Design & Development of Low Cost Solar Tracker Using Microcontroller

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Abstract

This Paper covers the control system design and implementation of the Sun-tracker. The approach presented is simple and low cost for domestic application. Digital control implementation make system works in adverse conditions. Dynamics of solar panel mount are discussed and sun sensor design is presented. PD controller is designed to decrease oscillations and reduce settling time up to 2s. Battery charging circuit designed is incorporated with features like battery thermal protection, day/night switching and battery voltage level display.

Keywords —Solar Tracker, PD controller, Sensor differential configuration, Microcontroller, Sampling time, Control Algorithm

I. Nomenclature

PD	Proportional Derivative
ω	Angular Speed
V	Voltage
T_P	Peak Time
T_S	Settling Time
G_C	Controller Transfer Function
ADC	Analog to Digital Converter
$e(t)$	Error Signal
T	Sampling Time

Introduction

The ever increasing demand for energy and depletion of the fossil fuel reservoirs pushed the researchers and scientist to search for other energy sources. Among different candidates for alternative energy, solar power is the dominating one. Work has being done on the development of photo sensitive material to` get maximum conversion efficiency. With sufficient R&D and budget, to this date solar cells commercially available are 19% efficient [1].

Sun tracking techniques can add in this regards with low budgeting. Much of research has been published on sun tracking and there are lots of patents. Bulks of companies are developing sun trackers for commercial use by passive or active techniques. Sun-tracking generally increase power upto 30 to 40% [2].

Active techniques are based on intelligent control systems as described in [1]. Tracking systems that use predefined sun position information is presented in [3]. There are some trackers, with their control systems based on FPGA [4]. An optimized solution based on Genetic Algorithm is presented in [5]. Microprocessor based solar tracker using stepper motor have also been proposed in [6].

This paper presents the design of a reliable, intelligent and cheaper control system for sun tracking using industrial grade microcontroller. Based on the components being used; this system is low cost and implementation requires less complexity that makes it suitable for domestic applications.

Control system operates through the battery which is being charged by solar panel. Two parts of tracking system include automatic battery charging circuit and control circuit. Charging circuit has temperature sensor for battery thermal protection and light sensor for Day/Night switching. Seven-segment display has been used to display the battery voltage.

Control unit consists of microcontroller-based closed loop control unit that aligns the solar panel towards the sun by determining it real time position. A prototype has been built and control system has been successfully tested for required results.

This innovation will surly add to fulfilling the energy demand of Pakistan.

System Design

System design is based on the stepper motor. Individual transfer function of the motor is not feasible as driven load can affect the back EMF in windings, therefore complete transfer function is incorporated by including current model, gears and mount shaft of solar panel. Gears transmit power through timer belt which reduced the possibility of lag generation. Panel shaft is modeled as an inertial element with friction. Block diagram of complete mechanical system is shown in Fig.1 (angular speed transfer function of the system ω/V).

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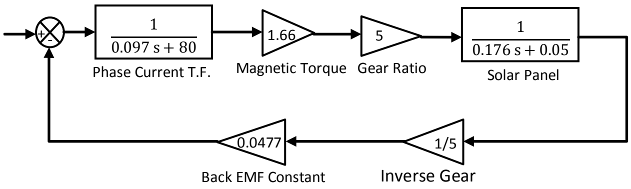

Fig.1: Motor transfer function

Sun sensor is made using light dependent resistors (LDR). Differential sensor configuration presented in [7] is used. When there is offset in sun incident angle; error signal will increase or decrease across a midpoint value (voltage at perfect alignment) depending on the direction of offset. When such a sensor is placed on rotating shaft being controlled, there will be an inherent feedback property in the system and system is stable with no steady state error. Fig.2 represents system block diagram with differential sun sensor.

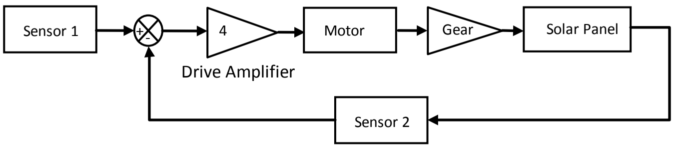

Fig.2: Feedback system

System dynamics incorporates solar panel (Inertial mass) mounted on torsional rod; with two complex poles. Such system exhibits oscillatory response with settling time up to 28s. Step response of the system is shown in Fig.3

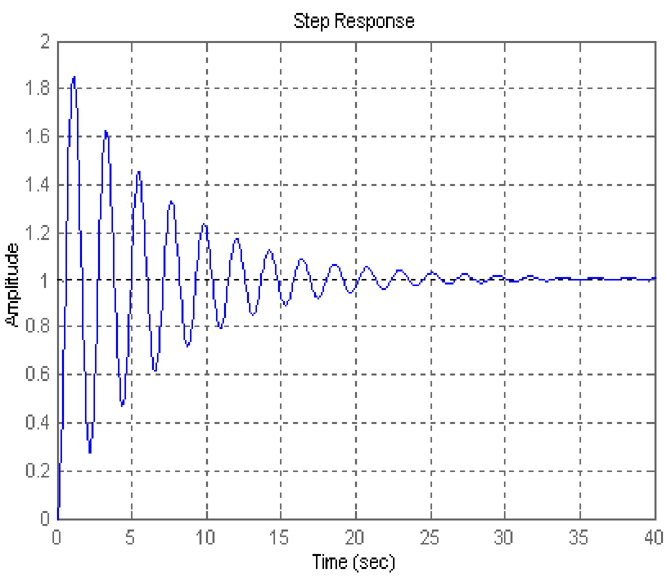

Fig.3: Uncompensated response

Controller Design

Proportional derivative (PD) control is implemented to reduce settling time, because oscillatory response required derivative control and integral control is not necessary in loop (Fig.4) as there is no steady state error.

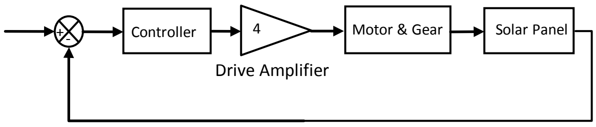

Fig.4: Control loop

Desired peak time (TP) and settling time (TS) specifications are 1 and 2 seconds respectively. Controller is designed to meet response criteria using root locus technique (Fig.5), placing a zero and tuning gain. Controller equation is given (1);

$$G_c = 1.82\,(s+5.07) \qquad (1)$$

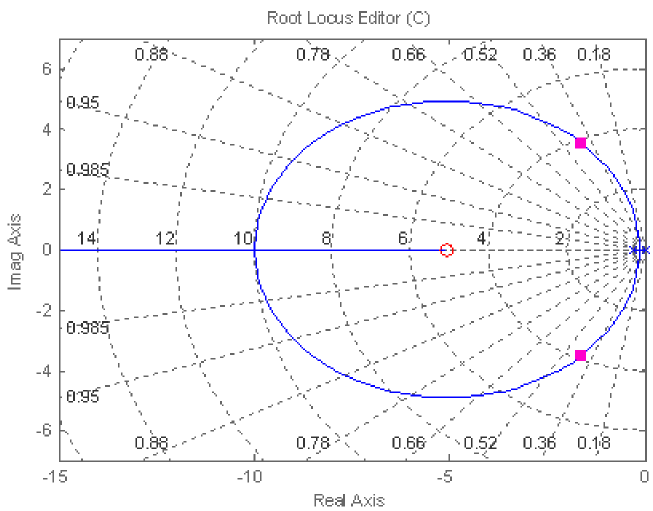

Fig.5: Root locus design

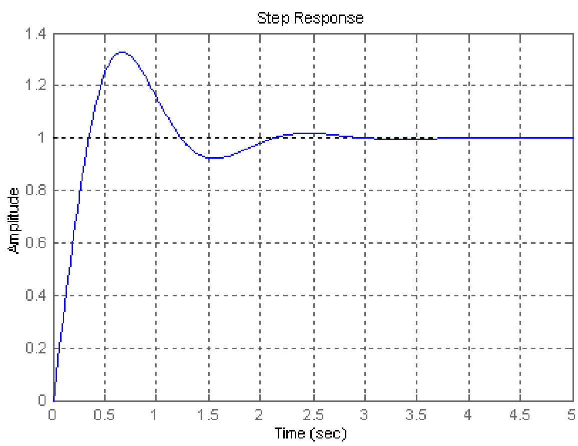

Fig.6: Compensated response

Fig.6 shows compensated response of the system; settling time is improved from 28s to 2s.

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Implementation

Control system is designed in complex domain using continuous system approach; however, the system is implemented using digital components (ADC & Microcontroller). There are two sampling times in loop: ADC-0804 has 110µs (free-mode operation [8]) and PD control subroutine designed takes 20ms on Atmel-89c51 with a 12MHz oscillator (measured using oscilloscope). System peak time (1s) is much higher than the two sampling times; therefore, designed controller is considered to be valid for digital controller implementation. Fig.7 is detailed model with all required components in loop.

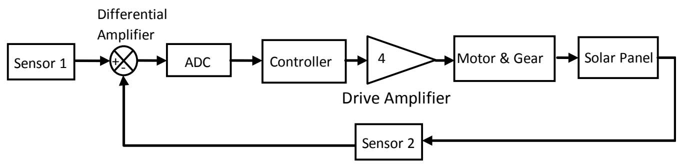


Fig.7: Complete control loop

Implemented controller has form:

Control flow chart of the system is shown in Fig.8; here ‘a’ is the ADC output for a particular Sun position. For perfect alignment a=85, corresponding to midpoint voltage of 1.65V. During implementation it is realized that due to high sensitivity of the sensor; perfect alignment condition may not be feasible for adverse conditions, like system starts alignment from a higher angular offset. Problem is catered by specifying a ±5o accuracy correspond to 71<a<99.

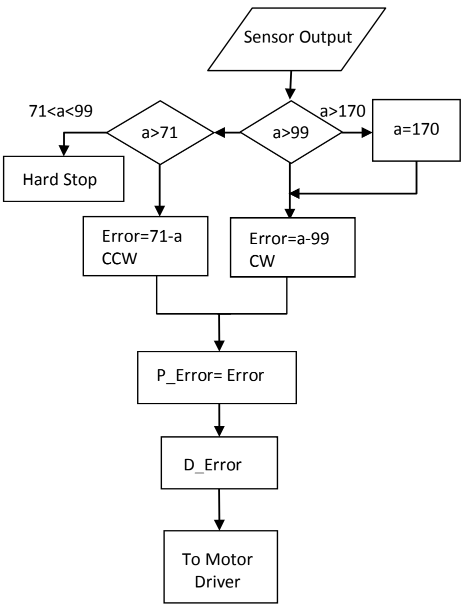


Fig.8: Control flow chart

As described in system design, the unique shape of sensor support structure provides best estimate of light source position. Sensor is shown in Fig.9; light source either on left or right side will put one of the sensors in shadow that will create voltage difference.

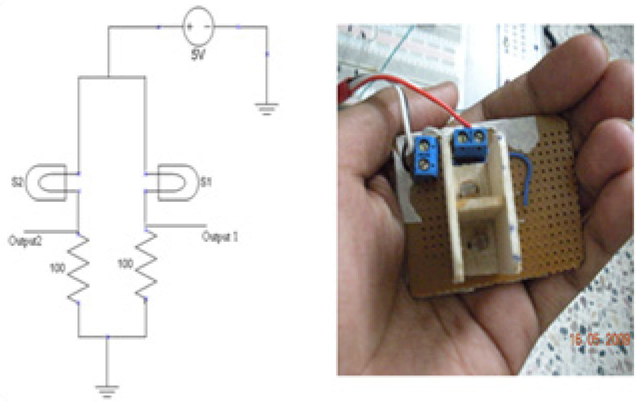


Fig.9: Differential sun sensor

Voltage drop against two 100Ω resistors (each in series with a LDR) is sum-up using differential amplifier. Resultant error signal is scaled and shifted to vary in full ADC input range (0 to 5V); circuit diagram is presented in Fig.10. ADC output is supplied to input port of microcontroller where control command is calculated. Speed control of stepper motor is achieved by controlling frequency of phase excitation. H-bridge (L298) motor driver is used to provide interface between motor and microcontroller [9].

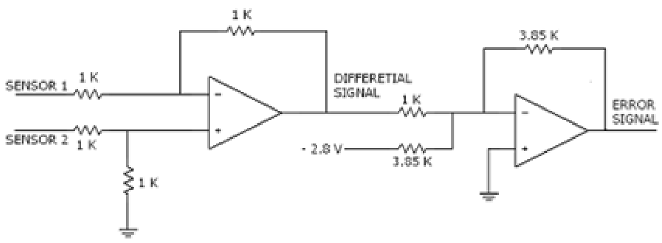
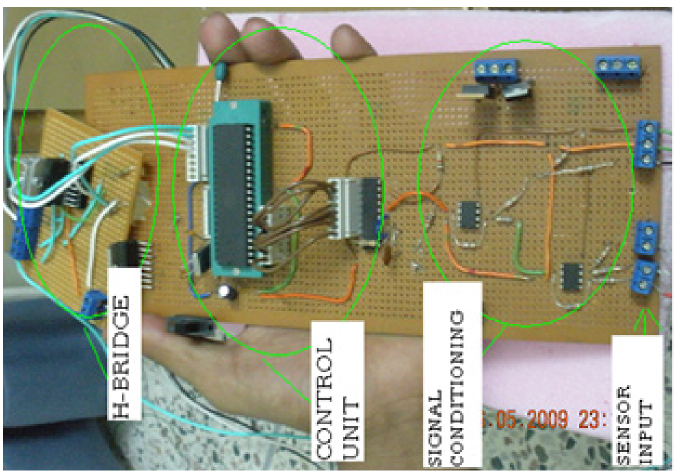


Fig.10: Signal conditioning



Complete control circuit; as shown in Fig. 11

Charging Circuit Design

Circuit includes regulated voltage supply thermal protection, automatic switching to Sun & eclipse mode, finally a battery voltage level display. Li-ion battery is selected by defining FOM based on system reliability. Battery pack used is made of SONY-18650 cell with nominal voltage of 3.7 V [10]. Battery characteristics are provided in TABLE I. Specification and tested charging & discharge curves for the cell are shown in Fig.12 and Fig.13 respectively:

TABLE 1.

Nominal capacity (mA.h)	2350
Maximum charging current (A)	2.4
Maximum discharging current (A)	4.6
Internal Impedance (Ohm)	90 x10 -3
Temperature limit (Co) [10]	57

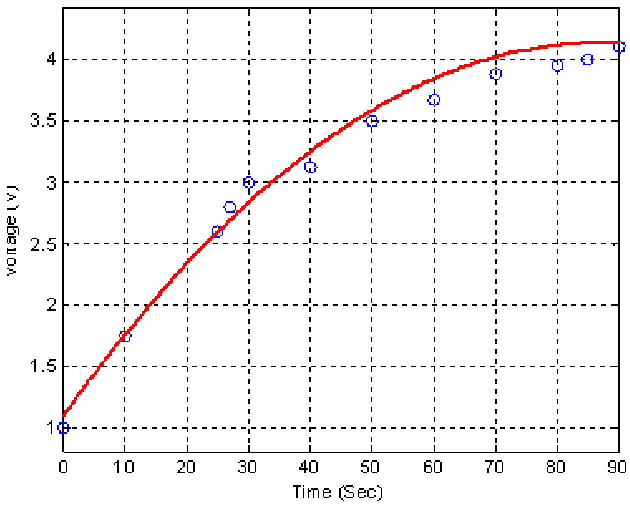


Fig.12: Charging curve

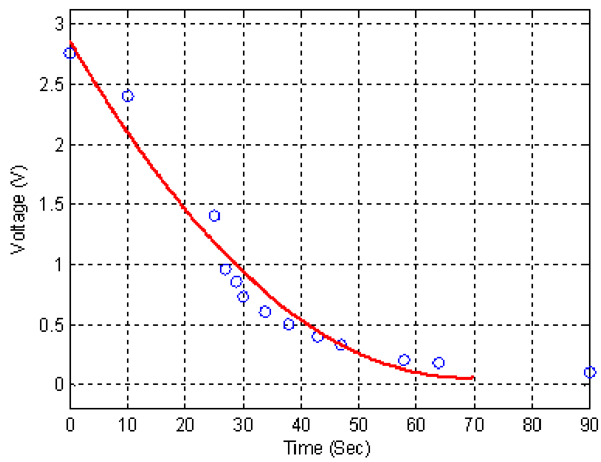


Fig.13: Discharging curve

The objective is to make 15V charging circuit; therefore battery pack is made of four cells in series. Battery overheating is controlled at 40 Co using LM-35DZ; 15V regulation is achieved using LM-317 with output voltage given as [11]:

$$V_o = V_{REF}\left(1 + \frac{R_2}{R_1}\right) + I_{ADJ}R_2$$

Sun-Eclipse circuit operation incorporate solar panel in circuit while display showing panel voltage; during eclipse, panel is shut-off and battery drives load and seven segment display shows battery voltage.
Battery voltage is displayed by first converting to digital using ADC-0804 and then supplied to seven segment interface.
Designed circuit is shown in Fig.14 and working circuit is shown in Fig. 15

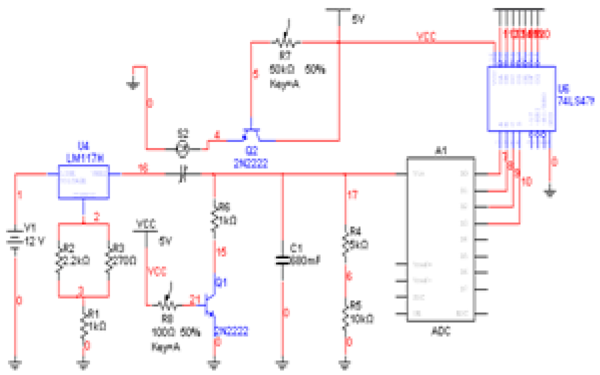


Fig.14: Charging circuit diagram

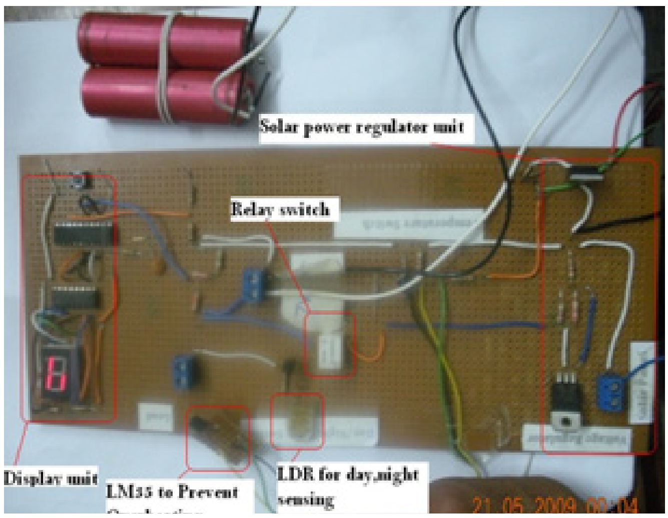


Fig.15: Charging circuit

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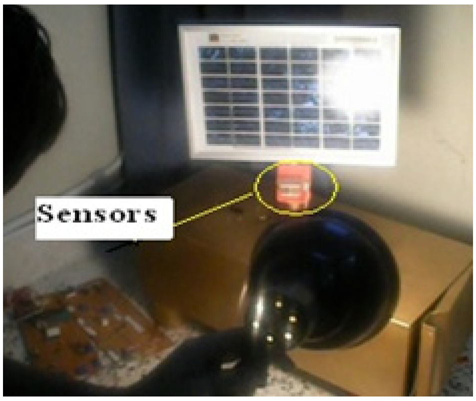
Implemented control system is shown in Fig.16;

Fig.16: System testing



Results

Table II show test data collected on a full sunny day, with column 1 and 2 showing average power in watts with fixed solar panel and with tracker implemented. Results reveal 33.33% increase in power on average Fig.17.

TABLE 2.

Power Without Tracker	Power With Tracker	Hours of Day
1.6	2.1	1
5	14.7	2
9.2	20	3
14.6	20	4
20	20.2	5
20	20.3	6
20	20.35	7
14.3	20	8
8.78	20	9
5	15	10
1.4	2.1	11

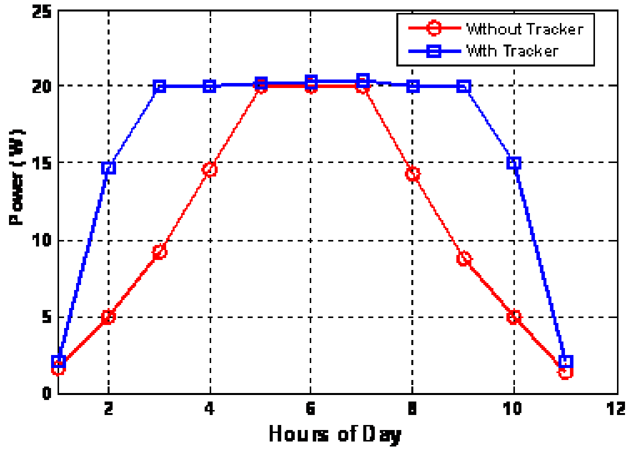


Fig.17: Power generation efficiency

Conclusion

Designed control system has been implemented on a solar panel and has shown good tracking capability. Solar panel with and without tracking system is tested in April on a full sunny day in Pakistan at 33°43′N 73°04′E, and tests reveal an increase in power generation of 30-35%. Due to its unique design, system will require less maintenance and will prove to be perfect for domestic use. Total cost of this solar tracking circuitry is approximately 850/-PKR which will further decrease during production while cost of solar panels to get required power without tracker is much higher.

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