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Analysis and Design of IoT Enabled Low Cost Distributed Angle Measurement System

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Abstract: Linear Fresnel Reflector (LFR) is a recent technology with good potential in small scale solar power applications. It is arranged from many long row segments of mirrors that focus the sunlight onto a fixed elevated tubular receiver. Mirror segments are aligned horizontally and track the sun such that the receiver is illuminated without the need of being moved. The efficiency at which LFR can convert solar to thermal energy depends on the accuracy of the sun tracking system. To maximize the degree of sunlight capture, a precise solar tracking is needed with the goal adequately focusing incident solar rays to the focal point given by the location of the tubular receiver. The tilt angles of each row are relevant for the tracking controller in order to achieve correct positioning. Encoders generally are employed in the closed-loop tracking systems as feedback signals used to inform the controller with the actual position of collector mirrors. Recently inclinometers have begun to largely replace encoders as the most viable and cost-effective sensor technology solution which offer the capacity for simpler and precise feedback, as they measure the angle of tilt with respect to gravity and provides the ability to adjust system to the optimal angle for maximizing output. This paper presents the research results on the development of remote measurements for the precise control of LFR tracking system, by using distributed angle measurements. The applied methodology enables the precision measurement LFR inclination angles through the fusion of data from multiple accelerometers, supported by low cost wireless transceivers in a wireless sensor network, capable of exchanging information in cloud infrastructure.

Keywords: Distributed Angle Measurement; Linear Fresnel Reflector; Wireless Sensor Network; IoT

1. Introduction

Linear Fresnel Reflector (LFR) solar thermal system is a promising technology in solar thermal application that has taken a significant attention recently especially in a small-scale size with heat output in the range of 150–300 C [1]. It is arranged in several long row segments of flat or slightly concave mirrors that focus the sunlight onto a fixed elevated tubular receiver running parallel to the reflector rotational axis. Mirror segments are aligned horizontally and track the sun such that the receiver is illuminated without the need of being moved. The heat transfer fluid (HTF) inside the receiver is heated up to a reference temperature, then it is directly used to run a thermodynamic power cycle to heat another working fluid through a heat exchanger. A sun tracking system is provided to allow the mirror segments to rotate around an axis parallel to the receiver. The accuracy of the solar tracker is a key parameter to maximize the solar collector efficiency.

Several solar controlling and tracking systems of LFR have been developed which can be classified according to their degrees of freedom or/and control system strategy. Regarding the degree of freedom, there are two main types of tracking systems; single-axis trackers and dual-axis trackers. LFR systems are usually installed with one-axis tracking [2–5], however, recently, two-axis tracking system has been used to improve the optical efficiency of LFR systems [6,7]. Regarding the control strategy, two main types open-loop [6–8] and closed-loop controlled trackers [5,9,10]. In open loop tracking system, mathematical calculations of the sun position are applied without any feedback signal. In [4] an open loop control tracking system is proposed, consisting of a microcontroller board, Arduino UNO, and one stepper motor for all mirror rows which were connected by a sprocket–roller chain system. In [8] the tracking system of 50 lines of LFR mirrors achieved using the concept of parallelogram linkage mechanism (double crank mechanism) where the motion transmitted to a single tube by a gear mechanism is transmitted equally to all the other tubes. The gears are rotated at the rate of 150 per hour by a small motor. In closed loop tracking systems, feedback signal from sensors are used to determine how to drive the actuators and position the tracker structure. Few closed loop control methods are applied.

The system described in [2] used an electric motor for each of 10 mirror rows, while the optical model was used to calculate the tilt angle for each row. While [3] proposed a mechanical system for the tracking system using sprocket and chain drive transmission mechanism driven by a stepper motor for each mirror row. Encoder and Limit Switch were used for determining the rotational position of the each row.

In [5] the tracking system of 10 lines of LFR mirrors composed of ten parallel lever arms, one for each line, connected by the actuator bar. The projected mechanism can rotate the mirror lines by 80°, tracking the sun almost the entire day, form -80° to 80°. A PWM speed controller was used to decrease even more the speed of the actuator, increasing the position controllability accuracy. The tracking mechanism uses only one motor to move all mirror lines with one inclinometer installed at the second line of the collector. The system described in [9] proposed a tracking system of 11 lines of LFR mirrors divided into two rows using a drive actuator for each mirrors' row to move independently of the adjacent ones. Each mirror row is equipped with a potentiometer, to determine the current position of the mirrors. In [10] each mirror row is equipped with a potentiometer to provide a feedback measure of the actual position of the mirror rows during operation with accuracy of 0.1º.

From literature review it is clear that, the applied solar tracking systems for LFR plant use only one accelerometer either for the whole plant or for each row for providing a feedback signal about real position of mirrors. It means that in the case of some problem such as wear and tear in the tracking system mechanism, erroneous angular readings are detected after a long time and result in inaccurate tracking of the sun position.

This paper describes methodology to improve the tracking accuracy of LFR plant. The proposed system involves using multi accelerometer for each row of LFR plant instead of one, providing a more robust angular reading. Moreover, the collected data is transmitted over a wireless sensor network a communication gateway instead of using a wired system approach. It is relatively simple and cheap system as the price of the accelerometer in this paper is about 5UER.

The proposed LFR plant is installed in SEKEM medical center near Belbis city, Egypt. It is a multi-generation solar plant consists of LFR solar collector, thermocline storage tank, Organic Rankine Cycle (ORC) and Thermally Driven Chiller (TDC) as shown in figure.1. The solar field consists of 13 modules with a total collector area of 296 m2; one basic IFC-1832 solar collector module has approximately a total length of 4 m and 18 rows of mirrors, each 0.32 m wide [11]. Each mirror is produced with a specific curvature to focus the reflected beams into the absorber tube.

Figure 1. SEKEM LFR multi-generation plant.

2. Materials and Methods

To verify the proposed system, the accelerometers performance in a real environment, a small WSN network consisting on a gateway and four nodes was deployed on PV panel. Each node consists of Arduino Uno with XBee module and 3-axis accelerometer as shown in Figure 2. Two different low power consumption accelerometers have been used:

- FXLN8361: low power consumption with high precision 3-Axis acceleration sensor measure the acceleration during the object motion with optional sensitivity of ±2g/8g.
- LIS2DH: ultra low-power high-performance 3-Axis accelerometer which is based on MEMS. The module is fitted with a Gravity I2C interface with optional sensitivity of ± 2g/± 4g/± 8g/± 16g.

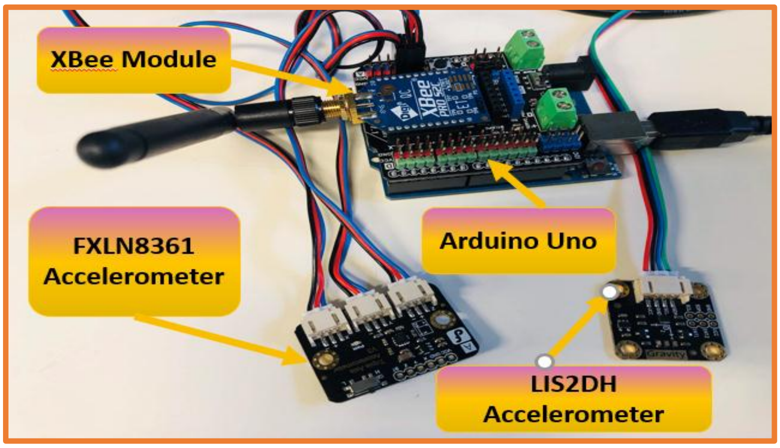

Figure 2. Schematic of the implemented distributed angular data acquisition system (prior to enclosure).

The first step is to test our methodology on photovoltaic (PV) panel installed on a roof at the JdA building of the Public University of Navarre (UPNA). It has a similar structure like LFR structure, where it consists of one moving structure for three PV panels from Romag as seen in Figure 3. One is made with monocrystalline silicon technology, model SMT 180M (5165) with peak power of 170 W and the other two are polycrystalline, model SMT 155P with peak power of 155 W. The accelerometers are distributed on the PV panel structure where nodes 1 & 2 are connected to LIS2DH accelerometers and nodes 3 & 4 are connected to FXLN8361accelerometers, which are located on the backside of PV panels.

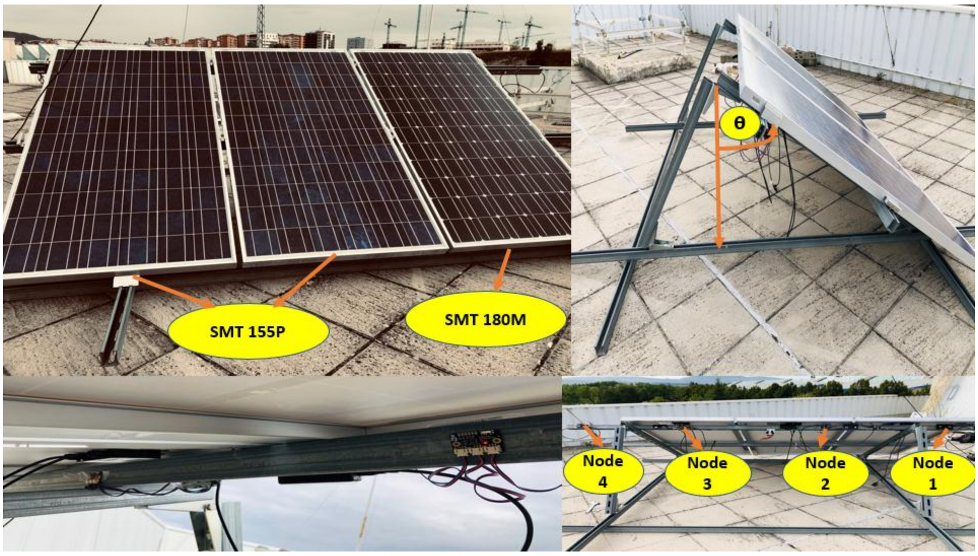

Figure 3. Experimental setup within the JdA building (UPNA).

The 3-axis accelerometer contains 3 analog outputs for X, Y, Z axis accelerations which are converted into angles in relation to each axis. The output voltages are connected to the analog inputs of Arduino UNO to be measured. Tilt angle measurement requires initial calibration, based on gravity effect for each accelerometer. The tilt angles are given by:

$$\theta = \tan^{-1}\left(\frac{X}{\sqrt{Y^2 + Z^2}}\right)$$

$$\Psi = \tan^{-1}\left(\frac{Y}{\sqrt{X^2 + Z^2}}\right) \quad (1)$$

$$\Phi = \tan^{-1}\left(\frac{\sqrt{X^2 + Y^2}}{Z}\right)$$

where θ as the angle between the horizon and the *x*-axis of the accelerometer, ψ as the angle between the horizon and the *y*-axis of the accelerometer, and ϕ as the angle between the gravity vector and the *z*-axis, as shown schematically in Figure 4. The tilt angle data from all the nodes is sent via wireless sensor network to the communication gateway, in order to enable further processing and angle data verification.

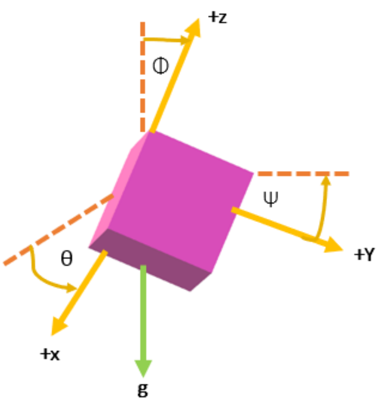

Figure 4. Schematic of Tilt angles and corresponding axis.

3. Results

In this paper we will deal with single axis tracking system where the effective tilt angle is θ (the use of other angles will be discussed in future works). The data for the position of nodes1 & 4 were registered every 1 s, while the data for the position of nodes 2 & 3 were registered every 2 min, as shown in Figure 5. The observed measured accelerometer data is noisy, requiring further data filtering. For θ = 68.7° maximum and minimum data from node1 are 75.1° and 66.8°, for node2 are 72.4° and 71.3°, for node3 are 71.5° and 70.8°, node4 are 72.7° and 70.5°. For θ = 68.2° maximum and minimum data from node1 are 75.1° and 66.8°, for node2 are 76.9° and 69.5°, for node3 are 70° and 70.4°, node4 are 74.7° and 68°. For θ = 60.6° maximum and minimum data from node1 are 60.3° and 63.5°, for node2 are 66.5° and 63.3°, for node3 are 64.4° and 63.9°, node4 are 64.5° and 64°. For θ = 50.5° maximum and minimum data from node1 are 55.3° and 47.5°, for node2 are 55.2° and 50.1°, for node3 are 53.7° and 52.3°, node4 are 54° and 51.4°. Data from both LIS2DH accelerometers have presented more variation in tilt angle than FXLN8361 accelerometers. On the other hand, nodes with sample time of 2 s have smaller variation in measured angle than that with 1 s. In relation to one inclination angle, it can be seen that there are variation in measured angles from each, proving the previous assumption.

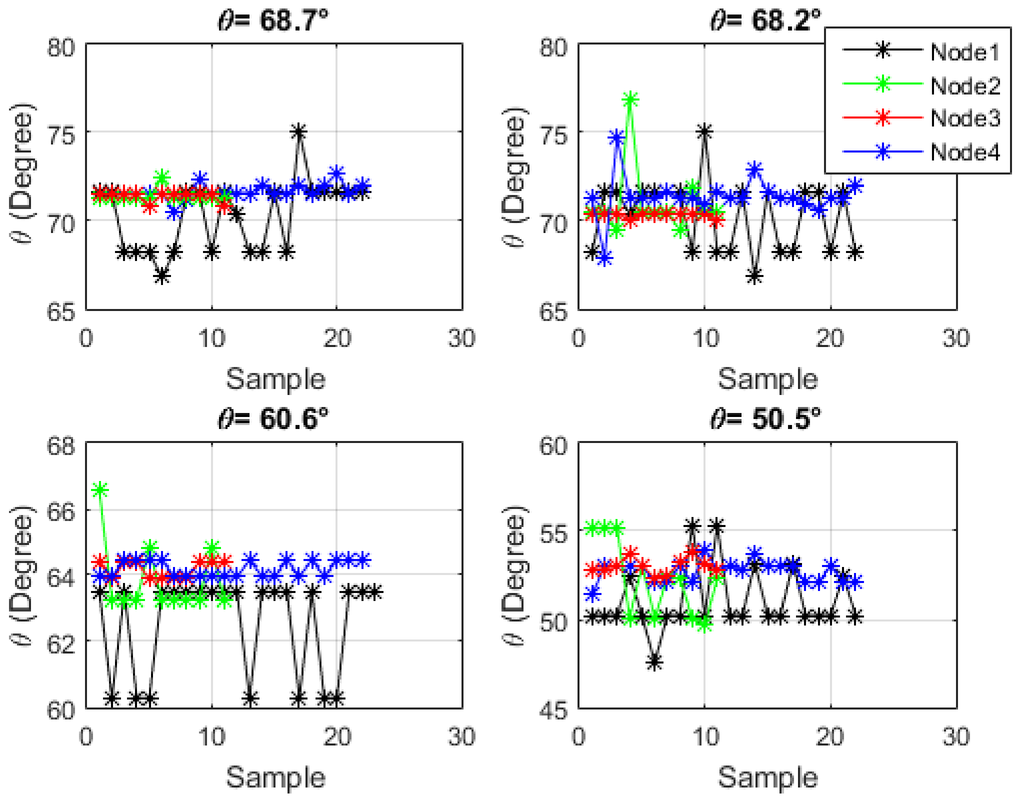

Figure 5. Collected data from each node as a function of subtended angle.

4. Discussion

Most of the solar tracking systems of LFR plant use one feedback signal of the current position for the whole plant or for each row, which can provide inaccurate position for the control system. This paper describes a system that can be used to supervise the tracking system of solar collectors with long mirror structures, by means of distributed tilt angles measurement devices easy to implement with low energy consumption and low cost. The proposed system employs a XBee ZigBee wireless sensor network to transmit the measured tilt angles using accelerometers to a monitoring server at a remote location. Thus in case of misalignment, it is possible to take the average value the distributed angle measurement data to increase the efficiency of the plant. Moreover, the proposed system can also aid in fault detection of the mirror mechanical systems, enabling flexible alarm transmission.

Several experimental tests were performed at different inclination angles. The experiment shows that data collected from FXLN8361accelerometers is better than data from LIS2DH accelerometers. However, the mean value for a number of samples must be calculated to cancel the effect of the presented noise. Moreover, the node with larger sample time was less affected with noise than that with smallest one. This was an important step on the development of WSN accelerometers that will be applied further on all rows of linear Fresnel concentrator plant.

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