Environmentally-Conscious Homes

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***Abstract*—Water shortages are growing more abundant, even in western countries. This will inevitably lead to droughts, especially in Utah, as Lake Powell and multiple others are rapidly losing water storage each year. On top of that, energy is an ever-present factor, with people constantly thinking about turning off lights to reduce energy usage. In order to efficiently use resources, each person must become conscious in their usage. But what if your home could take care of that for you? New, more environmentally conscious smart home system, empowered by the injection of artificial intelligence, will realize the potential of optimizing resource utilization to minimize waste. To start, we have created a smart home driver where you can swap out AI modules that that learns a person's behavior and reduces resource usage to suit their needs while leaving the user to their business and preserving precious resources.**

I. Introduction

RESOURCE shortages are a global issue that society has spent decades fearing. Glimpses of this are now more apparent. Up to 46% of the global population could face water shortages by 2050 [1]. Despite these fears, there is still time to act. Individuals can monitor their resource usage to prevent wasteful habits, but there is no guarantee for even a small percentage of people to have long-lasting habits. Although we cannot easily solve this looming threat, we can certainly demonstrate a proof-of-concept technology that, if widely adopted, could serve as tool for mitigating resource wastage. Smart home advancements have improved resources usage and requires further improvements to ensure a stable future [2].

An artificial intelligence based enhancement to existing smart homes is a small addition that can allow for intelligent sensory to optimize energy usage. This could remove the burden for people to be vigilant when taking a shower or washing the dishes. Instead, the AI will determine the minimum amount of that resource is needed. This reduction in resources could have a meaningful impact on resource wastage if it is adopted by a small percentage of homes. The smart homes of the future will take the hard work of being environmentally conscious off the user.

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II. Related Work

A. Smart Homes

Smart Homes and home automation have a large, existing market. Most of these look to automate heating, lighting, and energy usage without user input. But these are typically set as tasks by the user themselves (e.g., turning the lights on at 5 P.M. and off at 9 P.M. automatically).

For this project, the *Control4* smart home platform is the focus. This company provides tools for the user to control lighting, security, home theatre systems, and more using their open-source Smart Home OS and smart home hub. These tools give additional control to the user, even to change lighting in their home when in a different country.

While all of these give the user more control over their home, this project aims to handle certain parts for the user while still allowing them full control. For example, the water faucet is set to output 75% water while being used, because the AI system determined that is how much the person needs. If necessary, the user can change the exact number to their liking, but the goal is to have the AI handle it for the user.

B. Artificial Intelligence

Since the advent of computers, scientists have been studying how computers can learn to think. While this project will not focus on higher-level thinking in computers, it does require that a computer automatically identify different properties of different persons, such as age. The AI module of the project will use *OpenCV*, which is a popular library for computer vision.

OpenCV was chosen for its open license, computational efficiency, and focus on real-time applications [3]. These will provide a seamless experience that a user would expect in the smart home. Additionally, this AI could be used in limitless ways to improve existing current smart home technology. This project provides a driver that can be switched with different AI models to control the smart home however the user pleases.

III. Design

A. Technical Overview

Our system is a flexible, generic approach to resource management such that it could be applied to a wide-variety of resources in a smart home. This is done by changing what kind of sensor and model can be used as an input, and what can be controlled on the output. Simply put, allow any machine learning model to control any part of a smart home the user desires. In this case, the proof-of-concept approach for this project is to demonstrate a system with a camera input with an age-recognition model for detection and a water faucet as an output to limit water flow depending on need, or in this case, the age of the person where if they're younger we expect to provide less and if they're older we expect to provide more. We also integrated an emotion detection machine learning model that is set to output different amounts of water for different emotions. For example, happy is able to use 100% capacity while anger is denied any water.

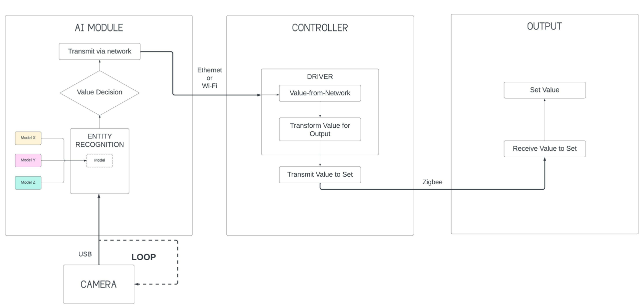

Fig. 1: Block diagram showcasing how different parts of the project communicate to decide how much of a resource to use.

As such, it is comprised of three main sections. The first is the AI module, where intelligent sensory can occur. The NVIDIA Jetson Nano 2GB board and connected camera fill in this module, utilizing computer vision to detect any desired qualities, such as age or emotion .This module also decides how much of a given resource is allowed to be used. This will be running as a Python application due to Python's capabilities as a data science an machine learning language. Specifically, OpenCV and Tensorflow libraries are used for their ease of use and ubiqutiousness.

While Control4 has many drivers built into the system, our implementation skipped the native driver and instead communicated to the Control4 Controller to get or set values. This allows more flexibility with the Control4 application programming interface (API). The controller is a device which serves as the hub for the entire smart home, taking an input (usually connected to an app in the form of a user interface) and giving an output to then control any given device in the home. In this case, we can replace the "user" with the intelligent sensory form the AI module connected to the controller, effectively automating the control process.

The end of the flow would be the output, which can simply take instructions via a wireless network, such as Wi-Fi or Zigbee. We can implement any device with a wireless receiver which can then control voltage output into it, allowing for granular adjustment. In this case, we will connect a motorized valve which will then connect to a faucet, such that the valve limits the maximum water output from the faucet. See Fig. 1 for further detail. This device can essentially be anything that plugs into the wall. In our case, we printed a PCB to rectify the AC voltage from the wall to a safe 0-10V DC range that the motorized valves can use as an input signal.

B. Computer Vision Framework

We use both OpenCV and Tensorflow as our computer vision libraries. OpenCV and Tensorflow are libraries used across many industry applications and allows for the use of many ready models as well as custom models we can train ourselves. This flexibility allow us to quickly integrate models into our program. We added an age detection model that uses OpenCV and an emotion detection model using Tensorflow. Note that OpenCV was compiled to use NVIDIA Compute Unified Device Architecture (CUDA) cores that are found in the NVIDIA Jetson. This results in almost five times performance improvements with frames processed per second increasing from 3-4 to about 15. CUDA cores are designed for heavy, parallel work, such as machine learning and computer vision algorithms [4]. While this same improvement was attempted for Tensorflow, it was not successful. This is due to versioning issues between the NVIDIA Jetson and the version of Python we decided to use (3.7.5).

C. Control4 Communication

The Control4 smart home controller ultimately decides the value for each device in the smart home. Therefore, it is imperative to be able to efficiently communicate with the controller from the Jetson. To do this, we connected the Jetson and EA-1 controller via Ethernet and communicate using Control4's RESTful API, which is abstracted using the PyControl4 library. It brokers the connection between the AI module in the Jetson Nano and the output, which we consider to be the faucet for our demonstration. It runs on the control hub, which is a device that links into the home network in order to communicate with all the devices. Built in to the device are Wi-Fi and Zigbee wireless communication transmitters and receivers and Ethernet wired ports. Any device which we desire to be controlled by the controller must be paired with the control hub via Control4's Composer software. The device used for our demonstration is a dimmer outlet, which outputs varying AC voltage levels. We implemented this in a modular way, with each computer vision model being constructed in an object-oriented way for quickly switching models. This allows for both generic devices, as long as they can connect to the Control4 network, and generic machine learning models, all while staying within one smart home ecosystem.

Fig. 2: Typical smart hub used to control various parts of the household. This one panel can control lighting, security, and AV systems. Provided by ValleyHomeTheatre.com

D. *Bill of Materials*

Below is a list of hardware and software requirements used on this project. To see specific hardware details, see Table I.

Hardware:

- Standard water faucet. typically found in American restrooms.
- Proportional electric motor valve
- NVIDIA Jetson Nano 2GB
- Control4 Smart home infrastructure
  - Control hub
  - Dimmer outlet

Software:

- Control4 Composer
- Computer vision
  - Python 3.7.5
  - PyControl4
  - OpenCV
  - Tensorflow

TABLE I: Different parts and their respective manufacturer required for this project.

Qty	Part
1	Part: IMX219-160IR - IR Camera Mfr: Waveshare
1	Part: Jetson Nano 2GB Mfr: NVIDIA
2	Part: 10V Electric Proportional Valve Mfr: Tsai Fan
1	Part: Smart Home EA-1 Controller Mfr: Control4
1	Part: Smart Home IO Extender Mfr: Control4
1	Part: Smart Home Dimmer Outlet Mfr: Control4

IV. Delivery

There are different parts of the project that require individual progress tracking. There are various hardware, software, and planning stages that must work together to form a cohesive project. Here is a breakdown:

- Project Meeting URL: Project Notes
  - Each planning meeting is recorded here, with various notes and details included.
- GitHub page: Clime-Smart-Homes
  - The repository containing all source code (where legally allowed) necessary to build the project yourself. Note that some Control4 functionality may require licensing and is not able to be published publicly.

A. *Results*

The system is made up of multiple parts. There is the smart home system, water faucet, and single-board computer that is communicating between the other two. This single-board computer acts as the AI brain, taking in information from the camera and telling the smart Home system how much water to use. This project focuses more on the AI training rather than the hardware side, so it builds off existing smart home technology, specifically on the Control4 environment. This allows us to talk with the API of their smart home system to control various parts of the home. A trained machine learning model running on the single-board computer reduces water based on the weight or emotion of a person via the smart home controller.

We were able to construct a fully functional model smart home with integrated faucet, Control4 controller, and NVIDIA Jetson. Unfortunately, during our demonstration on campus, the networking had prevented the

Jetson and controller from communicating, preventing interaction. While we had believed to have solved this by having a laptop act as a router, it still did not work when demo day came around. When integrated with an existing networking with internet connection, such as one you might find in any modern home, the system works together well.

In terms of direct performance, the machine learning models had varying degrees of success. The age detection model ran well with CUDA integration, running at about 15 frames per second and accurately identifying an individual's age. But the emotion detection had worse performance, only achieving about 2-3 frames per second. This is due to the Tensorflow binary provided by NVIDIA not working with the Maxwell GPU architecture. Attempts to compile our own version were fruitless, potentially due to differing Python versions. Additionally, the emotion model was not as consistent as the age detection model, but would usually identify happy or angry accurately. We had attempted to also integrate a glasses detection model, but the model we found did not have enough accuracy for our liking.

B. Milestones

Here are the main milestones accomplished with our project.

- ☑ Construct model smart home faucet
  - Large aquarium to hold water.
  - Standard sink faucet
  - Motorized valves
- ☑ Setup NVIDIA Jetson development environment
  - We chose Python 3.7.5, which is above the default Jetson version of 3.6.9. This because of the asyncio library being more fleshed out and versatile for Python 3.7.
  - Compile OpenCV for CUDA core acceleration
  - Integrate machine learning models with corresponding output levels for Control4 Controller.
  - RESTful server to easily change the active model
- ☑ Integrate model faucet with Jetson
  - Networking between Jetson and Control4 API.
  - PCB to rectify output from dimmer outlet.
  - Complete age identification and water adjustment without any direct input from the user.

C. Testing and Integration Strategy

- Water flow sensing - Measure how much water is flowing through the pipe before and after the computer vision models recognizes various features.
- AI training - Find high accuracy models that perform well against validation data sets.
- Integration - Provide accessible user interface such that the anybody walking up to the camera sees instant change without active input on their end.

Overall, the project was a success in demonstrating what we sought out to do: integrating smart homes with artificial intelligence. By making these first steps, smart home developers can employ AI into their ecosystem, while still meeting the needs of the end user. We have smart houses, so let's be smart about our resource wastage.

Conclusion

Smart home technology is allow for higher quality of life and increased convenience. We hope to expend these features to include reduced resource usage. As a team, we believe we have proved the concept of integrating smart home technology with AI, without reinventing the infrastructure of modern smart homes. Just in this example, existing Control4 systems could integrate with almost any machine learning model with developer resources. Developers or smart home users can train their own AI models to look for certain parameters, causing a desired part to change its output, whether it be a light bulb, faucet, or something else that communicates with the smart home. While NVIDIA Jetsons and smart faucets may not be a staple in every household, we hope employing AI to reduce resource wastage is the key takeaway.

Acknowledgement

We would like to thank Control4 for their contribution. They provided smart home equipment for us to use as a development platform. We would especially like to thank Jeff Thomas, Vice President of Product Development at Snap One (Control4), for acting as a mentor and guide to learning resources.

Additionally, we would like to thank Chris Schuller for providing technical assistance for hydraulics relating to the motorized faucet.

Finally, we would like to thank Ken Stevens for his guidance this semester.

References

[1] S.N. Gosling and N.W. Arnell. "A Global Assessment of the Impact of Climate Change on Water Scarcity". In: *Climatic Change* 134 (2016), pp. 371–385.

[2] Harpreet Kaur et al. “Chapter 10 - Intelligent Smart Home Energy Efficiency Model Using Artificial Intel ligence and Internet of Things”. In: *Artificial Intelligence to Solve Pervasive Internet of Things Issues*. Ed. by Gurjit Kaur, Pradeep Tomar, and Marcus Tanque. Academic Press, 2021, pp. 183–210. ISBN: 978-0-12-818576-6. DOI: https://doi.org/10.1016/B978-0-12-818576-6.00010-1. URL: https://www.sciencedirect.com/science/article/pii/B9780128185766000101.

[3] NVIDIA Developers. *What is OpenCV?* 2022. URL: https://developer.nvidia.com/opencv.

[4] J. Nickolls and W. J. Dally. “The GPU Computing Era”. In: *IEEE Micro* 30.2 (2010), pp. 56–69. DOI: https://doi.org/10.1109/MM.2010.41.