Solar Powered Air Cooling for Idle Parked Cars: Architecture and Implementation

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***Abstract*—This paper presents the design and implementation of a novel, low-cost solar powered car cooling system for idle parked cars. This system is targeted towards Gulf countries such as the United Arab Emirates as high ambient temperature changes may cause interior damage to the car and pose a significant burn threat for young, disabled or elderly passengers. The main objective of this system is to significantly reduce the temperature inside the parked vehicle without starting the engine and using vehicle's own A/C system. The proposed cooling prototype utilizes thermoelectric element to cool the air inside the car and mirco fan system to accelerate the heat exchange. The system is powered by the external battery and recharged by the top-mounted solar panels. The system's connectivity is leveraged by Wi-Fi technology operated via mobile phones that enable remote monitoring and control of the temperature inside the car. The initial tests carried out on the car model indicate modest cooling effects in the range of $4^\circ C$, but can be significantly boosted by the increased power and improved heat exchange.**

***Index Terms*—Solar panels, Thermoelectric device, Mobile application, Microcontroller**

I. Introduction

Embedded systems have shown explosive growth in the past decade and are defined as hardware-constrained systems running a dedicated software. They provide solutions to various problems due to their reliability, accuracy, size and low cost. Embedded systems are often based on micro-controllers to perform specific tasks and can be optimized based on their applications which range from critical medical devices such as cardiac pacemaker, to communication devices such as cellular phones and in the field of robotics etc. Embedded systems receive commands from, and respond to, an external controller. The communication link between them can be of any physical medium such as Wi-Fi, ethernet, radio frequency, etc.

A. Problem Statement

The United Arab Emirates has a tropical desert climate. The average temperature during the summer time usually reaches above 40°C (104°F)[1]. The temperature inside a parked car under direct sunlight can be 30°C higher than the ambient temperature outside. Such high temperatures may cause heat related illnesses such as loss of consciousness, weakness, suffocation and headache [2]. The worst scenario could involve babies or disabled people that are at risk of burning without the chance to move or inform the driver who might not actually be in the car.

In addition to that, heat exposure can cause elevated body temperatures in the body. This can lead to a well-known condition in the medical field such as febrile seizure where children go under convulsion due to high fever or a sudden increase in temperature[3]. Even though, it is not a life threatening disease, it is difficult for parents to see their children in such conditions. Hence, early intervention is required which can prevent recurrent seizures in the near future. The proposed system will be beneficial for the population of the United Arab Emirates as it uses solar power to cool sun-exposed parked cars down to more acceptable temperatures that would pose significantly less health risk and material damage.

B. Proposed Solution

The proposed system differs from commercial products as the driver can control the fans and monitor the temperature inside the car wirelessly through an external device. As a result, he can obtain an updated status of the temperature inside the car and can cool his car before entering it. Furthermore, the cooling device is designed in such a way that it uses solar energy and rechargeable battery as its power supply. Solar power is abundant in the United Arab Emirates and pollution free. In addition, it does not produce any greenhouse gases which makes it a more practical system for use.

This paper is divided as follows : Section II discusses the overview of the entire system while section III presents the architecture of the proposed system along with its components in detail. In section IV, the final prototype is discussed while section V, describes the testing phase of the system prototype. The summary of the achieved outcomes and the future enhancements is outlined in the last section.

II. System Overview

The proposed system is a real time embedded system that captures the temperature inside the car using an accurate temperature sensor and sends the measured data to the user via a wireless connection. The data is then viewed using a web application that consists of a simple user-friendly interface. The core part of the cooling system is a thermoelectric cooling (TEC) device which will remove the heat from the car. This is achieved by connecting the TEC device to heat sinks and across interior brushless motor (fans) and an exterior brushless motor such that the hot air is blown out of the car. As

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observed in Fig. 1, the cooling module is controlled by a micro-controller which uses a relay as a switch to save power. The user can control the cooling system via a web application by pressing ON and OFF buttons. In order to make the system more efficient, a solar charge controller is used to control the amount of charge entering into the rechargeable battery from the solar panel. It powers on a DC load such as a microcontroller board in this case.

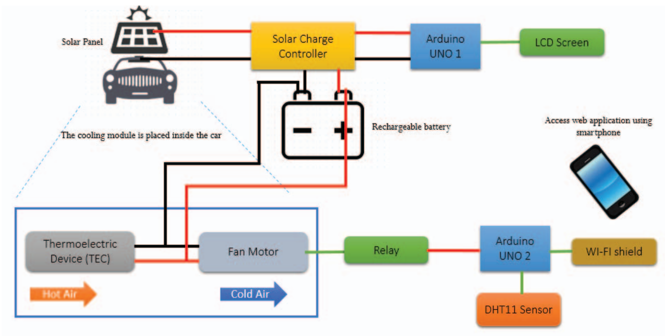

Fig. 1. System overview illustrating the components of the proposed embedded system

III. System Architecture

The system architecture consists of the structure, model and behavior of the proposed system. The system prototype is divided into two hardware and software sub-sections that will be explained in great detail.

A. Hardware

1) Rechargeable battery: Based on the power consumption of the cooling system, two 12Ah, 12V rechargeable battery are used. The type of battery used is VLRA battery which is valve-regulated lead acid battery, most commonly known as sealed battery. It is suitable for the proposed system, as it meets the required specifications of the hardware components and its self-discharge is lowest among all the rechargeable battery systems.

2) Cooling System: Fig. 2 shows the cooling module used for the system; it comprises a thermoelectric cooling device (TEC), heat sink and three brushless motors. Its power consumption is about 240W. The dimensions of the cooling module is $250 \times 132 \times 135mm$. The thermoelectric device is an active cooling device which creates a temperature difference on two dissimilar materials when a voltage is applied. As a result, there is a hot side and cold side where the hot side is attached to a heat sink (passive cooling) otherwise it will be damaged. The reason for choosing TEC device compared to other cooling technologies such as compressors is that TEC consists of no moving parts thus it is maintenance free, has small size and weight, does not require coolant unlike compressors[4]. Hence, it is also environmentally friendly.

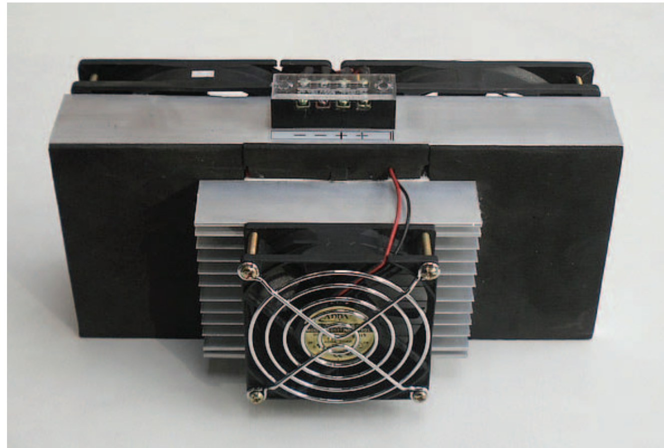

Fig. 2. The Cooling Module

3) Temperature Sensor: To capture accurate temperature readings inside the car, DHT11 sensor is used. It is a simple, low cost capacitive humidity sensor and thermistor. It operates between 3-5V and can measure temperature readings with ± 2 °C accuracy and humidity readings with 5% accuracy[5]. The sensor's output is a digital signal which is read by the microcontroller.

In addition to that, a digital thermometer is used as shown in Fig. 3 (b) to measure the ambient temperature. This enables the user to compare the two temperatures for further analysis.

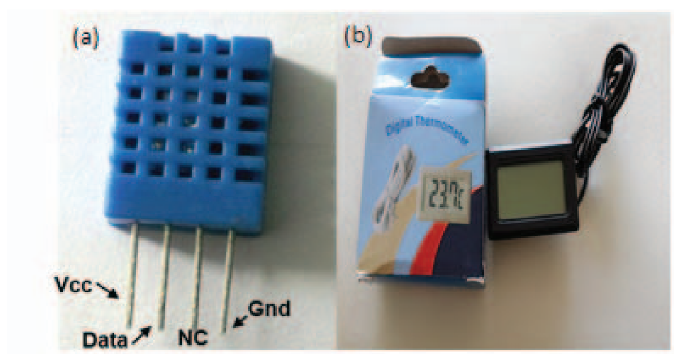

Fig. 3. shows the two types of temperature sensor (a) DHT11 sensor to measure the temperature inside the car; (b) Digital Thermometer to measure the ambient temperature.

4) Relay: The relay is very useful in terms of saving power and energy. It is a switch that operates with a small amount of current to induce much higher current in a secondary circuit[6]. Relay is an essential component for the proposed system as it activates large current consuming devices such as the cooling module by using a much small current. In this system prototype, a 24V BOSCH relay is used to control the cooling unit by a low power signal which is done using the micro-controller and a transistor circuit.

5) LCD Screen: This is required to display the charging percentage of the battery (battery status), load status and to monitor the solar panel voltage and battery voltage. The LCD is connected to the micro-controller board. However, this component is optional.

6) Solar Panels: Solar power is one of the most abundant sources of energy in the United Arab Emirates which serves as an advantage, however it incurs high installation costs and gives low energy conversion efficiency. For this system, a 40W multi-crystalline solar panel is used to ensure maximum power production during sunlight. However for testing purposes, a 5W solar panel was used initially.

7) Solar Charge Controller: The solar energy that is captured using solar panels will be stored in batteries and for powering the DC load. A charge controller circuit is required to regulate the voltage and current that is coming from the solar panels and entering into the battery[7]. The correct operation of a charge controller will prevent over-charging or over-discharging of a battery regardless of the load design and operating temperatures. They are designed to extract the maximum power from the panel and deposit it in the battery[7]. Lack of a charge controller circuit will damage the battery due to over-discharging[7]. According to the system specification, a PWM (Pulse Width Modulation) charge controller is used which is an effective means to achieve constant voltage battery charging by adjusting the duty ratio of the switches (MOSFET). In PWM regulation, the current from the solar panel tapers according to the battery's condition and recharging needs. Hence, a PWM charge controller is built from scratch as it is a good low-cost solution for smaller systems compared to other charge controllers.

8) Wi-Fi Shield: As mentioned earlier, embedded systems need a communication link to interface with other external devices. The Wi-Fi shield can be easily stacked on top of a micro-controller board or soldered. It connects the micro-controller system to the internet using 802.11 wireless specification. Once the sketch of the Wi-Fi shield is uploaded to the board, an IP address is displayed on the serial monitor which can be tested successfully by using a basic LED. The ON and OFF status of the LED can be controlled using a web browser or a mobile application. Fig. 4 illustrates the basic testing of the Wifi Shield. In our proposed system, it is required to enable continuous monitoring of temperature and controlling of the fan motors via a mobile application. Adafruit CC3000 is used which includes features such as: SPI (Serial Peripheral Interface) for communication, full compatibility with Arduino micro-controller boards, low power and existing libraries which makes it easy to use.

9) Microcontroller: A microcontroller is needed to control, program and organize the tasks of all these different components. According to the system specifications, the Arduino microcontroller family is used, more specifically the Arduino UNO as it is the most common microcontroller board used nowadays due to its simple, easy to use open source programs.

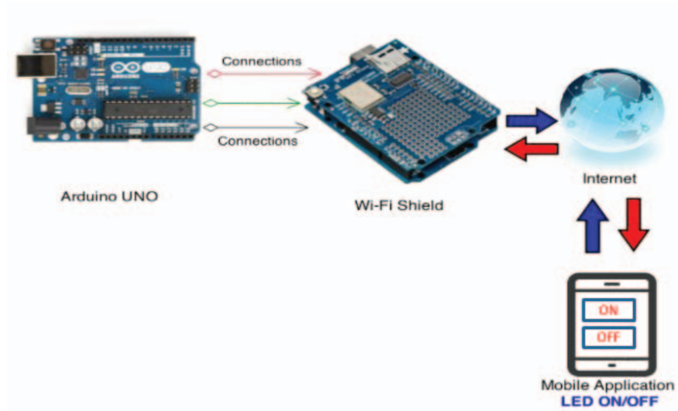

Fig. 4. Interfacing with the prototype via Wi-Fi connection

The decision to choose Arduino UNO was based on several factors such as the cost that meets the project's budget, the type that can support the sensors and other components used in the system, the availability and simplicity of codes, and the capacity of the microcontroller to run the required tasks efficiently. Arduino UNO is based on the ATmega328 core, has 14 digital I/O pins where 6 are PWM and operates at a voltage of 5V[8]. It has 32KB of flash memory, 2 KB of SRAM and 1 KB of EEPROM.

B. Software

1) Arduino IDE (Integrated Development Environment): An application software for the Arduino microcontroller board. In our proposed system, Arduino is used to program the function of the solar charge controller, Wi-Fi shield, temperature sensor, relay and fan motors.

2) Mobile Application: A mobile application is needed to interface with the prototype using a Wi-Fi connection. The mobile platform chosen is an online, open source web application provided by Google, called App Inventor. It creates software applications for Android operating system, hence it can only be used with Android devices. It is easy to use as it allows users to drag and drop visual objects such as if, while loop statements etc. The language block makes the mobile application process very easy. App inventor has a viewer screen, which is the screen observed by the user and a block screen, where the programmer designs and adds the blocks together. A screenshot of the mobile application interface is observed in Fig. 5. The button "Fan ON" and "Fan OFF" is to control the fan motors; while the button "Check Temperature" displays the measured temperature in °Celsius in the box placed beside it.

IV. System Implementation

The schematic of the entire system connection is provided in Fig. 6. When the "Check temperature" button on the mobile application is clicked, the temperature inside the car is measured and sent through the Wi-Fi shield to the application. If the temperature is very high inside the car, he can simply press FAN ON button on the application in order to run the

Fig. 5. Mobile Application interface using App Inventor

system. As soon as the user presses the button, the application communicates via the WiFi connection to turn the digital pin that controls the status of the relay to be ON. The relay acts as a switch to the entire system. When the digital pin is set to status HIGH, the current will run through the darlington transistor and through the coil of the relay. When the electric current passes through the coil, magnetic field is generated that will push the contact of the relay to be closed. Current will pass through the motors of the fans and the thermoelectric device. Within a few minutes, the thermoelectric device gets colder and blows cool air inside the car.

Fig. 2 showed how the thermoelectric device's hot and cold sides are separated and sealed. This is to avoid any hot air diffusion inside the car. The system is redundant during the driving the car, hence the driver can press the OFF button on the mobile app to turn off the relay and shut down the entire cooling system.

Regarding the charge controller, there are three stages of charge cycle[9]. The first phase is known as the bulk phase, where the voltage of the battery usually reaches around 14.4-14.6V and the voltage increases gradually as the battery is charged up. The second stage is the absorption phase where the battery becomes more fully charged. In the float phase, the voltage is lowered to float level usually around 13.4-13.7V and the battery draws a small maintenance current until its next cycle. The PWM charge controller that is operated initially checks if the solar panel voltage is lesser or greater than the battery voltage. If it is greater, then the microcontroller sends PWM signals to the MOSFET switch and then performs a second check to see if the battery voltage is less than the float charge set point (13.6V). Once both the conditions are satisfied, the battery will be charged. Otherwise, when the solar panel voltage is less than the battery voltage, the microcontroller does not send any signals and disconnects the load automatically as this happens during dusk time. Furthermore, when the battery voltage is between the float charge set point (13.6V) and boost charge set point (14.4V) the duty cycle is reduced but the battery still gets charged in float mode.

As mentioned earlier, each battery is rated to be 12V, 12Ah. By connecting them in series, the equivalent current is 12A while the equivalent voltage is 24V. The relay needs 24V between its contacts to switch on and this is possible by the series battery connection. As the cooling system consists of four connections, they need to be connected as shown in Fig. 7. The diode is connected to a transistor where the base of the transistor is connected to the Arduino pin which gives a logic output of 1 or 0, when the user wants to switch ON or OFF the fan respectively.

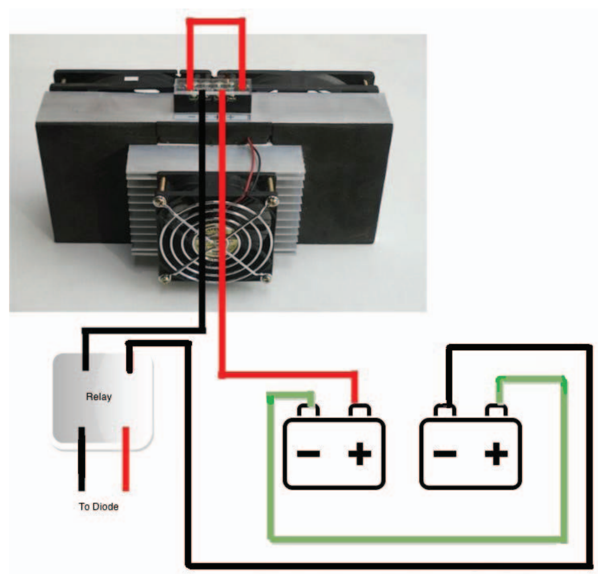

Fig. 7. Connection between the relay, cooling device and battery

V. Testing

The system is assembled in a car prototype made of wood while its windows are made of a good insulating material. After several discussions on the dimensions and design parameters of the car, the prototype has been built as shown in Fig. 8, where the solar panel is placed on the roof of the car so that it utilizes maximum power efficiency and provides the largest possible area to be exploited by the panel. The components are connected in the interior of the car where the front side of the car consists of slits to allow the hot air to be blown

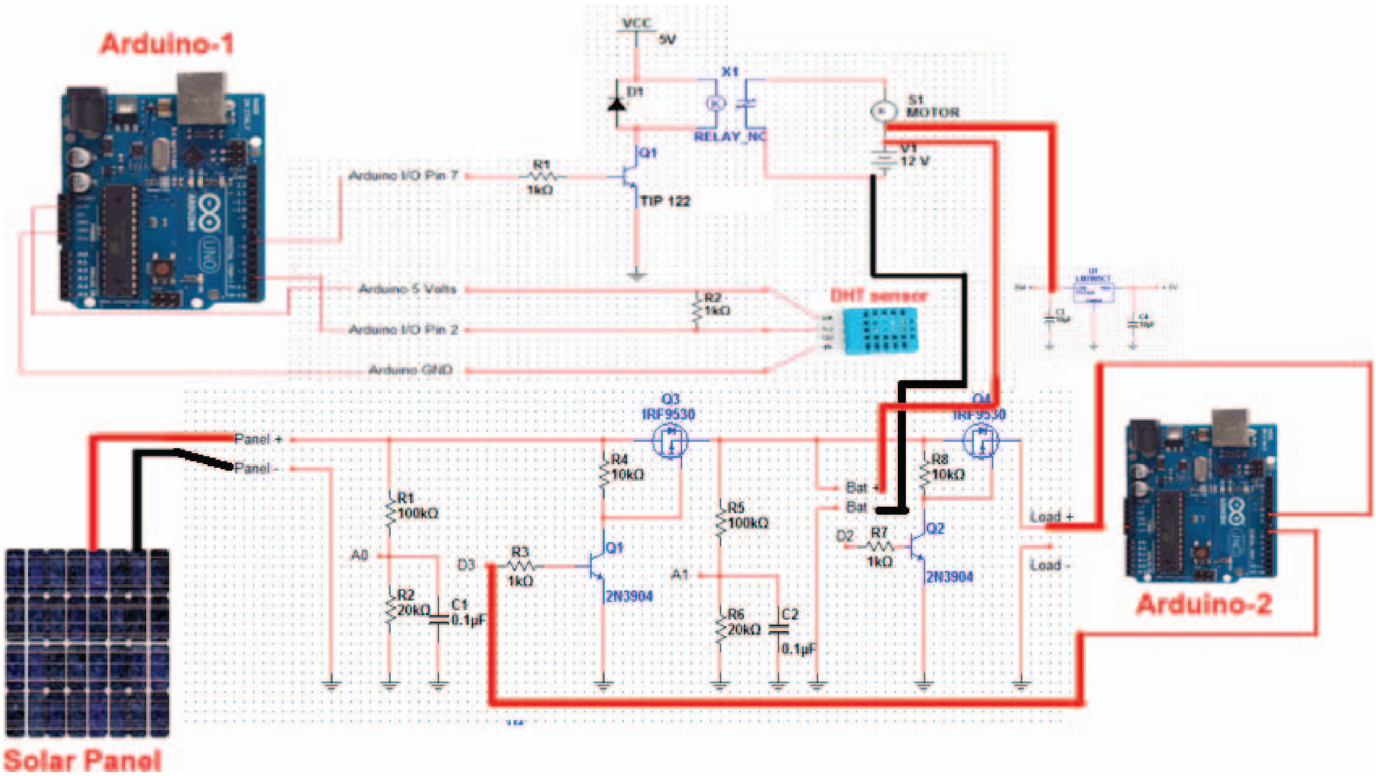

Fig. 6. Schematic connection diagram of the entire system

outside at the same time cooling the car inside. During the indoor testing carried out for 15 minutes the temperature fell by 4°Celsius from 27° to 23°. When running the system at the university campus, the IP address kept changing, hence as it is recommended to use static IP routers that would not require modifications in the mobile app each time the prototype is run.

Fig. 8. Design of the car prototype with its components assembled inside

VI. Conclusions and Future Work

We proposed an eco-friendly system of air-cooling inside idle parked car that utilizes thermo-electric effect and is powered by the renewable solar energy. We presented solutions to several functionality and architectural challenges involved in the design, cost-efficient development and intelligent control in-line with the Internet of Things (IoT) technology. We built a working prototype of the proposed cooling system fitted on the wooden car model and demonstrated remote control of the inside car temperature using mobile app communicating with the system using WiFi technology. The testing results indicate modest cooling power. However, the significant improvements can be achieved by increasing the systems's power, improving the heat exchange and installation in the much better insulated real car. Our system would also benefit from enhancements such real-time temperature monitoring and thermal data storage capability.

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