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Daylight Harvesting Control System

A novel and open source approach to a greener future

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***Abstract*— Alot is being talked about renewable energy, green energy, energy which is sustainable and inexpensive. The highlight in the 21st century has been the advent of growing energy needs, as our world continues to grow the need to conserve and effectively use our resources is tracing an exponential path. Current set ups in industry and residential premises are bringing rain water harvesting into their design, but they are leaving another source of energy whose potential is as enormous as the size of our universe, light. Daylight harvesting is an age old concept and can be traced down in history as it is embedded in the architecture of ancient civilizations. However our focus is to bring the limelight to a new, effective, and inexpensive and result driven method which will harvest daylight in real time and will eventually lead to thermal and visual comfort.**

***Keywords*— Green, sustainable, design, light, daylight harvesting, real time, thermal comfort, visual comfort.**

I. INTRODUCTION

The Earth receives about 174PW of energy on a daily basis and about 89PW of this energy is absorbed by land or by oceans[1]. It is needless to say that this energy is mostly untapped. For our study we will be considering the location of Manipal. Manipal is a university township located at 13.340°N; 74.7880° E. The average illuminance received at these coordinates is about 82,000 lux[2]. Daylight received is in abundance but there is no technology available to harvest this daylight, also the architecture of the buildings are such that emphasis on daylight for illumination of interior spaces in minimal and focus is more on artificial lighting. Too much daylight can result in glare or visual discomfort and concentration of light in a single space can cause localized thermal discomfort. However architecture of the room can play an important part in causing discomfort but to negate these effects we will be using adaptive motor controlled blinds and HVAC tuning to both harvest daylight and make the ambient indoor environment both thermally and visually comfortable[2].

II. DAYLIGHTING

A. Daylight factor

Daylight factor in lay man terms is basically the amount of natural daylight in a room on account of transmission through windows or other media if present. It is mathematically stated as

$$Daylight\ factor = \frac{Internal\ \ illuminance}{External\ \ illuminance} * 100$$
(1)

B. Light as dual nature of matter

Light is considered to possess dual nature i.e. it travels both as a wave and as a particle. This can be proved by using a simple Fresnel arrangement. When light is concentrated at a particular point. There is a significant change in the daylight factor at that point and the temperature at that point undergoes a ramp like increase. Photons release their energy on contact with the surface thus illuminating that point and excess energy is radiated in the form of heat. The spectral responsitivity curve shows normal distribution and the optical sensor grid shows a similar distribution when uncalibrated.

III. DAYLIGHT FACTOR CONTROL

The premise of our harvesting method is based on daylight factor control or daylight tuning. We will achieve this using an auto adaptive control strategy. This strategy will be employed to blinds. For our study we have considered vertical blinds. In this paper we will further see the effect of blind angle (ø) on illuminance and localized temperature of our model room. The model room in consideration is 3.75m×3.75m×2.5m and has two windows of dimensions 1.75m×1.75m, facing west and east respectively. In addition to controlling the blinds we will also tune our air conditioning system to maintain static conditions in the room. This is made to ensure that occupants of the said room are both thermally and visually comfortable. In simpler terms we are adjusting the internal illuminance using the motor controlled blinds by harnessing external – natural, sky illuminance thereby controlling daylight factor in the interior of the room.

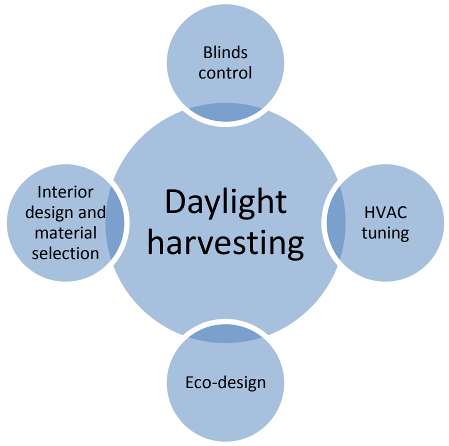

Fig. 1. Generalized theory behind daylight harvesting andit's prerequisites.

A. *Motor control*

The primary aim is to aid angular displacement of the blinds through certain angles ø. This angular displacement is only possible through a motor controlled drive system which couples the blinds mechanical drive system with the motors armature. The most important point here is that while coupling can be achieved in many ways it should be done effectively by not adding any weight to the already existing system. Addition of the system can result in instability and large errors and in control system terms will result in an extra unwanted zero.

Before setting up a drive system, the most important part is to conduct a study of the load characteristics. Load in this case will be the blinds itself. It was seen that the load is strictly frictional in nature. The effect of gravitational force was negligible compared to the friction offered against motion of the motor. Therefore to move the blinds by a certain angle, the initial toque required will be high and uniform and will later reduce as the motor gains momentum. Speed – torque characteristics for the load are given in the figure below.

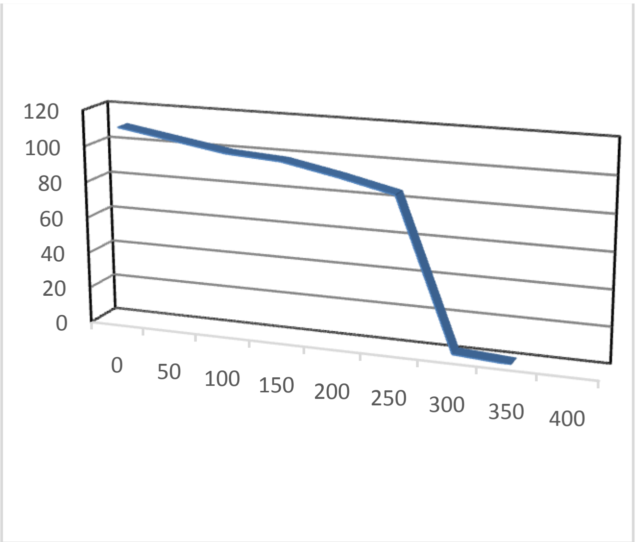

Fig. 2. % rated speed(rpm) vs. ratedtorque(N-m) for the load.

The figure above depicts a drooping nature for the load in terms of the speed vs. torque characteristics. Data acquired from sensors and various conventional techniques showed that the maximum slip in the case of this electromechanical system was roughly 18%. This is on the other hand acceptable as the system is complicated in nature. It only corroborates the fact that the system is robust and the systems design is well suited.

Design of the system should be such that weight of auxiliaries is as low as possible. This ensures robustness and stability during transition from one angle to the other. This also extends to it being portable and at the same time easily mountable. The heart of the entire system is an arduino board. The arduino is interfaced using LabVIEW and to allow bidirectional movement of the dc motor an H-bridge driver is used. Digital pulses are sent and received by the arduino and sensor data at the same time is acquired through the analog input ports. Typically speaking the system receives negative feedback from the sensor data acquired. However the main question here is on what basis is the motor causing angular displacement of the blind curtains? The answer is daylight tuning. Based upon how much light we want, the task to be performed in the room, we can set how much illuminance is required. An optical sensor arrangement consisting of a photodiode and a phototransistor are placed exactly at the center of the room. The data from that sensor arrangement is acquired through a data acquisition card and then read through LabVIEW. Sky illuminance is calculated by calibrating a typical 6V – 1W solar cell against a standard lux meter. Hence we are invariably using dual loop technology [3]. Once sky illuminance is known and the user feeds the illuminance value he or she wants to maintain, the motor will be activated to move in the appropriate direction and thus result in the blinds moving through a certain angle. Once the input and output come within a certain acceptable range i.e. 1% of the actual value inputted the motor will stop. Changes in weather might take place during the course of the day, so the blinds are made to move so that illuminance is maintained and daylight factor is relatively constant. However when the conditions outside are overcast and the sky illuminance is not enough to illuminate the room, the system will automatically detect this and will thereafter run in standby, thus saving energy. The system has an internal mechanism to check the sky illuminance for changes every few minutes. This can be changed depending on user requirements. Schematic of the design is given in the figure below, exclusive of the central optical sensor gird whose data is acquired through a data acquisition card.

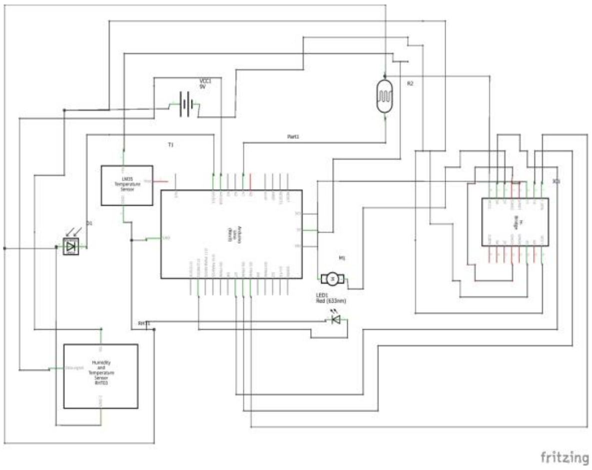

Fig.3. Printed circuit board schematic of the auxiliary system

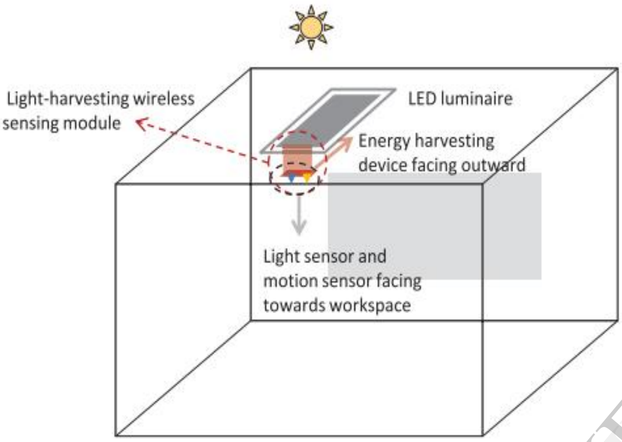

Fig. 4. Generalized system architecture

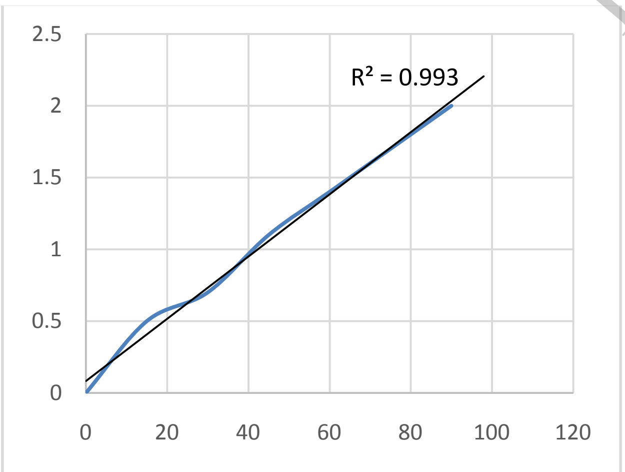

Fig. 5. Time (s) vs. blind angle (ø)

In the figure above we can see that time taken vs. change in blind angle is almost linear in nature, in fact the R^2 value is 99.34%, a great deal of linearity. It must be noted that the for calculation of time taken for each step increase in blind angle the corresponding value from the time axis should be subtracted. The black line in the figure above shows the trend and it can also be seen that it at ø =0° the time taken for moving to the next integral angle involves a small but definite time lag τ. This can be attributed to the frictional nature of the load.

B. Blinds and windows

On an average in Manipal we receive about 550W of infrared per square meter on the surface of the earth. This causes large amounts of solar gain to heat up localized environments. Blinds and windows are important not only from an aesthetic or functional point of view but also serve the purpose of blocking infrared radiation and thus reducing localized thermal gain.

Blinds should be preferably vertical in nature. This is because vertical blinds have better adjustment times compared to horizontal blinds. They should also be strictly in shades of white and should have a low value of transmittance. Deployment of blinds is important as improper positioning can cause increased solar gains and also to a small extent, glare.

Windows have been part of architecture since ancient times in order to provide illuminance to areas of human habitat. However ancient drawings show large windows i.e. length is greater than the width and a parapet. This has been scientifically proven that large rectangular windows are better for providing daylight than other variants[3]. To block infrared radiation and reduce solar thermal gain the use of tinted paper is highly recommended[4].

C. Visual comfort

Since we are dealing with daylight, visual comfort is an important parameter of concern. Daylight can be made available through various techniques, however the effect of day lighting must not affect glare. The international standards on illumination engineering suggest that glare must not exceed a UGR of 28[2]. In terms of visual comfort probability our model room has always maintained a VCP of 78% at minimum.

D. Thermal comfort

Solar gain is the primary source of heat being trapped in a room. Since light has dual nature and excess or very little heat can cause discomfort, thermal comfort is another important parameter of concern. Thermal comfort has to be seen with respect to three analog parameters i.e. temperature, relative humidity and thermal gain, sensors to tap these analog values have been incorporated in the design and interfaced with LabVIEW and the arduino board. The comfort indexes which serve the purpose of study and evaluation are PMV and PPD. The PMV index has a range of -3 to +3 with 0 indicating thermal neutrality. Negative PMV implies feeling cold whereas a positive value implies feeling hot, even though hot and cold are relative terms. PPD on the other hand shows the percentage of dissatisfied people at a particular PMV. It is denoted as a percentage and the value 5% is indicative of thermal neutrality[5]. The tables below give us an overview of relative humidity, temperature, PMV and PPD at different values of ø.

TABLE I. PMV & PPD at 22°C

Blind angle (ø)	*0°*	*15°*	*30°*	*45°*	*60°*	*75°*	*90°*
RH in %	33	38	43	65	40	33	24
P.M.V	-0.4	-0.4	-0.3	-0.2	-0.4	-0.4	-0.5
P.P.D	8.3	8.3	6.9	5.8	8.3	8.3	10.2

TABLE II. PMV & PPD at 24°C

Blind angle (ø)	*0°*	*15°*	*30°*	*45°*	*60°*	*75°*	*90°*
RH in %	33	37	39	54	48	40	33
P.M.V	-0.1	0.1	0.1	0	0.1	-0.1	-0.1
P.P.D	5.2	5.2	5.2	5	5.2	5.2	5.2

TABLE III. PMV & PPD at 26°C

Blind angle (ø)	*0°*	*15°*	*30°*	*45°*	*60°*	*75°*	*90°*
RH in %	33	32	52	67	48	35	23
P.M.V	0.2	0.2	0.4	0.3	0.3	0.2	0.2
P.P.D	5.8	5.8	8.3	10.2	6.9	5.8	5.8

TABLE IV. PMV & PPD at 28°C

Blind angle (ø)	*0°*	*15°*	*30°*	*45°*	*60°*	*75°*	*90°*
RH in %	33	36	33	63	45	35	31
P.M.V	0.2	0.2	0.5	0.8	0.6	0.5	0.5
P.P.D	5.8	5.8	10.2	18.5	12.5	10.2	10.2

From the tables above it can be observed that at a temperature of 24°C, blind angles 30° through 60° are most comfortable. PMV and PPD for these conditions average 0.067 and 5.13% respectively. Hence, strictly speaking we are in the comfort zone[2]. Temperature is maintained fairly constant using an air conditioning unit. Static conditions are maintained however the control system is dynamic in nature and adjusts angular displacement of the blinds according to the ambient set temperature.

On the other hand if we look at hourly thermal gains, without air conditioning we will definitely reach a point of discomfort. This can be seen from the figure below.

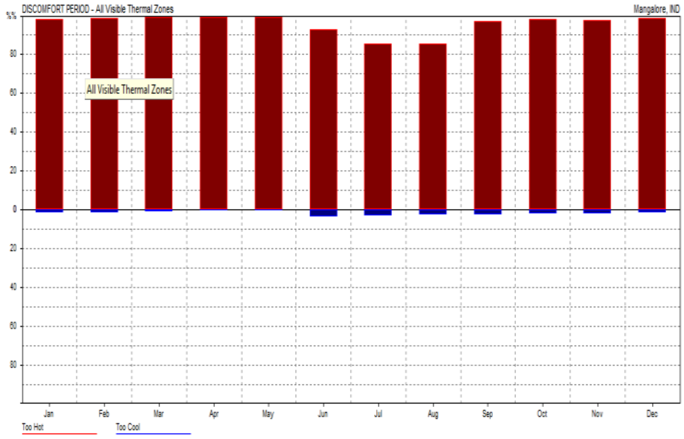

Fig. 6. Discomfort on account of thermal gain without air conditioning.

Turning on the air conditioning unit in this case is a viable option however it adds to thermal gain as on calculation of total thermal gain installation wattage has to be taken into account. In addition to this there is also significant energy consumption, but this can be offset to small extent by using an appropriate strategy for harvesting daylight and incorporation of the same in the physical architecture of the room.

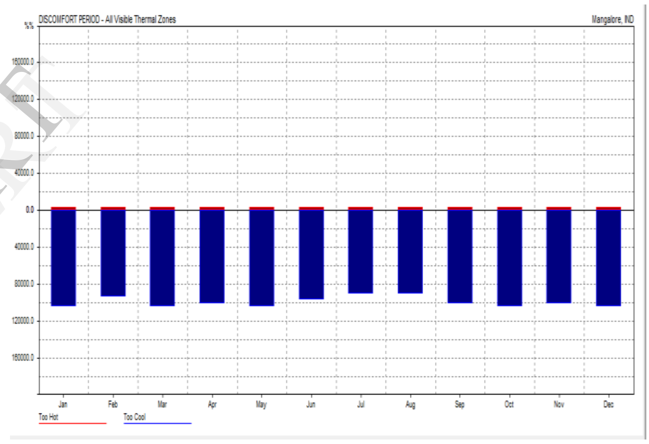

Fig. 7. Discomfort on account of thermal gain with air conditioning.

In the figure above we can see that discomfort is negative when the air conditioning unit is switched on. If we see the trend line it is analogous to a normal distribution curve. Please note that discomfort is expressed as a percentage of a percentage. On an average the discomfort for every month of the year is approximately 10%. This is acceptable as we are closer to thermal neutrality and the system is clearly responding well to any external changes in temperature and sky illuminance. The air conditioning unit is tuned by using an IR transmitter and receiver which is interfaced with the arduino board. The temperature of the room to be set is decided by the user and the arduino sends and receives signals and maintains the temperature in the room by cycling close to the set point temperature.

E. Energy savings

Energy savings are an important factor in the development of any electronic system. To start off, the auxiliary blind system is remotely powered by a battery. The dc motor which is mechanically coupled to the rotating shaft is usually at rest unless sky illuminance dips and the blinds need to be opening further more to allow more light in the room. When the motor is given the command to move, soft switching takes place.

Energy can also be saved by using commercially manufactured tinted paper on the windows. This will block almost 71% of infrared which enter the room otherwise. This in turn reduces thermal load and thus the air conditioning unit is virtually saving a few units of power.

Consider the case of an office room. Working hours are usually fixed and most hours fall during the course of the day. Using a morning warm up situation for the system it was seen that the system worked with greater efficacy than before[6]. This ensured that heating and cooling was cycled in an energy efficient manner without compromising on thermal or visual comfort. In morning warm up the control system was made to start about fifteen minutes prior to occupancy. This ensured that by the time someone enters the room, the conditions were favorable and comfortable. This saves time and increases human work efficacy by over 80%.

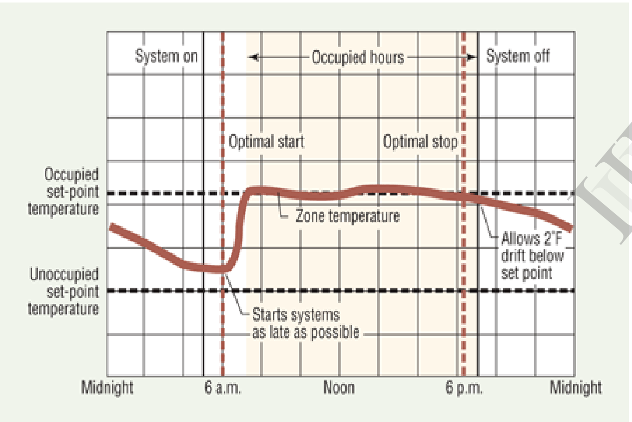

Fig. 8. Morning warm up for the control system.

IV. Analysis and Suggestions

On analysis of the data procured and the nature of curves plotted against various parameters we feel that certain emphasis must be given to electronic architecture and design of systems in general. This will facilitate better designed products which are eco-friendly, inexpensive and at the same time reliable and efficient. Electronic design has become advanced on many accounts. Production has become faster and automation has provided standardization in spite of large throughputs. However, we must not neglect the environment in our quest for growth and prosperity, hence we our thus laying the foundation for green architectural design in electronic control systems and also putting emphasis on co-design for the ultimate goal of reaching a lower carbon footprint on a global scale.

A. Green architecture

Development of modern control systems are crucial in many ways to mankind, however the effect of these systems may or may not affect the environment. It is thus for this reason that green architecture has become an important part of electronic system design and deployment.

We are dealing with natural daylight, energy which is everlasting and is absolutely clean to use. It has positive effects on the environment and is essential for all living organisms to survive. The principles of green energy are not violated by using sun light. In fact it is crucial that we learn to use this source of energy for meeting our growing energy needs.

The principles of green architecture should be tuned to the same frequency of the following points

- Material used should be eco-friendly and comply with both the ROHS and ISO standards.
- The end product must be able to harness at least one form of renewable energy.
- The end product should not produce any kinds of effluent either in the form of solid, liquid or gas.
- The end product should be light in weight unless in the case of macro designs.
- The end product should be portable unless in the case of macro designs.
- The end product must be made out of 85% material which is non- toxic in nature in its pure form.
- The space occupied by the end product must not exceed 125% of the total area of each individual entity unless in the case of macro designs.

It has been previously stated that tinted paper reduces the infrared entering the room by almost 71%. This in turn if we consider that each unit of energy costs Rs.12/unit then carbon emissions will reduce by almost 3125lbs and annual savings in energy amount to approximately Rs.25000[4]. This only adds to our index of green architecture and by extension green technology. It is a matter of pride to consider that our control system is complaint with all the above said standards.

B. Co-design method

Co-design is always a better way to go about things especially if you're in the intital stages of product development[8]. Even though the control system is light, portable etc. it is still auxilliary in nature and it only facilitates harvesting of daylight. However, if daylighting were to be incorporated in architectural design it could remove the need for having an auxilliary system for the same. In this case we should consider the incorporation of solar tubes and or fenestrations. Co-design method incorporates size and nature of exteriors and interiors. In our case we recommend using non polarizing material, anti-glare paints, light shades of color, energy efficicient gadgets to name a few[9].

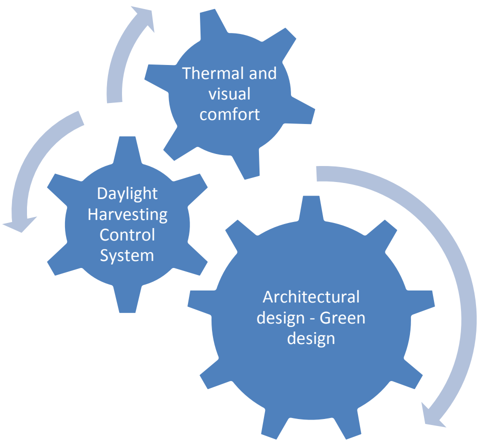

Fig. 9. Co-design metric

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REFERENCES

[1] www.climatecontrolme.com/

[2] Raafe Karim Khan, Sandhyalaxmi G Navada . " *Thermal - Visual Comfort Analysis* ", Vol. 3 - Issue 8 (August - 2014), International Journal of Engineering Research & Technology (IJERT) , ISSN: 2278-0181 , www.ijert.org

[3] Shailesh K.R;Raikar T.S.,"Computational analysis of daylight harvesting scheme in an office building in Mumbai",Sustainable Energy Technologies (ICSET), 2010 IEEE International Conference, pp. 1-8, 2010.

[4] http//solutions.3m.com/wps/portal/3M/en_US/mWindowFilm/Solutions/Residential/

[5] P.O Fanger, *Thermal Comfort, Analysis and application in Environmental Engineering*, McGraw Hill, 1972

[6] www.pnl.gov/buildingretuning/documents/pnnl_sa_85194.pdf

[7] http://hpac.com/ventilation-iaq/energy-saving-rooftop-vav-0429

[8] Pil-Ju Park, Kun-Mo Lee, "Development of ecodesign method for electronic products", Environmentally Conscious Design and Inverse Manufacturing, 2003, pp.381-382

[9] The Lighting Handbook, 10th Edition – IES – Illumination Engineering, www.ies.org/handbook.

[10] Ashish Pandharipande, Shuai Li, "Light harvesting wireless sensors for indoor lighting control, IEEE Sensors Journal, Vol. 13, No.12, December 2013, pp.4599-4606.