How many polar bears can you save with a Raspberry Pi?

[1]Nefeli Zikou, [2]Melina Zikou
4th High School of Alexandroupolis
[1]nefeliz@live.com, [2]melinaz@live.com

ABSTRACT

Global warming, partly due to waste energy, is the main reason the climate is dramatically changing and the polar bear's home is melting. We propose an innovative, easy to implement approach to monitor and optimize personal electricity consumption. Using a Raspberry Pi (an affordable, credit-card size computer), commonplace electronic components, and a novel web application, we developed a smart Internet-of-Things (IoT) device that monitors and optimizes electrical power for room appliances and lighting based on user presence or preferences. The IoT device records the state and operating time of an electric outlet. It also records the presence of a human based on infrared light sensor, and can capture photos when triggered. The device supports multiple modes of operation. The "WatchMe" mode records electric outlet operation time along with human presence in the room and generates maps of electric consumption. In the "SaveTheBear" mode, the device optimizes electric consumption by turning off selected appliances when no human is present. The "AlwaysAround" mode allows the user to remotely control the electric outlet via the internet. Finally, the "ProtectMyTerritory" mode uses the human presence detector and the camera to notify the lawful occupant of any intruder. In the paper, we describe the IoT device architecture, justify hardware and software choices and document the web application development. Finally, we discuss the reduction in energy consumption achieved by using the device and its impact on cost and climate preservation. Individual choices may seem too limited to stop climate change; but when scaled up in time and amongst society, they can certainly make a difference.

KEYWORDS: *energy consumption, Raspberry pi, global warming, smart electric outlet, Internet of Things.*

Introduction

The most recent International Union for Conservation of Nature (IUCN) report estimates there are roughly 26,000 polar bears (Wiig, et al, 2015). Polar bears rely on sea ice to hunt, travel, breed, and sometimes to den. The IUCN lists the polar bear as a vulnerable species, citing sea-ice loss from climate change as the single largest threat to polar bear survival. Recent findings (Regehr, et al, 2016) support the potential for large declines in polar bear numbers owing to sea-ice loss. Without action on climate change, scientists predict we could lose wild polar bears by 2100; two-thirds could be gone by 2050. Wasted energy is commonly considered as a major contributing factor to climate change and sea-ice loss. Current research focuses on new forms of clean, renewable energy that will not increase the burden on the climate. As about 80% of worldwide energy is still generated with methods that impact the climate, research also concentrates on energy saving operations and devices. Nowadays, a number of commercial solutions are available for smart energy reduction at home. In this paper, we propose an innovative, easy to implement approach to monitor and optimize personal electricity consumption. Using an affordable, credit-card size computer, and commonplace electronic components, we have developed a novel smart device that monitors and optimizes electrical power for room appliances and lighting based on user presence or preferences.

Background

Sea ice loss is mainly caused by the global warming, that is, the increase of Earth's average surface temperature due to effect of greenhouse gases, such as carbon dioxide (CO_2) emissions from burning fossil fuels or from deforestation which trap heat that would otherwise escape from Earth (for a formal definition see: IPCC 2014). Buildings account for about 40% of the global energy consumption and contribute over 30% of the CO_2 emissions (Yanga, Yana, & Lam, 2014). The residential sector contributes significantly to global climate change, as it represents 27% of global energy consumption and 17% CO_2 emissions; moreover, it was found that global residential energy consumption grew by 14% from 2000 to 2011 (Nejat, Jomehzadeh, Taheri, Gohari, & Abd. Majid 2015). Therefore, reducing household energy consumption is critical to improving carbon footprint (Kailas, Cecchi, & Mukherjee, 2012). In the 1990s, the concept of smart homes has been introduced to include all these innovations that create an intelligent living space that is able to respond accordingly to the behavior of residents (Liyanage, Chamin, & Iskandar, 2012). One of the central issues is energy efficiency, which involves controlling energy usage either on user demand or even better adapting it to user needs.

Showing electricity consumption to users has been shown to create adequate awareness and help users modify their energy consuming behavior to save up to 30% (Darby, 2006). Experiments have demonstrated that energy management systems for residential applications allow energy costs to be reduced by about 18%, while preserving the user comfort (Siano, Graditi, Atrigna, & Piccolo 2013). Data from Intergovernmental Panel on Climate Change (IPPC) showed that behavioral changes could affect energy savings in domestic lighting by up to 70% (IPCC, 2014).

A recent systematic review (Lobacarro, Carlucci, & Lofstrom, 2016) presents the current state of existing software, hardware, and communications control systems for smart homes currently available on the market. Such solutions include house wide electric grid interventions to manage overall house energy. More advanced systems monitor users' habits and learn to anticipate and facilitate their energy consumption needs. Such integrated solutions are increasingly installed in North America and north European countries (Lobacarro, Carlucci, & Lofstrom, 2016), but require a fundamental capital investment.

An alternative is to use small sized computers connected to home devices to provide means for control via the internet. This approach is also known under the term Internet of Things (IoT), which refers to a system of interrelated computing devices, mechanical and digital machines, and other objects (that is, 'things') that are interconnected and can be controlled via the internet. A number of such programmable micro-devices are available in the market nowadays and commonly offer standard interfaces to a variety of add-on modules, thus allowing the user to develop rich energy controlling applications. A recent study (Lobacarro, Carlucci, & Lofstrom, 2016) provides a comparative review of such available micro-computers, including Arduino (http://arduino.cc/), Banana Pi (http://www.bananapi.org/), BeagleBone Black (http://beagleboard.org/black), Raspberry Pi (http://www.raspberrypi.org/) and Libelium Waspmote (http://www.libelium.com/).

Architecture

The goal of this work is to use off the shelf, affordable components to develop a novel and affordable smart device to help users reduce wasted energy consumption in room appliances, such as desktop and floor lights, radios and other sound systems, TV sets, Christmas tree lights, etc. Empowering the user to use energy wisely should start with knowledge and self-awareness: the user should be able to monitor current energy consuming habits. Subsequently, the system should provide tools to reduce energy consumption. This should include the option to remotely control an electric outlet on demand, and also should support a smart control of the electric outlet based on user presence. Finally, to engage users and increase their determination to use the device and change their energy consumption habits, the system should offer some useful added-value.

Figure 1: High level architecture of the electRuBus system.

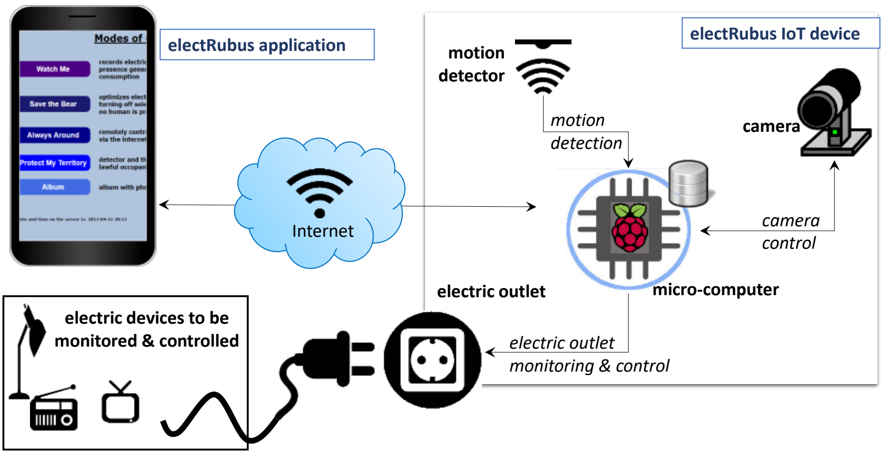

Figure 1 shows the high-level architecture of the proposed electRuBus IoT device and the respective application. (Note: Rubus is a genus of flowering plants including raspberry). The core of the device is a micro-computer which controls an electric outlet. The micro-computer includes a database and is also connected to a camera and a motion detection device. This IoT device is accessed and controlled via the internet by the electRuBus web application. The electRuBus IoT device supports the following four main functionalities:

(1) *WatchMe*: Through this mode the device records the time the outlet is switched on and off. Based on this information and knowledge of the device energy consumption,

the total cost can be calculated. This functionality allows the user to become aware of his or her energy consumption patterns.

(2) *SaveTheBear*: In this mode of operation, the device makes use of the motion sensor. When movement is detected, the light is switched on and in human absence is turned off again. With this functionality wasted energy is saved.

(3) *AlwaysAround*: This function of the device allows the user to turn on and off the light remotely and manually. This can happen through the web application or with the use of the button on the device.

(4) *ProtectMyTerritory*: With this functionality, when the sensor is triggered by human presence, a photo is taken and saved immediately. This allows the user to see who used a room while they were absent.

Implementation

The electRuBus IoT system consists of a smart device and the respective software application. The core of the electRuBus device is the Raspberry Pi micro-computer (Raspberry Pi Foundation, https://www.raspberrypi.org/), a low cost, credit-card sized computer that plugs into a computer monitor or TV, and uses a standard keyboard and mouse. Raspberry Pi provides a set of pins, called General Purpose Input Output (GPIO), that can be programmed for input or output and control electronic components such as an infrared motion sensor, push buttons, temperature sensors, etc. Raspberry Pi was introduced to help children and adults learn programming and currently exhibits a very large community with numerous support documents and forums. The Raspberry Pi is connected with a relay, which is an electrical switch that opens and closes an electrical circuit. The Raspberry Pi is also connected to a passive infrared sensor (PIR sensor); an electronic device that measures infrared light radiating from surrounding objects, calculates differences in light, and translates this into motion in its field of view. Finally, the Raspberry Pi is connected to a software controlled web camera.

Figure 2: electRuBus device photograph (left) and connectivity schematic (right).

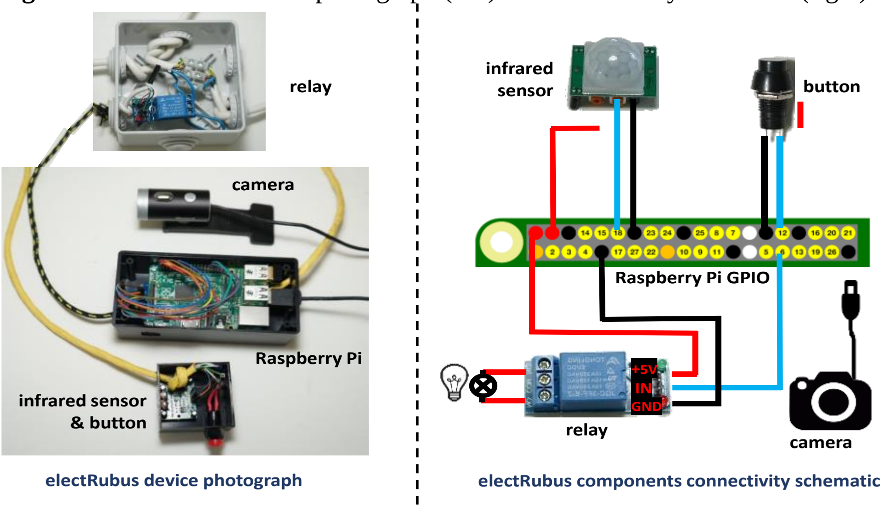

Figure 2 shows the connectivity of the various components we used to develop the electRuBus IoT device (right) and a photograph of the actual device. The components were assembled into a practical, easy to use device using two plastic casings: (1) one to wrap the relay and the electric outlet (as these components are high voltage, an adult supervised their assembly) and (2) one casing for the micro-computer and its connections to the peripheral devices.

The software developed to realize the four main functionalities consists of the main electRuBus Service, implemented on the Raspberry Pi and an electRuBus web application implemented on a web server. The electRuBus Service processes input from the GPIO, camera and web application and creates the appropriate triggers as an output to the GPIO connected devices and the camera. This main program is responsible for tracking user actions according to the mode of operation that we discussed in the previous chapter. It consists of a main thread that constantly monitors connected sensors, logs user action in a database, and controls the web camera and the relay.

Figure 3: Python routine to control the relay status (left) and Flask code to turn on the electric outlet via the web application (right).

```python
#sets light according to status
def set_light(status):
    global light
    if status == True:
        io.output(pin_relay, 1)
        print("ON")

    else:
        print("OFF")
        io.output(pin_relay, 0)

    light = status
    return
```

```python
#turns light on
@app.route("/AlwaysAroundOn")
def on():
    mode_operation = 1

    set_light(True)
    log_action(1,True,'', presence)

    if (light==True):
        state = "on"
    else:
        state = "off"
    now = datetime.now()
    timeString = now.strftime("%Y-%m-%d %H:%M:%S")

    templateData = {
            'title' : "Always Around ON",
            'time' : timeString,
            'status': state
    }

    return render_template('on.html', **templateData)
```

The electRuBus Service was developed in Python version 3 (https://www.python.org/) and implements the following functionalities: (1) reads sensor input from infrared sensor; (2) reads user input from button; (3) reads input from web camera; (4) controls output to the relay; (5) stores user activity to the database and (6) coordinates interaction with web application and user actions therein. For reading sensor input from infrared sensor and user button and setting the relay status, we used the GPIO library that comes with Raspberry Pi. For example, in order to set the relay status, we developed the code shown in Figure 3. In order to take image snapshots using the web camera, we used the Cv2 Python library.

Input and processed data are also stored in a local database. This was implemented in SQLite3 (https://www.sqlite.org/), a very light SQL database for Raspberry Pi with good support for Python. The database has two main tables, one for storing all user actions and another for calculating energy cost. Images are stored as .png files in the Raspberry Pi's memory card and the image file path is stored in the database with a timestamp, so as to be displayed to the user via the web application.

The electRuBus web application deployed in the local network allows the user to choose which mode of operation they wish to use. It consists of a main menu with the names of the modes. The user can click on the mode they want to put the device on and later click on the button "Back to Menu" to return to the main page. The web application was developed in HTML version 5 (https://www.w3.org/html/) and Flask version: 0.12 (http://flask.pocoo.org/), a micro web development framework for Python. Flask allows us to easily expose program state to the user and take user input. For example, the Flask code to turn on the device is shown in Figure 3 (right).

Figure 4: electRuBus web application example screenshots.

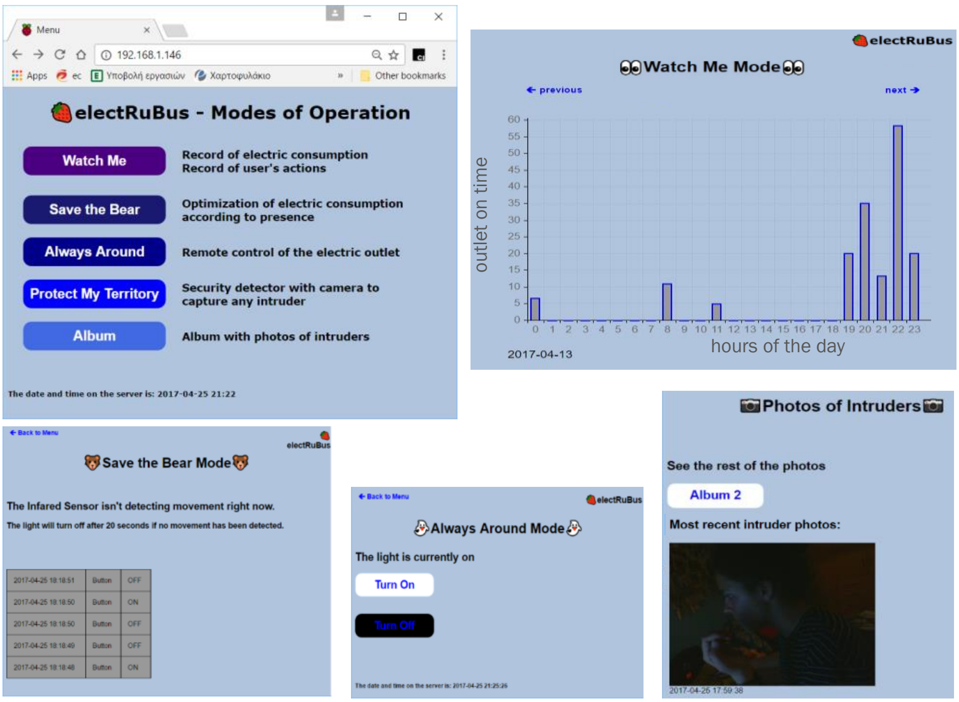

Figure 4 shows the electRuBus web application landing page and some example screenshots of the pages corresponding to the main modes of operation. The "Watch Me" functionality displays recorded data on the electric outlet operation in tabular form and in graph form, created using the Chart.js JavaScript library (http://www.chartjs.org/). In the "Save the Bear" page the user can visualize the current state (on or off) of the outlet, as this is set by the electRuBus software, either automatically based on motion detection or remotely set by the user. In the "AlwaysAround" mode the user can observe the current status of the electric outlet and remotely switch it on and off. The 'ProtectMyTerritory" mode allows the user to get information about recent intruders and view all photos automatically recorded by the device.

The electRuBus software consists of 661 lines of Python code and 855 html code; it is open source under the terms of MIT License and is available for download from Github (https://github.com/NefeliZ/electRuBus). Two prototypes of the electRuBus device were deployed for use by two users for a period of two weeks.

Discussion

This paper presents the novel electRuBus IoT device and software for smart control of an electric home outlet. The system provides support for remote control of the device, smart operation based on user presence and overall visualization of outlet operation and thus energy consumption. Also, it supports added value services, such as intruder detection and reporting. The device is home-made, assembled out of affordable, easy to use components, and it is accompanied by a web based application for user friendly device remote control and energy consumption visualization. The paper presents the assembly schematics in detail so that the device can be easily replicated. Also, the accompanying software is provided as open source for others to download, to use, extend and improve.

The core of the electRuBus is the Raspberry Pi micro-computer, which is currently used for a variety applications, from education for teaching computing (Kolling, 2016), in home automation (Dhami, Chandra, & Srivastava, 2017), in industrial automation (Anwaruddin, & Ali, 2017), even in applications running on the International Space Station (http://astro-pi.org/). Our project falls in the home automation category of Raspberry Pi projects and combines remote control options with smart energy saving solutions and intruder monitoring.

Research indicates that showing the energy consumption can create user awareness and lead to energy consumption changes that ultimately save energy (Darby, 2006). The electRuBus provides a user friendly, web-based interface to monitor the duration of an outlet operation and thus energy consumed. Also, the system can minimize waste energy by turning off the outlet when the user is not present. Currently, the device and software are deployed for evaluation and electricity saving experiments involving volunteers.

Work in progress includes the following (1) add the functionality of calculating energy and cost based on outlet usage duration and estimating the respective carbon footprint; (2) create email messages with device operation summaries and intruder alerts; and (3) develop a smart phone application for the visualization and device control.

The electRuBus IoT device aims primarily to make consumers aware of their energy consumption habits and help limit waste energy. Individual choices on energy consumption may seem too limited to stop climate change; but when scaled up in time and amongst society, they can undoubtedly have a significant impact.

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Bibliography

Anwaruddin, M., & Ali, M.A. (2017). A review on Raspberry Pi based industrial process monitoring and control using Modbus Protocol, *International Journal of Innovative Technology and Research*, 5(1), 5483-5486.

Darby, S. (2006). *The effectiveness of feedback on a review for DEFRA of the literature on metering, billing and direct displays*. Environmental Change Institute—University of Oxford: Oxford, UK.

Dhami, H.S., Chandra, N., & Srivastava, N. (2017). Raspberry Pi home automation using Android application, *International Journal of Advanced Research Ideas and Innovations in Technology*, 3(2): 521-525.

IPCC (2014). Intergovernmental Panel on Climate Change. In *Climate Change 2014: Mitigation of Climate Change*; Cambridge University Press: New York, NY, USA.

Kailas, A., Cecchi, V., & Mukherjee, A. (2012). A survey of communications and networking technologies for energy management in buildings and home automation. *J. Comput. Netw. Commun.* 2012, ID 932181.

Kolling, M. (2016). Educational Programming on the Raspberry Pi, *Electronics*, 5(3), 33.

Liyanage, C.D.S., Chamin, M., & Iskandar, M.P. (2012). State of the art of smart homes, *Eng. Appl. Artifi. Intell*, 25, 1313–1321.

Lobaccaro, G., Carlucci, S., & Lofstrom, E. (2016). A review of systems and technologies for smart homes and smart grids, *Energies*, 9(5), 348.

Nejat, P., Jomehzadeh, F., Taheri, M.M., Gohari, M., & Abd. Majid M.Z. (2015). A global review of energy consumption, CO_2 emissions and policy in the residential sector, *Renewable and Sustainable Energy Reviews*, 43, 843-862.

Regehr, E.V., Laidre, K.L., Akcakaya, H.R., Amstrup, S.C., Atwood, T.C., Lunn, N. J., Obbard, M., Stern, H., Thiemann, G.W., & Wiig, O. (2016). Conservation status of polar bears *(*Ursus maritimus*)* in relation to projected sea-ice declines, *Biol. Lett.*, 12, 20160556.

Siano, P., Graditi, G., Atrigna, M., & Piccolo, A. (2013). Designing and testing decision support and energy management systems for smart homes, *J. Ambient Intell. Hum. Comput.* 4, 651–661.

Wiig, O., Amstrup, S., Atwood, T., Laidre, K., Lunn, N., Obbard, M., Regehr, E., & Thiemann, G. (2015). *Ursus maritimus*. The IUCN Red List of threatened species 2015: e.T22823A14871490.

Yanga, L., Yana, H., & Lam, J.C. (2014). Thermal comfort and building energy consumption implications – a review, *Applied Energy*, 115, 164–173.