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Fourier and Periodogram Transform Temperature Analysis in Soil

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Abstract
Fourier series and periodogram transform of three set of temperature data measured with constructed PIC 18F4520 based temperature meter were as interpreted. Measurement of 5-minute interval temperature variation with 3 LM34DZ sensors was made. The results show that Clay has the highest average Fourier transform (32.472) followed by loam (30.624) and sand (29.428). The periodogram analysis also varied in similar manner with clay having a mean periodogram 1899.97, loam 1694.84 and sand 1561.03. These show that temperature increasing most in clay caused higher values of Fourier and periodogram transforms. The average of the absolute deviation indicated loam has highest Fourier series changes (1.497) followed by sand (0.678) and clay (0.598) while the periodogram has deviation ranging from loam 165.48, sand 71.31 to clay 0.60. This indicates that loam soil has most sensitive response to temperature variations.

Keywords: *Soil Data, Fourier Transform, Temperature, Periodogram, Variation.*

I. Introduction

Temperature measurement on land can be affected by sideways or lateral and subsurface disturbances and field soils are heterogeneous in constituents. Sampling of soil and the temperature measurement in provides a best approach to eliminate error contribution from other materials. Time series analysis is associated with the time domain (i.e. trend component) and the frequency domain (i.e. periodic component). Temperature time series mainly consist of Trend component in the very short or daily duration and long run comprising of months' data with not so obvious periodicity.

Many years' data comprise of seasonal temperature associated with trend or a long term movement in a time series. It is the underlying direction (upward or downward) and rate of change in a time series, when allowance has been for random or chaotic residuals. They can account for less than a year's seasonal or cyclic component depending on the duration considered (Abdullah et al., 2009).

II. Material and Methods

The temperature sensor used is LM35DZ, P.I.C used is PIC18F4520 (programmed in C with MPLAB).

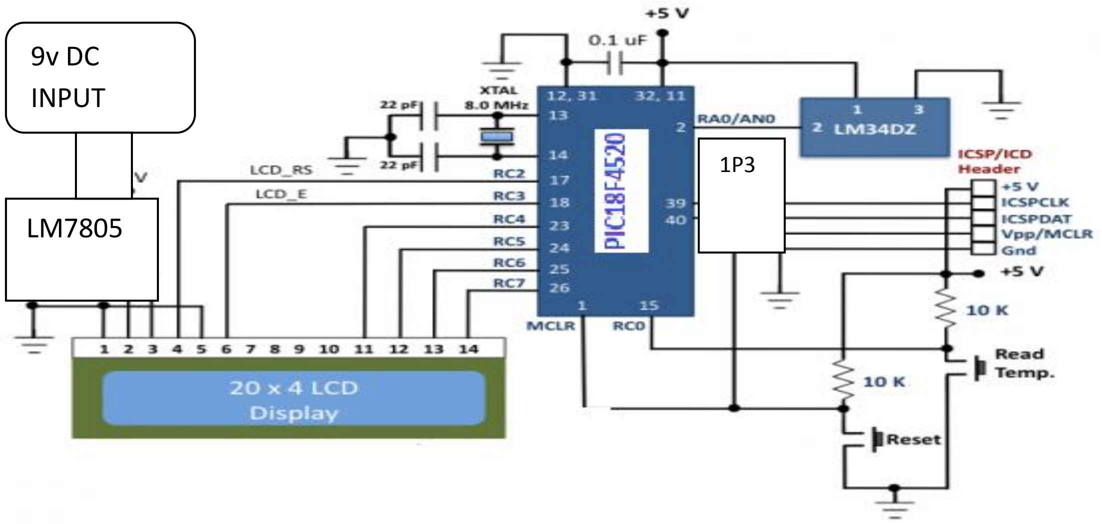

Fig.1 PIC18F4520 temperature circuit modified from http://embedded-lab.com, 2015.

The display is on 20x4 LCD. The whole constructed circuit was enclosed in a PVC case and the LCD was underneath a transparent Perspex cover. 2000 ml each of the 3 soils were mixed with 500ml water and the solution were put in a wooden box underlain inside with cellophane paper, each of all the three LM34DZ ICs 3 pins were insulated with thick masking tape away from the soil solution to avoid short circuit of the IC before the LM34DZ temperature sensors were immersed 1 cm into the soils. Temperature readings in centigrade were taken from the constructed temperature meter every 5 minutes from all the soils after switching with 1-pole 3-throw (1P3) switch (see Fig. 1) to the 3 LM34DZ sensors. .

III. Result and Discussion

The temperature data recorded from each soil are in Table 1. Soil temperature data recorded in 7th March, 2015 were checked and the data were consistent and continuous, Tushar and Keith, 2008

Table 1: Time temperature data for Sand, Loam and Clay Soils

Time	Time (MIN)	Sand Temperature (^oC)	Loam Temperature (^oC)	Clay Temperature (^oC)
11:55	5	27	26.9	31
12	10	27.8	27.9	31.7
12:05	15	28.7	28.1	31.9
12:10	20	28.8	28.9	32.9
12:15	25	28.8	29.9	33
12:20	30	29.9	29.7	33.9
12:25	35	29.8	29.8	32.9
12:30	40	29.9	30.9	32.9
12:35	45	30.1	29.7	32.9
12:40	50	29.9	28.8	33
12:45	55	29.1	30.1	33
12:50	60	30.9	29.7	32.8
12:55	65	30.8	30.9	32.8
13:00	70	29.9	29.9	32.7
13:05	75	29.8	30	32.8
13:10	80	29.8	30.8	32.8
13:15	85	29.9	31.7	32.8
13:20	90	29.8	32	32.7
13:25	95	29.7	32.9	32.8
13:30	100	29.9	32	32.1
13:35	105	29.8	31.8	32.8
13:40	110	28.9	32.8	31.9
13:45	115	28.8	32.9	30.9
13:50	120	28.8	33.9	30.9
13:55	125	29.1	33.6	31.9

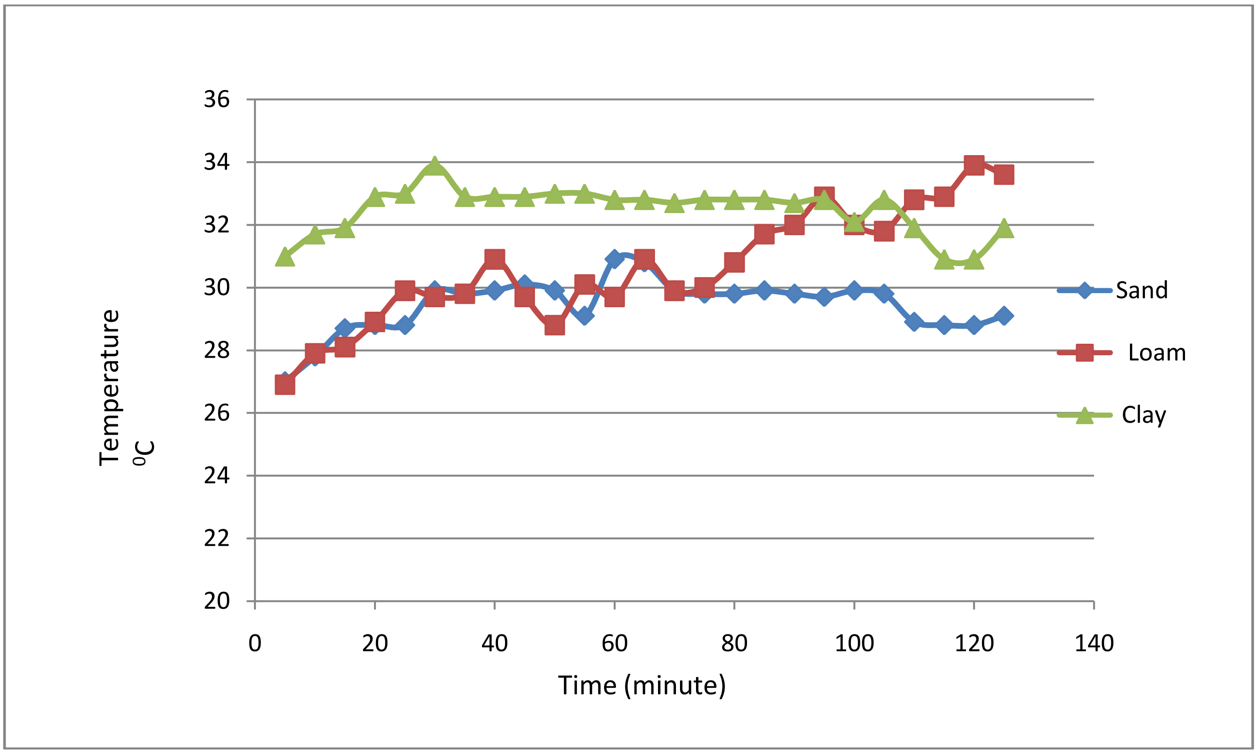

Fig.1 Temperature time series curves for sand, loam and clay

The temperature data showed Clay reached its maximum temperature of 33.9 ^{0}C faster than the other two soils at 12.20 pm followed by sand at 12.50 pm a maximum temperature of 30.9 ^{0}C. Loam took longest time to reach its initial maximum temperature of 33.9^{0}C at 13.50pm. The average temperatures recorded from the experiment are 29.428 sand, 30.624 loam and 32.472 clay.

The correlation of the 3 separate data shows that clay and sand vary similarly with Pearson correlation coefficient 0.66 in response to similar atmospheric condition while loam and clay do not correlate (-0.19). Sand and loam have low correlation of 0.28. The average of the absolute deviation from each of their mean shows that loam has highest temperature deviation with average absolute deviation 1.50 followed by sand 0.68 and clay 0.60. This means that the temperature of loam soil vary the most out of three soils considered.

Fourier Transform

Fourier transform (FT) is a mathematical function that can be used for mapping a time series from the time domain into the frequency domain. It decomposes a waveform or a function into sinusoids of different frequencies which sum to the original waveform. It distinguishes different frequency sinusoids and their respective amplitudes.

Fourier transform is expressed as x(t)→ X(f) according to

$$X(f) = \frac{1}{\sqrt{n}}\int_{t(0)}^{t(n)} x(t)\, e^{-i2\pi f t}\, dt \qquad \ldots 1.$$

for continuous function. The exponential involving $2\pi f t$ is θ in radian, simplified in form as

$$e^{i\theta} = \cos\theta + i\sin\theta \qquad \ldots 2.$$

A graph of the distribution of the Fourier coefficients in the complex plane is difficult to interpret (Abdullah et al., 2009). By using the real component of the sinusoid, and using the discrete form of equation 1 for a discrete process measured at equal intervals of time length, Δt, the discrete Fourier transform (DFT) is the outcome that is implemented as

$$\frac{1}{\sqrt{n}}\sum_{t(n=0)}^{t(n)} x(t) cos w \Delta t \qquad \ldots 3$$

For the soil temperature data with a finite sequence [xn] of sample from a series x(t), the discrete Fourier transform is defined by

X(f) $=\frac{1}{\sqrt{n}}\sum_{k=1}^{n=5} x(t) cos 2\pi \Delta t \frac{k}{n}$ ……………………………………………………………………………………………………4

Where k is k^{th} frequency sampled.

Periodogram

The complex magnitude squared of X(f) is called the power or periodogram . This strength of the periodic component is more often represented by the periodogram defined as

P(f)= $\left|\frac{1}{\sqrt{n}}\sum_{t(n=1)}^{t(n)} x(t)(cosw\Delta t - isinw\Delta t)^2\right.$……………………………………………………………………………….5

$P(f) = \frac{1}{n}\sum_{t(n=1)}^{t(5)}\{x(t)\}^2\{(cosw\Delta t)^2 + (sinw\Delta t)^2\}$……………………………………………………………….6

The real part of equation 6 can be implemented in Microsoft EXCEL as ((H3/SQRT(5))*COS(6.284*5)*(1/5+2/5+3/5+4/5+5/5)+SIN(6.284*5*(1/5+2/5+3/5+4/5+5/5)))^2with the procedure of equation 5. Equations 5 and 6 are calculated and shown in tables 2 to 4 following.

Table 2. Fourier transform of Sand, Loam and Clay's temperature

Time (MIN)	x(FS)	x(FL)	x(FC)
5	36.22407	36.0898	41.59052
10	37.2973	37.4315	42.52966
15	38.50477	37.6998	42.79799
20	38.63893	38.7731	44.13962
25	38.63893	40.1147	44.27378
30	40.11473	39.8464	45.48125
35	39.98056	39.9806	44.13962
40	40.11473	41.4564	44.13962
45	40.38305	39.8464	44.13962
50	40.11473	38.6389	44.27378
55	39.04142	40.3831	44.27378
60	41.45636	39.8464	44.00545
65	41.32219	41.4564	44.00545
70	40.11473	40.1147	43.87129
75	39.98056	40.2489	44.00545
80	39.98056	41.3222	44.00545
85	40.11473	42.5297	44.00545
90	39.98056	42.9321	43.87129
95	39.8464	44.1396	44.00545
100	40.11473	42.9321	43.06631
105	39.98056	42.6638	44.00545
110	38.7731	44.0055	42.79799
115	38.63893	44.1396	41.45636
120	38.63893	45.4812	41.45636
125	39.04142	45.0788	42.79799

Table 3. Periodogram of Sand, Loam and Clay's temperature

Time (MIN)	p(FS)	p(FL)	p(FC)
5	1313.064	1303.359	1730.788
10	1392.001	1402.03	1809.812
15	1483.559	1422.196	1832.714
20	1493.912	1504.301	1949.385
25	1493.912	1610.172	1961.25
30	1610.172	1588.71	2069.655
35	1599.423	1599.423	1949.385
40	1610.172	1719.643	1949.385
45	1631.778	1588.71	1949.385
50	1610.172	1493.912	1961.25
55	1525.187	1631.778	1961.25
60	1719.643	1588.71	1937.556
65	1708.534	1719.643	1937.556
70	1610.172	1610.172	1925.762
75	1599.423	1620.957	1937.556
80	1599.423	1708.534	1937.556
85	1610.172	1809.812	1937.556
90	1599.423	1844.219	1925.762
95	1588.71	1949.385	1937.556
100	1610.172	1844.219	1855.76
105	1599.423	1821.245	1937.556
110	1504.301	1937.556	1832.714
115	1493.912	1949.385	1719.643
120	1493.912	2069.655	1719.643
125	1525.187	2033.196	1832.714

The Fourier transform and Periodogram data from tables 2 and 3 are generally higher than the raw temperature data. They all show similar trends as the data they originated from. The Fourier transform correlation of sand and loam is low 0.279863 while that between loam and clay is the lowest -0.18981. The highest correlations of Fourier transform exist between clay and sand 0.6555599 while periodogram correlations are respectively similar but slightly lower (0.243921, -0.21756 and 0.650798). The transforms indicate that clay and sand temperature have similar response to external heat interaction while loam and clay do not have any similar response to heat as the negative correlation is too low for interpreting opposite response. This is conversely similar to the response between sand and loam with too low positive Fourier and Periodogram transforms.

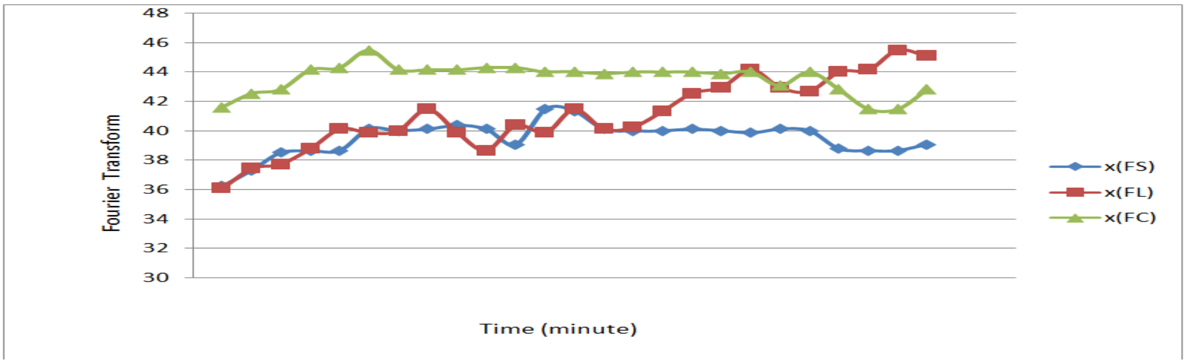

Fig.2 Fourier transform time series curves for sand, loam and clay

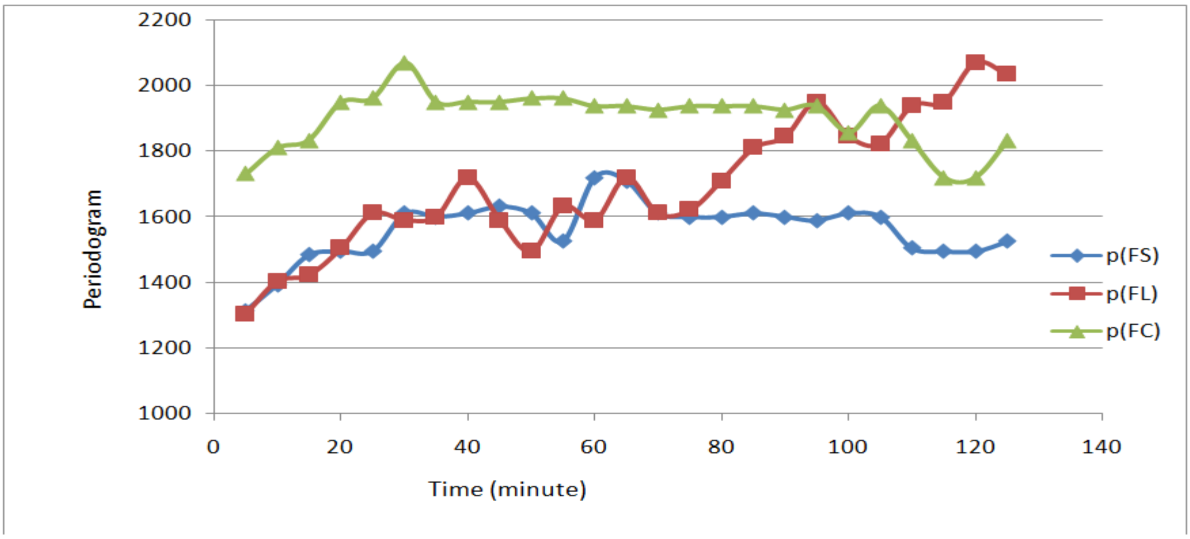

Fig.3. Periodogram time series curve for sand, loam and clay

The frequency curves of sand Periodogram data show clear changes due to temperature variation and the highest periodogram data occur in loam from 120th and 125th minutes corresponding to a time from 13.50 to 13.55 pm. Clay show early increase in Periodogram and frequency in the 30thminute or 12.20 pm. The periodogram and Fourier transform are useful to check interpretation error in the principal data and here they corroborate the earlier interpretation of soil, clay and sand temperature data and all the resulting curves.

IV. Conclusion

The 1 pole three throw switch temperature meter permitted the measurement of temperature in the samples of sand, loam and clay soils. Clay has the highest average temperature (32.472) followed by loam (30.624) and sand (29.428). The correlation of the 3 temperature data shows that clay and sand vary similarly with Pearson correlation coefficient 0.66 in response to similar atmospheric condition while loam and clay do not correlate (-0.19). Sand and loam have poor correlation of 0.28. The average of the absolute deviation indicated loam has highest temperature changes followed by sand and clay. This result is further confirmed by the Fourier transform and periodogram data that proved useful for investigating the interpretations from original data.

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