Smart Controller for Solar Thermal Systems

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Abstract. The paper presents the development of an innovative solution based on a smart controller for solar thermal systems. The controller can intelligently optimize all sources and consumers of heating energy in order to maximize the savings. It has an easy to use user interface that allows advanced configuration. The solution consists of solar controllers, other IoT devices and a platform that provides remote control, extended user interface, and a number of different services.

Keywords: IoT · Solar energy · Smart home · Systems engineering

1 Introduction

The heating takes a major share (80%) of the energy consumption in the residential sector. Households need thermal energy, but most of them use conventional energy causing pollution and CO2 emissions, instead of using solar energy. Despite the availability and sustainability of solar energy, its usage is much less than the potential, while thousands of people are dying each year because of pollution caused by fossil fuels burning.

The efficiency of thermal solar panels is 80% compared to PV panels with 15% only, but there are still not so widely used because of the following obstacles that the proposed solution overcomes [1].

- The available high-end smart controllers are very expensive;
- Lack of competency about haw to install and configure the devices;
- Difficult incorporation with the existing systems;
- Uncertainty about Return of Investment (ROI).

The goal is to provide a solution that has the following features:

- Fully configurable input and output interfaces
- Extra savings achieved by smart control of the providers (solar panels, solid and liquid fuel boilers, electrical heaters, etc.) and consumers (boilers, heating radiators, swimming pools, etc.) of thermal energy.
- Affordable price thanks to the cost-effective design.
- Easy incorporation with the existing systems.
- Certainty about ROI provided by calculating of solar to other energy ratio.

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- Control of the pan/tilt of the solar panels (according to daily sun movement) increases the efficiency and also solves the problem with extra energy
- Detection of failures provided by intelligent algorithm and output ports equipped with electrical current meter allows identifying pumps circuit cut-off, etc.
- High reliability and ultra-low energy consumption of the device.
- Variety of user interfaces and connectivity options

A typical solution consists out of the following elements:

1. A controller with connection to local IoT devices and with algorithms to optimize thermal heat balance in the building and to minimize the use of fossil powered thermal energy.
2. Devices (via other suppliers) such as:

   a. Sensors to measure temperatures, flows, pressure, and other parameters
   b. Actuators to control heat production sources, to control pumps and to control valves

3. A platform that connects all Controllers and supplies:

   a. Remote control and notifications
   b. Data analytics
   c. Additional services for extra savings (Weather data, etc.)
   d. Advanced configuration options
   e. Option to connect other IoT devices

The following sections describe the main components of the solution and their contribution to achieving the goals.

2 Smart Solar Thermal Controller

The main goal of the controller is to optimize all sources and consumers of heating energy in order to maximize the savings. This is achieved by using the available information and applying advanced control algorithms.

For example, the user can set the required amount of hot water for a specific date and time, so the controller will fulfill the requirements using as much solar energy as possible. For such task, the controller measures the actual power produced by solar panels, the power of the electrical heater, ΔT between the current and required temperature of the water tank at specific time and ΔT between the current time and that time.

As mentioned earlier the uncertainty about ROI is one of the major reasons discouraging people for investing in such technology. The controller provides advanced monitoring that allow the user to see the solar to other energy usage ratio, i.e. to track the return of his investment.

Other option for potential savings is use the weather forecast to predict whether it is more efficient to use the cheaper night electrical energy.

The controller interacts with different thermal appliances, which increases the possibility of failure in the systems, since there many components. Such kind of failures could lead to costly in terms of time and money issues. The controller provides several methods for advanced protection:

- For five wire motor-driven valves, it uses the information from the limit switches in order to guarantee that the commands are executed correctly.
- For the closed systems, it measures the pressure level in order to detect leakages and other failures.
- The output ports are equipped with an electrical current meter for power measurement that allows detection of failures such as pump circuit cutoff, etc.

Additional option is the two dimensional solar tracker that can control the pan/tilt of the solar panels array according to daily sun movement. This feature increases the efficiency and is very useful especially when there is a limited space on the roof for extra panels.

It also elegantly solves the problem with the extra energy during the hot days by automatically turning the array on the opposite sun direction.

After recovering (in case of power failure) thy system gets the actual time and date from NTP server (suppose Internet connection) in order to calculate the optimal pan/tilt of the solar panels array.

Currently there are two models, one for domestic usage and other for industrial applications. The main difference is that the last one has more inputs and outputs ports.

The controller is based on ESP32-Pico-D4 [2] System-in-Package (SiP) which simplifies the PCB design and increases the reliability.

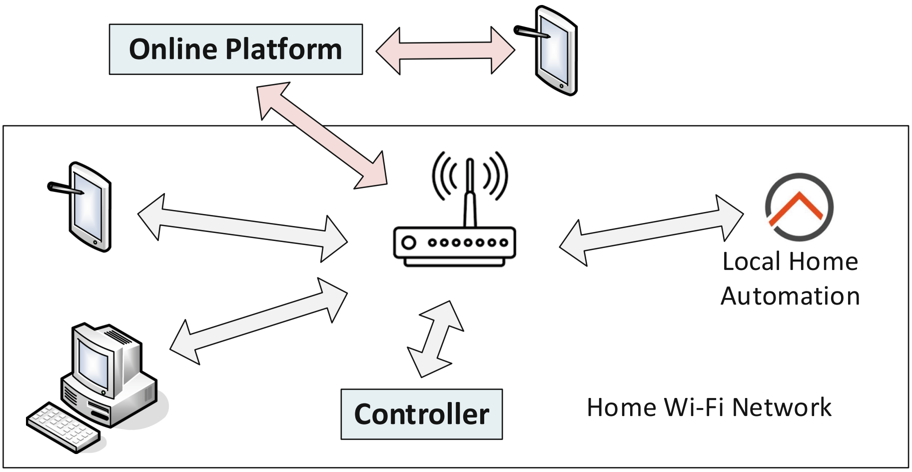

Fig. 1. Various way to access the UIs of the controller.

The controller has rich connectivity (Wi-Fi, Ethernet and Bluetooth) and several UIs options available: display, own web UI, existing home automation (openHAB [3], Home-Assistant [4], etc.) and our platform, Fig. 1.

The usage of MQTT protocol allows integration with existing home automation plat-forms via Homie specification [5] and the platform for remote access and control.

3 Web Platform

The web platform provides remote control, statistical data and advanced UI.

When the controller connects to the Internet it sends its unique Id to the platform, so the user does not need to enter it manually, as shown in the figure below. This process is required only for the first time and once the users are registered, they can use the platform. Then the controller sends MQTT messages to represent itself and starts sending measurements data (Fig. 2).

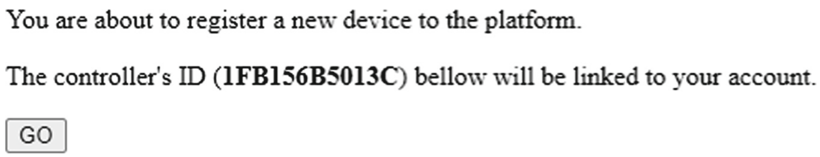

Fig. 2. The message displayed to the user during the initialization of the controller.

3.1 Architecture

The platform is designed to adopt a lambda architecture in order to process data in a more efficient way. It processes two kinds of requests - one for current data and one for statistics. The first one displays in the interface current/live data from the received sensors and the latter one displays data for a bigger period of time after querying the database (Fig. 3).

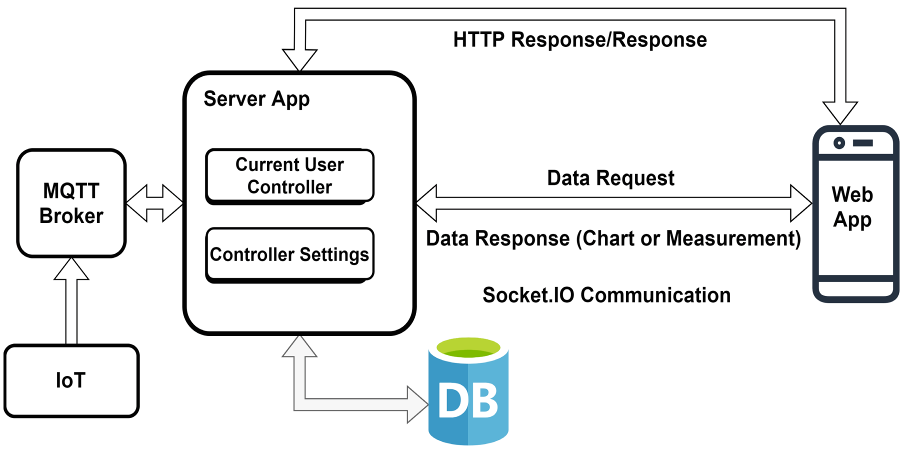

Fig. 3. Architectural overview of the web platform.

The MQTT [6] protocol was chosen as the message communication mechanism since it has been widely used and proven in IoT architectures. Last Will and Testament (LWT) feature of MQTT is used to notify the platform about an ungracefully disconnected device.

In order to reduce data storage and network traffic, the measured data is sent to the platform only if differs from the previous measurement. That allows fast response time with low network traffic, but can be more challenging for data visualization.

3.2 Database

The structure of the DB allows to add (and remove) different devices without changing the structure.

Additional table in the database allows to automatically associating the controller after replacement. Using the identification numbers of the sensor and other information about the systems, the platform can identify that the controller has been replaced, which significantly simplifies the support of the system (Fig. 4).

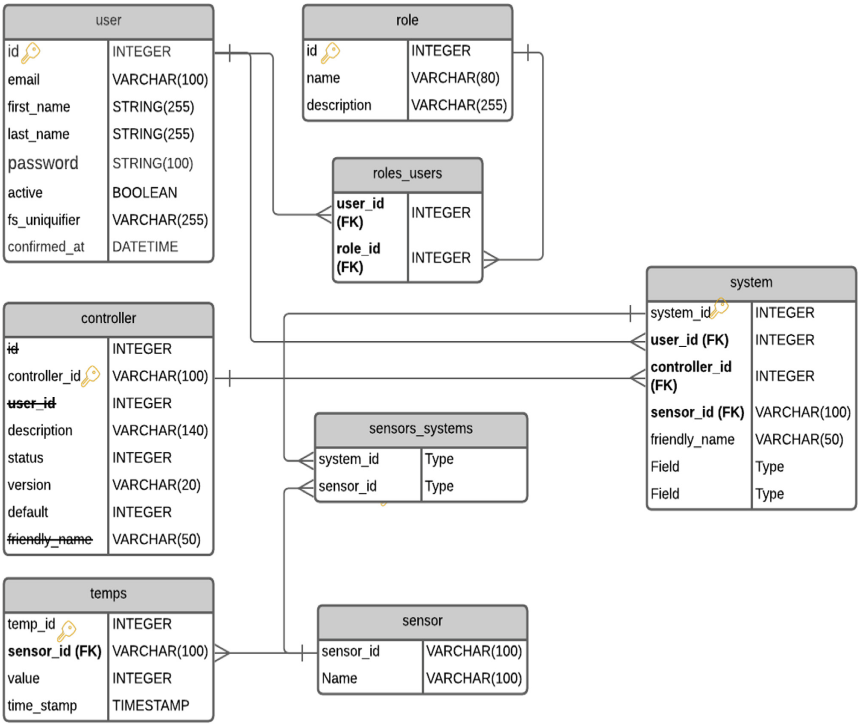

Fig. 4. Section of the database schema.

3.3 User Interface

The newer version of the UI presents the data in a more user-friendly and easier-to-use way. It, also, offers additional features such as an integrated weather forecast API.

In Fig. 5 below a screenshot can be seen, where the user is presented with current sensor measurements (upper half of image) and aggregated data for a chosen period of time.

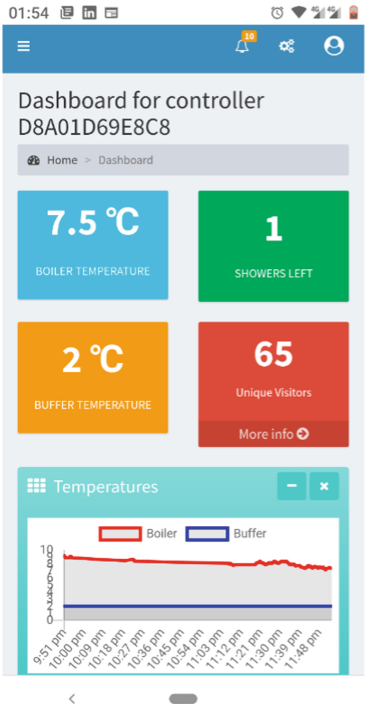

Fig. 5. A sample screen of the UI.

4 Conclusion

The proposed solution is designed for single households, but can be used in communities, industrial and office building, etc., allowing energy saving and sharing.

It allows increasing the share of freely available and clean energy usage. The precise control, monitoring, and effective usage of solar energy contributes to significant cost reduction. As future work, we aim to develop a visual programming tool that allows the users to incorporate external components to the system in a convenient way.

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