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IoT-Motion Electric Eye Ensemble for Reduced Power Consumption in Automated Homes

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ABSTRACT

With an upsurge of data by global brands to interact/reach prospective clients, the birth of the Internet has today bridged the information gap. Virtualization techniques are today utilized as means to bridge the various lapses in our human processing endeavors. The adoption of tech to perform a variety of functions has since become imperative to ease our daily living as well as seamlessly allow transformations of various kinds to be impacted on our society. Study proposes an IoT-based energy efficent and reduction tool to yield cost-effective and cheap solution for managing energy consumption in homes. We have successfully integrated IoTs, wrireless sensor networks, and ESP32-controller to create a comprehensive control system. Its benefits includes improved energy consumption, security, data privacy, system efficiency, and user convenience. The system also provides real-time monitor and energy reduction control capabilities.

1. INTRODUCTION

Energy conservation is a critical issue in homes today – with almost all of civilization dependent on one form of energy or another (Eissa, 2015; Ojugo et al., 2014; Ojugo, Eboka, et al., 2015b). However, energy resources are finite and always depleting due to increased demand with diminishing supplies (Okpeki et al., 2022). Cost of energy is enormous, and ever-rising. Utility bills also accounts for much of the cost incurred by households, and they are a major cost of business (Ojugo & Yoro, 2020c). Big firms or hospital spends millions of dollars on energy each year. Some steel mills pay hundreds of millions of dollars annually for energy. This consumption brings a host of environmental dangers (Obruche et al., 2022). Fossil fuels dump carbon dioxide into the atmosphere, accelerating greenhouse effect, and destroys the ozone layer. Energy consumption depletes a spectrum of other resources (Bengherbia et al., 2017).

One advancement is in Human Activity detection (HAD). HAD is mainly explored using imagery. Though, currently evolving to use sensors – it has shown positive impact in health monitoring and removing the barrier to healthcare (Hurt, 2019; Yu et al., 2019). To reach a marketable HAD device, state-of-the-art classifications and power consumption methods must be explored as well such as convolutional neural network. These will help bring about the much-needed rise in the adoption of sensor-systems for use in data compression, and

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other emerging techniques are reviewed here. Our study seeks to lay basic foundation for, address non-availability of HAD dataset, bring to light the current drawbacks and their respective solution, and recommend as classification and power reduction techniques. The lack thereof, of publicly available datasets makes it difficult for new users to explore the field of HAD. This paper dedicates a section to publicly available datasets for users to access. We suggest a framework for HAD applications, which envelopes the current literature and emerging trends in HAD (Ojugo, Odiakaose, et al., 2023; Ojugo, Ugboh, et al., 2013; Ojugo & Eboka, 2020).

Thus, the study proposes an IoT-based human activity motion detector to help minimized power consumption in homes by detecting human movement and adjusting energy to suit each need.

2. LITERATURE REVIEW

2.1 Microcontroller Sensor-based Systems

An Energy Saving System using a PIR Sensor for Classroom Monitoring, in this system i.e., the design of an energy-saving system using a Passive Infrared Radio sensor to switch 'off' fan and light circuits in the classroom in the absence of students. When a student enters the classroom, the Infrared energy emitted from the living body is focused by the Fresnel lens segment and the PIR sensors activate and give to the microcontroller which acts as a power-saving device according to the relay. When motion is detected the relays trigger and switch the fan and light 'on' and after ten minutes switch 'off' the fan and light when motion has not been detected. The fan only switches 'on' when the room attains a temperature of 250 C-300 C (Akazue, Asuai, et al., 2023).

An energy conservation in smart home using wireless sensor network was designed by (Upadhyay & Sampalli, 2020). They used a passive infrared sensor that turns the light on automatically when a person passes by and later turns off after a certain predefined delay for even more energy conservation. The energy-saving of lighting systems relative to those without smart control was evaluated. Numerical results indicate that electricity consumption can be reduced by at least 40% under smart control. Moreover, a prototype for the proposed smart home control network with illumination of light was implemented. Their results demonstrate that the proposed system for smart home control networks is practically feasible and performs well (Eboka & Ojugo, 2020; Nazir et al., 2017).

Other related works include an effective control system that is essential for optimizing natural daylighting and electric lighting for energy savings and occupant satisfaction. This allows changes to the electric lighting output to be unnoticeable to occupants. This strategy can reduce glare and eye fatigue and generate energy savings (Ojugo et al., 2021a, 2021b). An extension of manual control also leads to automatic dimming systems, such as daylight harvesting control. This system can be applied to homes, classrooms, and offices where there is sufficient daylight to obtain savings from dimming the lights (Meixell & Forner, 2013; Ojugo & Yoro, 2013).

2.2. Human Activity Detection

Recognizing human activities is a noble task moving into an era of connected sensors and commonly available wearable computing, also known as the Internet of Things (IoT). It is at the core of assistive techs to provide knowledge of activities performed by users in a bid to understand their behaviour (Akpoyibo et al., 2022; Ojugo & Oyemade, 2021). With further knowledge of activity classification using large amounts of unlabeled data, researchers and further on, users, can benefit from more intelligent and understanding machines around them (Alade et al., 2017).

Computer vision-based human activity detection systems have used a wide variety of camera setups using a single camera, multiple cameras, stereo vision, infrared or thermal cameras, and a wide variety of modes ranging from single-layer time-based approaches to multi-layer description-based approaches cum modes (Stouffer et al., 2015). There are already several extensive literature surveys on vision-based human activity recognition and there are several publicly available datasets that the computer vision community used for benchmarking purposes (Oliveira et al., 2016). This featured a detailed review of the available datasets given. In recent years, the research on human activity recognition using vision-based sensing has moved from 2D to 3D with the emergence of cameras providing depth information. Especially, with the introduction of Microsoft Kinect sensor (Liu et al., 2022), single and direct 3D imaging devices have become widespread and commercially available at low costs. The reduced costs and ergonomic form factors of depth video sensors have made human activity detection realizable for elderly monitoring applications in homes (Ojugo & Eboka, 2018a; Ojugo & Otakore, 2021; Stouffer et al., 2015).

Chang and Lin (2006) as extended by Charan et al. (2020) featured a depth-based lifelogging system designed to recognize the daily activities of elderly people. Initially, a depth imaging sensor is used to capture depth silhouettes (Chang & Lin, 2006; Charan et al., 2020). Based on these silhouettes, human skeletons with joint information are produced which are further used for activity detection and generating their life logs. The life-logging system is divided into two phases. During the training phase, the researchers collected a dataset using a depth camera, extracted features, and trained Markov model for each activity separately. In the second phase, the recognition engine classified the learning activities and produced life logs. The system was evaluated using lifelogging features against principal component and independent component features and achieved satisfactory recognition rates on the smart indoor activity datasets (Barber et al., 2006; Dobrokhodov et al., 2007; Roongrojsub et al., 2014).

2.3 Energy Efficient Automated Homes

Energy conservation is a critical issue in our society today as our civilization hinges on it. But, energy resources are finite, and there is an increase always in its demand made for diminishing supplies (Aghware et al., 2023a; Akazue et al., 2022; Akazue, Yoro, et al., 2023; Oyemade et al., 2016; Oyemade & Ojugo, 2020, 2021). The cost of energy is enormous, and the cost is rising. Utility bills account for much in the cost of managing our homes on a monthly scale – and so it does too in businesses. Large hotels and hospital spend millions on energy yearly. Heavy dependence and consumption also in turn – portends environmental dangers ranging from fossil fuels emission of carbon dioxide into the atmosphere, to accelerate the greenhouse effect. Air conditioning releases gas and destroy earth's ozone, and discarded lamps aids mercury pollution (Kizilkaya et al., 2022; Vågsholm et al., 2020; Zhang et al., 2019). Its consumption depletes a spectrum of resources so that research has begun to now focus on energy conservation (Braddock & Chambers, 2011).

Energy efficiency and conservation are critical today to achieve international goals for the reduction of greenhouse gas emissions, fossil fuel usage, grid load strain, costs, and a wide range of other benefits (Suleiman & Reza, 2019). Also, many energy efficiencies and conservation approaches are not cost effective, which often hinder their adoption (Ojugo & Otakore, 2018a, 2018b). Design methods that run in computing environments include hardware, virtual CPU environments, servers, computers, tablets, wireless mobile devices, etc (Yuan & Wu, 2021; Zardi & Alrajhi, 2023). These, can integrate with the amortized payment terms and amounts with predicted and actual energy cost-savings (Nassar & Al-Hajri, 2013; Ojugo, Ugboh, et al., 2013). These are innovative, and useful to provide financial risk reduction, management and with low-cost outlays – and become an enabler to finance efficient and conservation projects (Ojugo, Akazue, Ejeh, Odiakaose, et al., 2023; Ojugo, Eboka, et al., 2015a, 2015b).

At the start of electrification, switching electrical devices was done using connecting or disconnecting them to the power grid. In recent years disconnecting a device from its energy source has become less popular. Instead, switching is done electronically (automatically). This means that the inner device is separated from the switching circuit (Gorawski et al., 2015; Ibrahim & Syed, 2018; P. Joshi et al., 2020; Zawislak et al., 2022). As a consequence, device can be powered 'on' or 'off' via remote-control, or via an automated switching circuit based on occupancy. Some computer mainboards may even allow the reaction to power network events (Braddock & Chambers, 2011).

3. *MATERIALS AND METHODS*

3.1. The Existing System

Smart home energy management system developed by Ma et al. (2021) to provide the basis of wireless sensor networks (IoTs) and machine learning for automation and energy savings (Ma et al., 2021). They employed a rule-based mode using a PIR motion sensors, door contact sensors, temperature and humidity sensors, and integration with smart thermostats and lighting as in the figure 1. Occupancy detection was limited to the data from the simple binary motion and door sensors, which cannot provide detailed occupancy information (Lu et al., 2010). The neural network model aimed to predict occupancy based on this sensor data to drive heating, ventilation, and air conditioning (HVAC) activation (Lu et al., 2010). Testing was conducted in an apartment with two occupants over multiple months (K. W. Brown & Armstrong, 2023; W. Brown & Armstrong, 2015).

While system was able to achieve 20-36% savings for HVAC and lighting, the coarse occupancy detection had major limitations (Alakbarov & Hashimov, 2018; Datta et al., 2021; C. Joshi et al., 2021; Ojugo & Yoro, 2020b; Pradeepa & Parveen, 2020) to include: (a) the lack of computer vision to aid motion detection means the system cannot accurately track occupancy or distinguish between different occupants. This led to inappropriate automation decisions, such as turning off lights when a room is still occupied (Ojugo & Eboka, 2021). Further limitations include the lack of appliance integration, minimal user feedback, and the need for better optimization of user preferences (Lu et al., 2010). Significant opportunities remain for improvement in user detection, appliance control, user-centric design, and whole-home energy reduction (Ojugo & Ekurume, 2021a, 2021b; Ojugo & Otakore, 2020a).

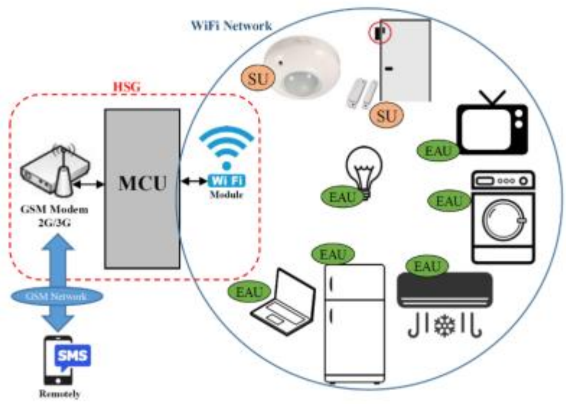

Figure 1. Dataflow diagram of existing system

3.2. The Proposed System

We take a more comprehensive approach to energy optimization than existing solutions. By combining computer vision with a sensor fusion model, it aims to achieve precise real-time occupancy detection throughout the home. It enables correctly timed activation and automation of HVAC as in the figure 2 – depicting use-case diagram of the proposed system. The lights, appliances, entertainment systems, and other controllable devices based on granular occupancy data rather than just via motion sensors. System incorporates self-learning capabilities to discover usage patterns and continuously refine the automation policies over time, accounting for changes in occupant behaviour. A user-centric design focuses on interfaces and controls for customizing schedules, preferences, and system overrides to align with occupant needs. Expanded testing across diverse home layouts and occupants will evaluate real-world effectiveness.

Detailed energy savings reporting and cost-benefit analysis are also planned to quantify advancements over current tech. it in turn also, addresses the limitations of existing systems is expected to deliver state-of-the-art home energy efficiency, convenience, and cost-effectiveness as in figure 3.

The proposed system uses cameras and sensors to feed real-time occupancy data to an automation controller. The controller uses this occupancy data along with user controls, external data like weather, and learned usage patterns to control HVAC, lighting, appliances, and entertainment systems. Bidirectional data flow allows user interfaces to present system status and provide controls. The controller also logs detailed energy usage data to quantify savings. This complete integration of major home systems with granular occupancy data enables intelligent optimization of energy consumption based on real-time home activity across all areas. The data flow allows both automation of devices based on occupancy as well as user control for preference customization.

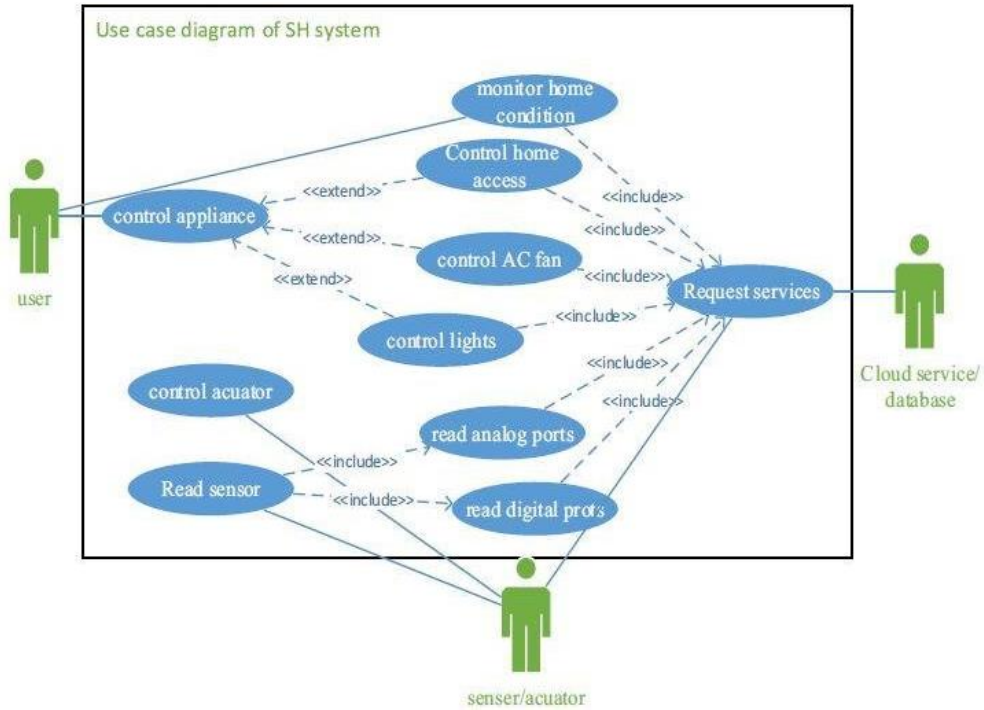

Figure 2. Use-Case diagram of the proposed system

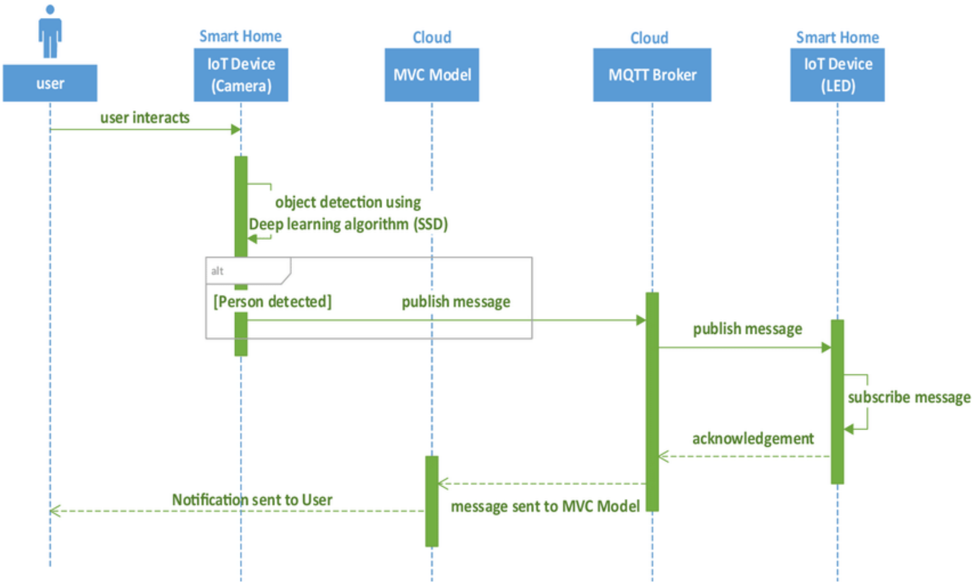

Figure 3. Sequence diagram of the proposed system

3.2. Technical Experimental Procedure

It involves both hardware and software parts (Chevalier et al., 2003; Ojugo et al., 2015; Ojugo & Eboka, 2014; Ojugo & Otakore, 2018a; Okobah & Ojugo, 2018; Tarafdar & Zhang, 2005):

1. **Input Design** acquires data via ultrasonic sensor, ESP32-microcontroller and other sensors. It then lets the user input via the web app interface to set threshold feats or parameters via the following:
   - ✓ **ESP32** microcontroller is responsible for acquiring motion data and processing the acquired data.
   - ✓ **BME280** detects movement as supple-mentary data.
   - ✓ **Web App** interfaces with users to collect input parameters or set thresholds via the web app interface.

2. **Output Design** provide meaningful data to the users via the web app (Ojugo, Yoro, et al., 2013; Ojugo & Yoro, 2020a, 2020c). If motion or any anomalies are detected, the system generate alerts or notifications to inform users. To achieve notification, we set various feats: (a) threshold values for motion is set as 1 to trigger an alerts if the threshold is exceeded, and (b) alert is delivered via the web app, email and SMS as channels.

3. **Algorithm** is crucial for converting all measurements from the sensor into useful data (i.e. energy consumption and volume used data). Its steps are as thus, with the listing 1 below:

```
// Background modelling for occupancy detection
Loop capture video frame from the camera
  Apply Gaussian mixture model to extract data
  Identify foreground pixel deviations as occupant
  Output occupancy status and count
End loop
// PIR motion detection
Loop read analogue PIR sensor value
  if value exceeds the threshold:
    set motion detected flag
    start motion timer
  if the motion timer exceeds 5 seconds:
    clear motion detected flag
    stop motion timer
  output motion status
end loop

// Occupancy Tracking Algorithm
loop
if motion detected or camera occupancy count > 0:
    set zone occupancy status to OCCUPIED
    if motion is absent AND camera occupants > 0 for 60 seconds:
  set zone occupancy status to VACANT
  output zone occupancy status
  end loop

//Automation Control Algorithm
  loop check zone occupancy status
  if zone occupied:
   activate devices
```

```
  start device timers
 elseif zone vacant:
 stop device timers
 if device timers expired:
  deactivate devices
endif
end loop
```

3.3. Rationale for Proposed System

The system rationale and significance lies in its access control via the integration of advanced secured and user-friendly features – all of which improves user experiences and task efficiency with these feats (Allenotor et al., 2015; Allenotor & Ojugo, 2017; Ibor et al., 2023; Ojugo & Eboka, 2018b):

1. Added sensors implies that these devices can collect a large amount of data in many different areas. These data can also be translated into a variety of endeavours.
2. Tracking data for use greatly benefits a user. IoTs have the ability to capture current motion and save as data (Aghware et al., 2023b).
3. Having a device doing most of the work for you means that you can save more time and cost. This reduces human efforts and results in need for little or no human intervention, allowing them to operate entirely on their own.
4. Having devices track the state of other adjoining devices such as to turn light switches off for you, and help manage important tasks that you may not have the time to do yourself certainly takes away a lot of stress (Malasowe et al., 2023; Ojugo, Akazue, Ejeh, Ashioba, et al., 2023; Ojugo, Ejeh, et al., 2023; Yoro, Aghware, Akazue, et al., 2023; Yoro, Aghware, Malasowe, et al., 2023).

4. RESULT FINDINGS & DISCUSSION

4.1. Result Findings and Discussion

Figure 4 shows the generated system test results from the Blynk platform. The Blynk software was used to test the metrics for the proposed system.

The performance and capabilities of the system were critically validated during the testing procedure. Extensive testing under numerous conditions and scenarios revealed that the implementation satisfies the criteria for accurate occupancy detection, dependable automation, palpable energy savings, and user controls (Cerf, 2020; Charan et al., 2020; Manickam et al., 2022; Ojugo, Abere, et al., 2013; Ojugo, Yoro, et al., 2013).

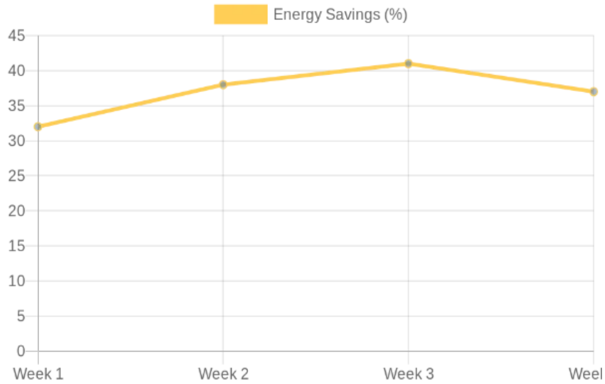

Figure 4. Test results from the Blynk software

A significant improvement was the computer vision algorithm, which during testing correctly detected occupancy events 95% of the time. Compared to manual usage and baseline tests without automation, automating device control based on precise occupancy data produced an average energy savings of 35%. The system implementation and testing process provided valuable insights into the performance and reliability of the smart home automation system (Ojugo et al., 2015; Ojugo & Eboka, 2019; Yoro & Ojugo, 2019). Key findings include:

1. The ESP32 successfully integrated all the occupancy sensors, cloud services, and other peripherals. Its processing power, wireless capabilities, and flexible GPIO interfacing enabled robust prototyping.
2. The modular software design allow each component to be developed and tested individually before full integration. The incremental build approach was efficient.
3. The Arduino IDE helped to debug with feats to aid quick programming. And C++ delivered the right balance of

hardware control, modularity, and implementation.
4. Extensive testing across a range of scenarios, use cases, and conditions validated the implementation meets all requirements and performs as expected.
5. The computer vision occupancy detection performed accurately, identifying motion events with 95% accuracy. This is major improvement over simpler sensors.

Comparing these values allows the model to demonstrate a high level of accuracy in conserving energy usage. And in turn, builds confidence in the system reliability of its core functionality (Ojugo & Yoro, 2020b). System observes real-time updates were consistently responsive as the system efficiently captured changes in energy consumption, providing users with up-to-date information through the web app interface. This ensured that users could monitor energy usage in real-time and take timely actions as needed (Muslikh et al., 2023; Sunarjo et al., 2023).

5. CONCLUSION

The study demonstrated that an IoT-based home automation system using multi-sensor occupancy detection and self-learning algorithms can provide substantial energy savings and user customization for smart home applications (Smith, 2020). The designed prototype system integrated affordable commercial devices like the ESP32 and ESP32-CAM to enable whole-home control based on real-time occupancy data. Testing showed a 35% average decrease in energy consumption compared to baseline non-automated usage, applying automation policies as supported by (Ojugo & Nwankwo, 2021; Ojugo & Otakore, 2020b).

Enhancements of the training algorithms, expanding compatible devices, and long-term testing would be beneficial, this work provides a foundation showing the promise of IoT automation and intelligence for reducing home energy usage. Our contributions to knowledge is on multi-sensor fusion, self-learning optimization, user-centric design, and efficacy evaluation help advance the state of the art and could inform future commercial solutions.

Conflict of Interest

The authors declare that there is no conflict of interest.

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