A Human Detection Method for Residential Smart Energy Systems Based on Zigbee RSSI Changes

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Abstract—The paper presents a novel method for human detection that is applied to the automatic control of home appliances’ power consumption. The method uses a wireless smart outlets network and changes of received signal strength indicator (RSSI) between stationary communication nodes (2.4 GHz smart outlets). The main idea is to monitor the changes of RSSI which violate the established radio communication field between nodes inside a room, due to a human’s presence. When a person enters into the established radio communication field, he/she induces the change of RSSI which is periodically read during the message exchange between wireless nodes. Based on the detected changes with regard to the initial thresholds, the system detects human presence and responds with the automatic control of power consumption of all appliances connected to the power network. Such an approach increases users’ awareness by contributing to the energy savings and low installation costs.

I. INTRODUCTION

Rapid technology development has brought a wide variety of available electronic appliances, but the requisite energy sources exploitation has become a serious problem. In order to decrease the energy wasting and to increase the energy awareness, several ideas have been proposed. Most of the energy saving solutions are based on smart outlets utilization [1], [2]. Using the smart outlets, consumers are able to monitor the power consumption of each plugged device and to enable a simple set of commands: on/off switching, displaying the status and network discovery. It is possible to display the consumption of each appliance as well as a group of appliances in real time or displaying the consumption in time on a daily, weekly, monthly basis in conjunction with the costs. By using the smart outlets, users are able to have better insight into the power consumption of their households.

The most of the available energy feedback solutions provide a very technical view on the consumption. Even the consumers have the insight into the consumption data; in many cases they take no corrective actions to improve the efficiency. A fast and busy way of living makes users oblivious to perform simple actions that would conserve the energy, so there needs to be an automatic solution for the energy consumption management. In our previous paper [3] we presented such an intelligent home system. It improves the energy efficiency by connecting smart outlets, smart light switches and a number of residential human detection sensors together to an ecosystem for smart home. In [4] we have elaborated different human detection technologies which can be easily integrated into a smart home to increase the users’ awareness in an attempt to form an Ambient Intelligence ecosystem. The system utilizes conventional methods for human detection based on: audio (microphone array), visual (3D camera) or passive infrared (PIR) sensors. Some novel localization techniques utilize RSSI-based (received signal strength indication - RSSI) information. It is the most applicable solution for wireless sensor networks due to the low deployment costs and easy integration in wireless systems [5], [6]. Such systems are mainly based on localization of mobile node in the network of stationary nodes by determining the distances from the known nodes locations. To the best of our knowledge, there is no available smart energy home system that is able to monitor the consumption and, at the same time, to sense the environment for recognizing the human presence by detecting the changes in RSSI between stationary nodes (wireless power outlets).

In this paper we propose a novel method for the human detection in energy aware homes based on smart outlets and smart light switches. Instead of integrating various sensors which require complex installation and processing algorithms, we propose utilization of existing smart outlets and light switches which have two roles: (1) they are in charge of controlling the plugged device as well as of giving an overview on energy consumption; (2) they detect the human presence inside a room by using an existing wireless network established for communication between nodes (smart outlets or light switches) and the change of RSSI.

In the following sections we explain the proposed method which extends the existing smart energy infrastructure with the possibility to detect a human presence. At the end of the paper we present the results which show the usability of the proposed solution and comparison with the most popular PIR sensor.

II. PRESENCE DETECTION METHOD

The main principle of smart homes requires integration of sensor devices which technical characteristics allow for adaptation to the rhythm and style of everyday life. Wireless sensor networks used for such environments receive a lot of attention nowadays due to their wide area of application. In such ubiquitous networks, human detection and localization are the most significant methods for sensing the environment which interactively reacts on the presence in a natural way.

For the purpose of this research we are mainly focused on human detection by using the RSSI values. Since the smart energy system that we previously proposed [3] is based on wireless 2.4GHz (Zigbee) outlets, we decided to decrease the installation, complexity and development costs which are

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induced by additional sensors. By using the existing outlets and enabling them to detect human presence (shown in Fig. 1) we successfully removed additional sensors from the smart home ecosystem preserving the level of in-built intelligence.

Fig. 1 Presence detection method

The first advantage of the presented solution is in reducing the number of physical devices and the elimination of additional sensor solutions (movement sensors or RFID tags). The second advantage is that for the first time we use the RSSI monitoring algorithm applied solely on the static network nodes (smart outlets) for the detection. Presented method analyzes the changes in the received signal strength indicator between nodes, conditioned by people entering or leaving the room. Based on the detected changes and supported with the thresholds automatically defined during the initialization, the system decides on the generation of a functional status.

Realization of the system includes at least two wireless nodes with the associated control unit that is implemented as a device for managing the control message flow and monitoring the RSSI changes. These basic system units communicate with each other and monitor the changes of RSSI between nodes during periodic polling. As the final result the system controls e.g. lighting in a room, but in addition to the lighting control, the system can be preconfigured to control any other device (on/off switching) which is connected to the smart outlets.

Smart outlets, smart light switches and the central control device which is implemented in the form of an embedded PC, include an implemented software establishing the initial phase. The initial signal strength measurements $P_0$ for each node and thresholds setting $Th_1, Th_2$ in an empty room for a time period $t$ are calculated during start-up phase. Including the attenuation factors of distance $Pd$ and spatial obstacles $Pa$, $\Delta RSSI$ which represents the detection of the signal strength change can be calculated by:

\[
\Delta RSSI = P(t+1) - P(t),
\]

\[
P(t) = P_0 - Pd(t) - Pa(t),
\]

\[
P(t+1) = P_0 - Pd(t+1) - Pa(t+1)
\]

\[
\Delta RSSI = \begin{cases} 
\text{presence}, \Delta RSSI > Th_2 \lor \Delta RSSI < Th_1 \\
\text{nopresence}, Th_1 < \Delta RSSI < Th_2 
\end{cases}
\] (1)

The detection based on the comparison of changes that occur in the signal strength as the final result generates a command that results in one of the functional states (e.g. switch off the light if none is present in the room).

III. EVALUATION RESULTS

In this research we have shown that the proposed method for human detection is more reliable and robust than using PIR technology. In Table I we present the comparison of these two approaches. PIR sensor is cheap and widely used solution which is mainly dependant on its lens quality and ambient temperature. As the temperature is higher, the difference to human body temperature is decreasing as well as the detection accuracy, which is not the case with radio signal’s RSSI. Also when there is no movement for a period of time, the PIR sensor is unable to detect presence, which is not the case with our method (100% accuracy). Proposed technology does not include additional costs or installation efforts because it is based upon existing wireless infrastructure (Zigbee outlets).

<table>
<thead>
<tr>
<th>Sensor type</th>
<th>Useful Information grade</th>
<th>Movement detection</th>
<th>Multiple Human detection</th>
<th>Human localization</th>
<th>Human activity</th>
<th>Human Price</th>
<th>Installation complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIR</td>
<td>Low</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Poss.</td>
<td>Low</td>
<td>Med</td>
</tr>
<tr>
<td>RSSI</td>
<td>Med</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Poss.</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

The proposed method for human detection can be easily implemented on different hardware platforms which utilizes wireless infrastructure. The solution improves the design of smart homes and energy aware networks without additional presence sensors, installation and expensive processing algorithms. By using the presented solution it is easy to implement human detection on various Ambient Intelligence systems which are based on Zigbee networks. The solution can compete with the existing human detection technologies, especially in the aspects where: there should be no additional hardware, the processing power for the detection algorithms is limited and humans can be immovable for a period of time.

REFERENCES


