator heating (vibration worsens as motor heats up).
Weakness/looseness of stator support, unbalanced phase resistance or coil sides Shorted stator laminations/turns	2 × line frequency	Radial	Referred to as "loose iron." Difficult to differentiate between this group using only vibration analysis, but they will also be apparent at no load as well as on load.
Loose stator laminations	2 × line frequency and components spaced by 2 × line frequency at around 1 kHz	Radial	Can have high amplitude but not usually destructive. The high-frequency components may be similar to static eccentricity.
Dynamic eccentricity	1 × rpm with 2 × slip-frequency sidebands and components at $\omega \times [((nR_x \pm k_e) \times (1 - s)/p) \pm k_1]$	Radial	Can result from rotor bow, rotor runout, or from local rotor heating (vibration worsens as motor heats up).
Broken or cracked rotor bar Loose rotor bar Shorted rotor laminations Poor end-ring joints	1 × rpm with 2 × slip-frequency sidebands and components similar to those given above for dynamic eccentricity with addition of 2 × slip-frequency sidebands around slot harmonics	Radial	The slip sidebands may be low level, requir- ing a large dynamic range as well as fre- quency selectivity in measuring instrumen- tation. Typical spectra show that these components in the region of the principal vibration slot harmonics also have slip-frequency sidebands.

Inductive engines

Vibration Cause	Symptomatic Frequency	Dominant Plane	Comment
Unbalanced Rotor Shaft	1 × <i>RPM</i>	Radial	Type of unbalance can be determined from phase relationships (see Table 2)
Bent Shaft or Angular Misalign- ment	1 ×, 2 × <i>RPM</i>	Axial	See Table 2 for more information
Parallel Misalignment	1 ×, 2 × <i>RPM</i>	Radial	See Table 2 for more information
Mechanical Looseness	1 ×, 2 ×, 3 ×, 4 × <i>RPM</i> etc. also 0,5 ×, 1,5 × <i>RPM</i> etc.	Radial	High number of harmonics and possible in- terharmonics characterizes truncation
Damaged Rolling Element Bearings	Induced resonance in the bear- ing housing and machine casing in the range 1 to 20 kHz typically		Resonance is excited by impacts of local faults in the bearing. Also frequencies due to fundamental impact repetition rates (see Fig.6), which are generally lost among other signals + noise at lower frequency however
Oil Whirl and Whip in Sleeve Bearings	0,43 to 0,48 × <i>RPM</i>	Radial	Sleeve Bearings are common in larger mo- tors
Static Eccentricity	2 × line frequency and compo- nents at $\omega \times [nR_s (1-s)/p \pm k_1]$	Radial	Can result from poor internal alignment, bearing wear, or from local stator heating ¹⁾ (Vibration worsens as motor heats up)
Weakness/Looseness of Stator Support, Unbalanced Phase Resistance or Coil Sides, Shorted Stator Laminations/Turns	2 × line frequency	Radial	Referred to as "loose iron" Difficult to differentiate between this group using only vibration analysis, but they will also be apparent at no load as well as on load
Loose Stator Laminations	$2\times$ line frequency and components spaced by $2\times$ line frequency at around 1 kHz^{\dagger}	Radial	Can have high amplitude but not usually de- structive. The high frequency components may be similar to static eccentricity [†]
Dynamic Eccentricity	1 × <i>RPM</i> with 2 × slip frequency sidebands and components at ω × [(($nR_s \pm k_e$) × (1-s)/p) ± k_1]	Radial	Can result from rotor bow, rotor runout, or from local rotor heating ²⁾ (Vibration worsens as motor heats up)
Broken or Cracked Rotor Bar, Loose Rotor Bar, Shorted Rotor Laminations, Poor End-Ring Joints	1 × <i>RPM</i> with 2 × slip frequency sidebands and components similar to those given above for dynamic eccentricity [†]	Radial	The slip sidebands may be low level, requir- ing a large dynamic range as well as fre- quency selectivity in measuring instrumen- tation. Typical spectra are shown in the ap- pendix showing that these components in the region of the principal vibration slot har- monics also have slip frequency sidebands

DC Generators

Categorizing Vibrations

Stationary Vibration
Non-Stationary Vibration
Deterministic Vibration
Random
Mixed



Energy & Power



Microcontroller ADuC7026

- Embedded Systems
- ARM7TDMI
- Olimex Development Platform
- Keil-Uvision Develoment Environment







Σχήμα 4.5

Σχήμα 4.1

Fault Detection using the microcontroller(1)

- Ordinance
- Sampling rate
- Variable Number of channels with variable depth of analysis
- **Data flow**



Possibility of locating sensors on gearbox

Fault Detection using the microcontroller(2)

- Code Structure
- Variables
- Data storage
- Functions & Processing
- Sampling Functions

Συνάρτηση δειγματοληψίας:

```
_irq void IRQ_Handler(void)
```

```
Buffers[NA].Buffer[ADCCP][pos]=(ADCDAT >> 16);
ADCCP=(ADCCP+1)%channels;
if(ADCCP==0)pos=(pos+1)%COL;
if((ADCCP==0)&&(pos==0))NA=(NA+1)%NOB;
return;
```

/*αποστολή 1 δείγματος*/

Fault Detection using the microcontroller(3)

- Filter Design Initialization High frequency cut-off
- Window
- System startup
 - CPU
 - Timers
 - Ports
 - Interrupts
 - ADC
- Processing
 - FFT
 - Scrambler
 - Twindle Factors
 - Butterfly
 - Reverse FFT
 - Cepstrum
 - Histogram
 - Power & rms
 - Continuous production of average value of a large number of consecutively added numbers
- Control Function

Filter & cutting off high frequency elements

Matlab

Filter1=fir1(9,0.001);

void sortFIR(void)	
{	
int i,j,k,m,n;	
i=0;j=0;k=0;m=0;n=0;addup=0;	
if (NA!=0)j=(NA-1); //Επιλογή buffer	
if (NA==0)j=(NOB-1);	
for(m=0;m <col;m++)< td=""><td></td></col;m++)<>	
1	
for(i=0;i <channels;i++)< td=""><td></td></channels;i++)<>	
{	
for(k=(bufferlength-1);k>0;k){Array[i].data[k]=Array[i].data[k-1];}	//Ολίσθηση
Arrav[i].data[0]=Buffers[i].Buffer[i][m]: //Τοποθέτησηση στι	ι δομή δεδομένων
ano toy buffer	
for(n=0:n <bufferlength:n++){addup+=array[i].data[n]*fir[n];}< td=""><td>//πέρασμα τιμών</td></bufferlength:n++){addup+=array[i].data[n]*fir[n];}<>	//πέρασμα τιμών
από το φίλτρο	
Arrav[i].G[m]=addup	
addup=0:	
1	
1	

fvtool(Filter1);



>> lowpass =

0.0161 0.0379 0.0931 0.1559 0.1969 0.1969 0.1559 0.0931 0.0379 0.0161

Scrambler

Bit-reversal

Initial Binary Scrambled 3 4 5 6 0 00 00 0					# E	Bits		
Initial Binary Scrambled 3 4 5 6 0 00 00 0			Mirrored					
Initial Binary Scrambled 3 4 5 6 0 00 00 0								
0 00 00 0 0 0 0 1 01 10 2 4 8 16 3 11 11 3 6 12 24 48 orange *2 4 0 1 2 4 8 violet (*2)+1 5 10 20 40 1 2 4 8 10 1 3 6 12 24 4 9 18 36 12 24 11 0 0 0 11 2 5 10 20 14 28 52 10 20 12 12 14 13 6 12 14 28 12 14 24 12 14 14	Initial	Binary	Binary	Scrambled	3	- 4	- 5	6
1 01 10 2 4 8 16 32 2 10 01 1 2 4 8 16 3 11 11 3 6 12 24 48 orrange *2 4 0 1 2 4 8 violet (*2)+1 5 10 20 40 7 3 7 14 28 56 3 0 0 1 2 4 9 18 36 10 11 3 6 13 26 52 10 20 11 3 6 13 26 52 10 20 11 23 6 12 44 13 6 12 24 44 13 6 12 24 44 13 6 12 24 44 13 6 12 44 13 6 12 44 14 13 7 14 28 50 6 1	0	00	00	0	0	0	0	0
2 10 01 1 2 4 8 16 3 11 11 3 6 12 24 48 orange *2 4 0 1 2 4 8 violet (*2)+1 5 10 20 40 7 3 7 14 28 56 8 0 0 1 2 4 9 16 0 1 2 4 9 16 0 1 2 5 10 11 3 6 12 24 11 3 6 13 26 52 111 3 6 13 26 52 112 11 3 6 12 24 113 2 5 11 22 44 14 13 7 14 28 15 37 15 30 60 12 25 16 0 <	1	01	10	2	4	8	16	32
3 11 11 3 6 12 24 48 orange *2 4 0 1 2 4 8 violet (*2)+1 5 2 5 10 20 40 6 1 3 6 12 24 8 7 3 7 14 28 56 8 0 0 1 2 4 9 2 4 9 18 36 10 11 3 6 12 24 11 3 6 13 26 52 111 3 6 13 26 52 112 20 1 3 6 12 24 13 2 5 10 20 11 22 44 14 15 3 7 14 28 12 34 14 15 3 7 15 30 60 12 25 50 <td< td=""><td>2</td><td>10</td><td>01</td><td>1</td><td>2</td><td>4</td><td>8</td><td>16</td></td<>	2	10	01	1	2	4	8	16
orange v2 4 0 1 2 4 8 violet (*2)+1 5 2 5 10 20 40 6 1 3 6 12 24 7 3 7 14 28 56 8 0 0 1 2 4 9 2 4 9 18 36 10 11 3 6 13 26 52 11 3 6 13 26 52 11 3 6 12 44 3 6 12 13 2 5 11 22 44 26 13 26 14 13 2 4 8 12 34 14 14 1 3 7 14 25 30 15 30 0 1 2 4 8	3	11	11	3	6	12	24	48
violet (*2)+1 5 2 5 10 20 40 6 1 3 6 12 24 7 3 7 14 28 56 8 0 0 1 2 4 9 2 4 9 18 36 10 1 2 5 10 20 11 3 6 13 26 52 12 0 1 3 6 12 13 2 5 11 22 44 14 1 3 7 14 28 15 3 7 15 30 60 16 0 0 0 1 2 17 2 4 8 17 34 18 1 2 4 9 18 19 3 6 12 <td< td=""><td>orange</td><td>*2</td><td>4</td><td>0</td><td>1</td><td>2</td><td>4</td><td>8</td></td<>	orange	*2	4	0	1	2	4	8
61361224737142856800124924918361012510201136132652120136121325112244141371428153371530601600012172481734181249181936122550200125102122136132213613262337142956240013625249193626125112227361327542801371429261371426205112346301371530	violet	(*2)+1	5	2	5	10	20	40
7371422568001249249183610125102011361326521201361213251122441413714281533715306016000121724617341812491819361225502001251021221361322136132623371429562400136252491936261251122273613275428013714292613714			6	1	3	0	12	24
3 0 1 2 4 9 2 4 9 18 36 10 1 2 5 10 20 11 3 6 13 26 52 12 0 1 3 6 12 13 2 5 11 22 44 14 13 7 14 28 15 37 15 30 60 16 0 0 0 1 2 4 8 17 34 13 1 2 4 13 1 2 4 9 18 13 2 4 9 13 6 12 25 50 20 0 1 2 5 20 0 1 2 5 20 0 1 2 5 21 25 10 21 42 22 1 3 6 13 26 23 3 7 14 24 0 0 1 3 26 2 4 9 19 26 2 5 11 22 27 3 6 13 27 26 1 3 7 14 28 0 1 3 7 26 1 3 7 14 28 0 1 3 7 <td></td> <td></td> <td>2</td> <td>3</td> <td>1</td> <td>14</td> <td>26</td> <td>50</td>			2	3	1	14	26	50
3 2 4 9 18 36 1012 5 10 20 1136 13 26 52 120136 12 132 5 111 22 44 1413 7 14 26 15337 15 30 60 160001 2 172 4 8 17 34131 2 4 9 18131 2 4 9 18131 2 4 9 18131 2 4 9 18131 2 4 9 193612 25 50 2001 2 510 21221 3 6 23 3 7 14 240 7 14 252 4 9 261 2 511 273 6 13 27 2801 3 7 14 28 01 3 262 5 11 23 262 5 11 23 262 5 11 23 262 5 11 23 262 5 11 23 <tr<< td=""><td></td><td></td><td>8</td><td>0</td><td>U</td><td>1</td><td>2</td><td>2</td></tr<<>			8	0	U	1	2	2
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$\begin{array}{c ccccccccccccccccccccccccccccccccccc$			25	2	a	0	10	38
27 3 6 13 27 54 28 0 1 3 7 14 28 2 5 11 23 46 30 1 3 7 15 30			26	1	2	5	11	22
28 0 1 3 7 14 29 2 5 11 23 46 30 1 3 7 15 30			20	3	6	15	27	54
29 2 5 11 23 46 30 1 3 7 15 30			28	0	1	3	7	14
30 1 3 7 15 30			20	2	5	11	23	46
			30	1	3	7	15	30
I								

32	0	0	0	0	1	
33	2	4	8	16	33	
34	1	2	-4	8	17	
35	3	6	12	24	49	
30	0	1	2	4	- 9	
37	2	5	10	20	41	
38	1	з	6	12	25	
39	3	7	14	28	57	
40	0	U	1	2	-5	
41	2	4	9	18	37	
42	1	2	- 5	10	21	
43	3	6	13	26	53	
44	0	1	3	6	13	
45	2	5	11	22	45	
40	1	З	- 7	14	29	
47	3	7	15	30	01	
48	0	U	U	1	- 3	
49	2	4	8	17	35	
50	1	2	4	9	19	
51	3	6	12	25	51	
52	0	1	2	-5	11	
53	2	5	10	21	43	
54	1	3	6	13	27	
55	3	7	14	29	59	
50	U	U	-1	3	-7	
57	2	4	9	19	39	
58	1	2	- 5	11	23	
59	3	6	13	27	55	
60	0	1	3	- 7	15	
61	2	5	11	23	47	
62	1	З	- 7	15	31	
63	3	7	15	31	63	

Simulation(1)

- Simulation capability with keil uvision
- Simulating inputs
- Capability of verification of variable values and data flow
- Proper FFT operation

Logi	Analyzer	• ¤ ×
Set	Min Time: Max Time: Range: Grid: Zoom: Code: S Export 2.217824 s 2.425367 s 0.200000 s 0.010000 s In Out All Set Show In	Setup Min. Auto
adc0	2- 0-	
adc1	5-	
adc2		\sim
adc3		NNN
adcdat	x10000000- 0x0- 2.230000 s 2.330000 s 2.	430000 s

	, J			
Channel	0	1	2	3
0	15418	15396,88	15608	15787
1	4066,8	4308,172	4444,3	3826,5
2	2196,4	2197,82	2335,4	2858,3
3	2455,5	2458,822	2485,7	2810,8
4	0,481	153,4095	262,87	471,83
5	2575,9	2579,041	2609,6	2954,6
6	3418,7	3415,734	3472,7	3517,9
7	1862,9	1893,09	1931,5	1843,8
8	4062,8	4057,608	4103,8	4450,4
9	479,37	1037,408	1370,9	2621
10	2195,4	2192,311	2215,9	2462,6
11	5260,5	5262,413	5302,7	5541,9
12	0,6152	196,8524	253,55	459,75
13	2400,7	2404,721	2426,7	2474,4
4.4	3417.8	3425.244	3571,1	4049,8
14	0411,0			
14	6161,3	6257,119	6359,7	6554,8
14	6161,3 0 Hz	6257,119 10 Hz	6359,7 100Hz	6554,8 350Hz
14	6161,3 0 Hz	6257,119 10 Hz -21,48	6359,7 100Hz 190,09	6554,8 350Hz 368,99
14 15 0 1	6161,3 0 Hz	6257,119 10 Hz -21,48 241,36	6359,7 100Hz 190,09 377,54	6554,8 350Hz 368,99 -240,29
14 15 0 1 2	6161,3 0 Hz	6257,119 10 Hz -21,48 241,36 1,39	6359,7 100Hz 190,09 377,54 138,97	6554,8 350Hz 368,99 -240,29 661,84
14 15 0 1 2 3	6161,3 0 Hz	6257,119 10 Hz -21,48 241,36 1,39 3,36	6359,7 100Hz 190,09 377,54 138,97 30,26	6554,8 350Hz 368,99 -240,29 661,84 355,38
14 15 0 1 2 3 4	6161,3 0 Hz	6257,119 10 Hz -21,48 241,36 1,39 3,36 152,93	6359,7 100Hz 190,09 377,54 138,97 30,26 262,39	6554,8 350Hz 368,99 -240,29 661,84 355,38 471,35
14 15 0 1 2 3 4 5	6161,3 0 Hz	6257,119 10 Hz -21,48 241,36 1,39 3,36 152,93 3,10	6359,7 100Hz 190,09 377,54 138,97 30,26 262,39 33,65	6554,8 350Hz 368,99 -240,29 661,84 355,38 471,35 378,61
14 15 0 1 1 2 3 4 4 5 6	6161,3 0 Hz	6257,119 10 Hz -21,48 241,36 1,39 3,36 152,93 3,10 -2,93	6359,7 100Hz 190,09 377,54 138,97 30,26 262,39 33,65 54,04	6554,8 350Hz 368,99 -240,29 661,84 355,38 471,35 378,61 99,28
14 15 0 1 1 2 3 4 5 6 7	6161,3 0 Hz	6257,119 10 Hz -21,48 241,36 1,39 3,36 152,93 3,10 -2,93 30,18	6359,7 100Hz 190,09 377,54 138,97 30,26 262,39 33,65 54,04 68,59	6554,8 350Hz 368,99 -240,29 661,84 355,38 471,35 378,61 99,28 -19,10
14 15 0 1 1 2 3 3 4 5 6 7 8	6161,3 0 Hz	6257,119 10 Hz -21,48 241,36 1,39 3,36 152,93 3,10 -2,93 30,18 -5,23	6359,7 100Hz 190,09 377,54 138,97 30,26 262,39 33,65 54,04 68,59 41,00	6554,8 350Hz 368,99 -240,29 661,84 355,38 471,35 378,61 99,28 -19,10 387,58
14 15 0 1 1 2 3 3 4 5 6 7 7 8 9	6161,3 0 Hz	6257,119 10 Hz -21,48 241,36 1,39 3,36 152,93 3,10 -2,93 30,18 -5,23 558,04	6359,7 100Hz 190,09 377,54 138,97 30,26 262,39 33,65 54,04 68,59 41,00 891,55	6554,8 350Hz 368,99 -240,29 661,84 355,38 471,35 378,61 99,28 -19,10 387,58 2141,68
14 15 0 1 1 2 3 3 4 5 6 7 7 8 9 9 10	6161,3 0 Hz	6257,119 10 Hz -21,48 241,36 1,39 3,36 152,93 3,10 -2,93 30,18 -5,23 558,04 -3,09	6359,7 100Hz 190,09 377,54 138,97 30,26 262,39 33,65 54,04 68,59 41,00 891,55 20,45	6554,8 350Hz 368,99 -240,29 661,84 355,38 471,35 378,61 99,28 -19,10 387,58 2141,68 267,23
14 15 0 1 1 2 2 3 3 4 4 5 6 7 7 8 9 9 10 11	6161,3 0 Hz	6257,119 10 Hz -21,48 241,36 1,39 3,36 152,93 3,10 -2,93 30,18 -5,23 30,18 -5,23 558,04 -3,09 1,95	6359,7 100Hz 190,09 377,54 138,97 30,26 262,39 33,65 54,04 68,59 41,00 891,55 20,45 42,24	6554,8 350Hz 368,99 -240,29 661,84 355,38 471,35 378,61 99,28 -19,10 387,58 2141,68 267,23 281,45
14 15 0 1 1 2 2 3 3 4 4 5 6 7 7 8 9 9 10 11 12	6161,3 0 Hz	6257,119 10 Hz -21,48 241,36 1,39 3,36 152,93 3,10 -2,93 30,18 -5,23 30,18 -5,23 558,04 -3,09 1,95 196,24	6359,7 100Hz 190,09 377,54 138,97 30,26 262,39 33,65 54,04 68,59 41,00 891,55 20,45 42,24 252,94	6554,8 350Hz 368,99 -240,29 661,84 355,38 471,35 378,61 99,28 -19,10 387,58 2141,68 267,23 281,45 459,13
14 15 0 1 1 2 2 3 3 4 4 5 6 7 7 8 9 9 10 11 11 12 13	6161,3 0 Hz	6257,119 10 Hz -21,48 241,36 1,39 3,36 152,93 3,10 -2,93 30,18 -5,23 558,04 -3,09 1,95 196,24 4,04	6359,7 100Hz 190,09 377,54 138,97 30,26 262,39 33,65 54,04 68,59 41,00 891,55 20,45 42,24 252,94 26,05	6554,8 350Hz 368,99 -240,29 661,84 355,38 471,35 378,61 99,28 -19,10 387,58 2141,68 267,23 281,45 459,13 73,67
14 15 0 1 1 2 2 3 3 4 4 5 6 7 7 8 9 9 10 11 11 12 13 14	6161,3 0 Hz	6257,119 10 Hz -21,48 241,36 1,39 3,36 152,93 3,10 -2,93 30,18 -5,23 30,18 -5,23 558,04 -3,09 1,95 196,24 4,04 7,46	6359,7 100Hz 190,09 377,54 138,97 30,26 262,39 33,65 54,04 68,59 41,00 891,55 20,45 42,24 252,94 252,94 26,05 153,31	6554,8 350Hz 368,99 -240,29 661,84 355,38 471,35 378,61 99,28 -19,10 387,58 2141,68 267,23 281,45 459,13 73,67 632,03

Supervizer an engle minered

Simulation(2)

Έτσι προκύπτει:



Simulation(3)

Sinusoidal signal with noise:



Channel	0	1
0	15418	15442,9
1	4066,8	4150,825
2	2196,4	2226,635
3	2455,5	2464,847
4	0,481	144,1399
5	2575,9	2585,461
6	3418,7	3428,348
7	1862,9	1880,781
8	4062,8	4069,918
9	479,37	813,0291
10	2195,4	2199,528
11	5260,5	5270,973
12	0,6152	138,2589
13	2400,7	2406,118
14	3417,8	3460,375
15	6161,3	6212,131
	0 Hz	50 Hz noised
0	0 Hz	50 Hz noised 24,54
0	0 Hz	50 Hz noised 24,54 84,02
0	0 Hz	50 Hz noised 24,54 84,02 30,20
0 1 2 3	0 Hz	50 Hz noised 24,54 84,02 30,20 9,39
0 1 2 3 4	0 Hz	50 Hz noised 24,54 84,02 30,20 9,39 143,66
0 1 2 3 4 5	0 Hz	50 Hz noised 24,54 84,02 30,20 9,39 143,66 9,52
0 1 2 3 4 5 6	0 Hz	50 Hz noised 24,54 84,02 30,20 9,39 143,66 9,52 9,68
0 1 2 3 4 5 6 7	0 Hz	50 Hz noised 24,54 84,02 30,20 9,39 143,66 9,52 9,68 17,87
0 1 2 3 4 5 6 7 8	0 Hz	50 Hz noised 24,54 84,02 30,20 9,39 143,66 9,52 9,68 17,87 7,08
0 1 2 3 4 5 6 7 7 8 9	0 Hz	50 Hz noised 24,54 84,02 30,20 9,39 143,66 9,52 9,68 17,87 7,08 333,66
0 1 2 3 4 5 6 7 7 8 9 9	0 Hz	50 Hz noised 24,54 84,02 30,20 9,39 143,66 9,52 9,68 17,87 7,08 333,66 4,13
0 1 2 3 4 5 6 7 7 8 9 10 11	0 Hz	50 Hz noised 24,54 84,02 30,20 9,39 143,66 9,52 9,68 17,87 7,08 333,66 4,13 10,51
0 1 2 3 4 5 6 7 7 8 9 10 11 11		50 Hz noised 24,54 84,02 30,20 9,39 143,66 9,52 9,68 17,87 7,08 333,66 4,13 10,51 137,64
0 1 2 3 4 5 6 7 8 9 9 10 11 11 12 13	0 Hz	50 Hz noised 24,54 84,02 30,20 9,39 143,66 9,52 9,68 17,87 7,08 333,66 4,13 10,51 137,64 5,43
0 1 2 3 4 5 6 7 8 9 9 10 11 11 12 13 14		50 Hz noised 24,54 84,02 30,20 9,39 143,66 9,52 9,68 17,87 7,08 333,66 4,13 10,51 137,64 5,43 42,59

Simulation(4)



Simulation(5)

Monitoring & Control Standard values Using the power variable Led activation

	GPIO Port 3	I
	GPIO Configuration & Data	
	GP3DAT: 0xFF01FF01	
	31 Bits 24 Direction:	
	23 Bits 16	
ĺ	15 Bits	
	At Reset: VVVVVVVV	
	0x01 7 Bits 0	

Conclusions

Piezoelectric transducers

Suitable to be used as sensors

System Monitoring

- Condition diagnosis
- Timely repair
- Fault detection
- System type recognition

Keil-Uvision

- Capability of developing and simlating application
- Inputs Simulation
- Peripherals Simulation

Thank you for your attention.