Distributed Climate Control (DCC) - Project Summary

By Team **Slam Town**
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Overview: Welcome to the Distributed Climate Control (DCC) project. This system will help businesses, homeowners, and other institutions save money on energy spending by dramatically reducing the amount of heating and cooling spent on air space that no one is occupying, as well as contributing to global efforts to create affordable, sustainable energy technologies. This project specifically aims to provide information specifying how many people are in a room, and where they are situated. This information will be used by a HVAC system which can target specific regions of a room. This project is inspired by the ARPA-E's research and funding of advanced energy systems.

Intellectual Merit: This Small Business Innovation Research Phase I project will have to effectively use a variety of sensors to obtain features to train an accurate machine learning model. The device will combine thermal, color, and depth imaging to track where in a room people are, and specifically how many people occupy certain areas so that an HVAC device could heat or cool only regions of the room occupied by people. The sensors used will be a flir lepton thermal camera and a kinect v2 RGB-D camera. Significant challenges of this problem include accurately calibrating the system in the room despite not having a long-range depth sensor, and making the system portable so that it can be placed at a high vantage point and out of the way from any of the activity in the room. Additionally, the device should be able to communicate to a separate, more powerful machine which can help with additional processing including training the headcount and distribution model. Due to the small field-of-view of the thermal camera and the need to combine the images of multiple sensors, the kinect and flir lepton thermal camera will have to pan and tilt to capture a full image of the room, requiring strong and accurate motor control to capture a point in time accurately in a short time frame.

Broader/Commercial Impact: This project will demonstrate a new method of saving energy in a way that is attractive to businesses and homeowners. The non-intrusive nature of our device combined with the amount of money to be saved by consumers makes a strong argument for the DCC's success on the market, and furthers research of sustainable and forward-thinking energy technologies. Additionally, the DCC will explore the ability to create a device with currently obtainable and affordable technology, strengthening the importance of an effective prototype.

Distributed Climate Control (DCC) - Elevator Pitch

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Heating, ventilation, and air conditioning make up 48% of the energy used in a typical U.S. home. HVAC makes up the largest energy expenditure of households, as well as many typical businesses. However, a great portion of HVAC resources are spent in locations where people don't even occupy, repeatedly heating and cooling air surrounding nothing. This is waste of money, and energy which could easily be solved by our product: The Distributed Climate Control system.

DCC is an embedded solution to today's HVAC problems. By using an assortment of sensors and S.O.C.'s, we have designed an inexpensive, accurate way to determine the number of people occupying a room, where they are situated, and how comfortable the air temperature surrounding them is. Using this data, HVAC systems will be able to target locations of a room where people exist and are situated in uncomfortable climates. This data will be collected real time, so that people entering and leaving the room will instantly allow the systems to know when to start and stop.

Our implementation involves using a Kinect RGB-D sensor to capture rigidbodies in the room as well as high resolution images. This data will be combined with a heatmap captured by the flir lepton 3 thermal camera in order to train a machine learning model which can be calibrated to work with variable sized rooms and large groups of people. The thermal camera will also be able to determine the relative temperature in room locations, meaning that the HVAC system can further save energy and money by shutting off if a well-populated region is already sufficiently cooled. Both camera modules will be mounted on top of a single automated pan and tilt bracket driven by servo motors, allowing the two sensor modules to synchronize their data easily and accurately.

There are several main problems that need to be solved in order for our system to have full functionality. One of these is training a machine learning algorithm to interpret our data and produce accurate information on population and heat distribution in a room. It is likely most of the training done for our machine learning model will be done by hand via counting the amount of people in the room and telling our algorithm the correct answer, or by having to build our own some type of program to assist us in training the model; in either case this requires a significant amount of time. Other problems that arise with this are data storage and getting real-time results. In order to train our algorithm and process all of the different types of data we are getting, we will need to be able to store large amounts of data. We will need to figure out the best way of storing/streaming our data to simplify this process. Obtaining results in real-time is also a large problem that we may run into. Since we are doing our processing on the UP Board, it could prove difficult to get our information routinely and reduce latency.

Distributed Climate Control (DCC) - Elevator Pitch (Revised)

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Commercial and Social Impact

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Introduction

The Distributed Climate Control project presents value in multiple areas. The project's success is assured by the nature of energy being a universally expensive as well as limited environmental resource. Not only will DCC be a successful business venture, but it will be an important research initiative into the still under-explored realm of machine learning and energy conservation.

The Commercial Opportunity

At first the product will be marketed towards large companies and businesses. Usage will be marketed as for conference halls and other large open areas. This is important as it will be much more difficult to market towards smaller spaces like apartments, homes, and small businesses. Later on, once it is proven successful in that field, it can be adjusted to be marketed for home use. It may be expensive and not beneficial in the short run for some small-space users. However with shown strength in use in industrial use, it would be more convincing. This combined with effective marketing and statistics should allow for marketability for homeowners.

The prototype model for our senior design project will cost around $800. This includes the 2 sensors, SOCs, wires, servos, and pan/tilt bracket. With streamlined production and better organization, the price could get as low as $400 for the setup. This does not include the actual HVAC systems that are being created for the distributed cooling and heating. That will be a separate setup and cost, which is up to the discretion of that team. Based on their project, it should cost around $1500. As described before, the customers in the end will be homeowners and businesses/companies. Again, at first marketing will be directed at large/small companies, as it will be easier to see the beneficial impact for those groups. These groups will have access to large conference-like spaces in all likelihood, where the system is designed to work optimally.Once proving that it works in this environment, it will be much easier to market towards homeowners. The DCC system works well in a large, open environment. Fortunately, these areas exist in many American homes. A living room in a suburban home, or a studio apartment; these are great places to put a DCC system, as the sensors are able to get a great view of the whole environment.

The competition for DCC is, in all likelihood, not going to change greatly by the time it enters the market. HVAC in its current form has existed for many years, and only in the past ~20 years has it evolved with "smart" technology and connection with the Internet of Things. These advancements work towards integrating many other services together for a simpler user-end experience. An example of one of these products is the Nest thermostat system. This product uses methods to find patterns in what temperature the user needs/wants depending on the time of day. Options or the temperature can be controlled from the user's phone as well. DCC actually does not necessarily interfere with this technology. It will still accept a certain temperature for a room, which could be set from the Nest, and just monitors/distributes air in a different and more efficient way than traditional HVAC. Other evolutions in the field involve air-purifying technology, reducing the amount of harmful particles present, increasing efficiency and reducing greenhouse gas emissions. DCC approaches air-purifying at a different angle, reducing the amount of greenhouse gas output by only heating or cooling one portion of a room at once. Thus the system is reducing greenhouse gas output in a different way than current air-purifying technologies. It also is somewhat independent, such that the air-purifying could be implemented for DCC without any major changes at all. Thus DCC does not have much competition in terms of other products providing the same service, the real risk is whether the changes it brings to the table are useful enough to be implemented.

Marketability is going to be significantly more difficult for smaller businesses and homeowners compared to larger groups. Again, as said before, marketing for larger businesses first is essential to establish a proof-of-concept to become more broadly marketable. The reasoning behind this is that for smaller residences and offices, the results in terms of lowered energy usage and costs would be less substantial and potentially not worth the cost of installation. Over time, DCC should be worthwhile for any moderately sized room, but for certain types it may be much longer before the benefits outweigh the costs. For example, in a living room of a person's home, if it is used frequently by multiple people at once, most or all of the HVAC systems may need to be used at once, making it behave similarly to traditional HVAC. Also, if a user in a suburban, two-story home wanted to install DCC all across their space, they would need multiple systems to account for each room. This could get expensive, and simply may not be worth it for the average homeowner. Bringing this back to the beginning, this is another reason why a more corporate/industrial marketing strategy at first is important. If DCC cannot succeed in that environment, it is extremely unlikely that it will be at all successful in other areas.

According to ARPA-E's DELTA program (https://arpa-e.energy.gov/?q=arpa-e-programs/delta), a system like DCC that distributes heating and cooling more efficiently throughout a room could reduce costs for a home's HVAC by 15%. Translated into actual cost reduction, this would result in around a $150 cost reduction per year. This is a substantial decrease, albeit with significant installation costs, and if marketed well enough, would be an important statistic to convince consumers to invest in DCC. These benefits would be even greater than 15% for places like large conference halls as discussed earlier, and should be even more convincing for companies.

Societal Benefits

This project is addressing the massive amounts of energy wasted in everyday life by cooling and heating air in which there are no human beings occupying. The current model of Heating and Air Conditioning homes and buildings is simply broken and outdated. Currently, 65% of energy in the United States is still supplied by burning fossil fuels, which is the largest portion of any other energy source currently in use. This is particularly bad because burning fossil fuels releases a lot of carbon emissions, and is very destructive to animal habitats.

An immediate benefit of the DCC project is reducing the usage of these environmentally damaging energy sources. By reducing the amount of total energy used both on a national and international scale, we can collectively move more towards clean energy options supplying a larger percentage of energy to handle the smaller load. During and after a development like this, the system is still effective; regardless of where the energy is being sourced, the DCC will use less of it. This is important for the continued of the DCC and energy use in general. The DCC is not tied to any resource in particular, so regardless of any new developments in the field we can apply our technology to gain the same environmental and economic benefit and success.

It’s very reasonable to imagine many homeowners or businesses with modern heating and cooling appliances to adopt our system of climate control. At a price of a single installment of a few hundred dollars per room and even less once the system is produced by well-organized manufacturing, the DCC could be an international standard in terms of how HVAC works. While the project is sharply focused on reducing energy for environment reasons, it is necessary to have such traits which support its commercial success in order to entice the general public to invest in it. Regardless of an individual's environmental consciousness, the economic incentive alone for installing the DCC suggests that it will be sustainable for long-term development. With such commercial success, we can expand our user-base to contain a large demographic of people who are solely interested in saving money. With this in mind, it's important to note that the product will be more successful in countries and regions which are developed enough to support modern heating and cooling in homes as well as in corporate spaces. This is already a large demographic, and as more regions develop socio-economically, their homes and businesses can be fitted from the start to take advantage of the DCC.

Unfortunately, there are some security and ethical issues related to our project and its implementation. This boils down to two areas specifically: the RGBDT image feed, and the system’s connectivity.

The DCC requires the use of several image feeds to train its machine learning model and determine the temperature of the room as well as the people occupying the space. This could be seen as an invasion of our client’s privacy if they don’t trust the handling of this video data. This issue should not be a cause for too much concern, because video cameras have become common in many household items such as smartphones, laptops, security systems, baby monitors, and video game consoles. We will not actually be uploading any of the actual image or video data to our servers, but we must be very conscious of cyber attacks on our customers privacy to prevent this measure.

Regarding the security of our device, we will have to worry about malware our the network. The need for connectivity between multiple SOC’s as well as reporting information and performing diagnostics on our system means that it will be connected to the internet, at least on a periodic basis. Reducing the time the system is connected to the network will help prevent against malware, so a periodic transfer of data and updates using a highly secure encryption method would make the DCC resistant to attacks. This periodic upload would also not be very time sensitive, meaning slower but more secure methods of data transfer over the network would be possible. In addition to third-party security threats, it's also important to acknowledge that the owner of a system may attempt to abuse the data being collected by the DCC. We don't want users to collect video footage of guests or employees using the system, and therefore must keep the device itself secure from data collection by any users besides our own infrastructure. This means that users should be able to configure temperatures they prefer and other preference based settings, but not have access to changing source code or making hardware modifications.

Summary

The DCC aims to promote more efficient energy use on a global scale through a design that is efficient, secure, and applicable to many different environments and technologies that make it sustainable for use in both the present day as well as many years into the future. As local thermal control means improve, the DCC will remain effective by providing the information and configurability needed to make users happy while saving money and energy in the process. The DCC's attractiveness to a large demographic of users and applications suggests that it's commercial success will allow it to be profitable while blazing the trail for efficient climate control and sustainable energy technology for the future.