Putting HVAC to Music

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Introduction

As educators in an exploding world of technical knowledge, we must always look for ways to get students to learn material faster. One way of doing that is to stimulate more of the students' senses. The magic of the computer allows us to do that. At PennState Fayette campus, we offer an ABET accredited Associate Degree program called Building Environmental Systems Technology (BEST). This program prepares students for all aspects of the Heating, Ventilating and Air-conditioning (HVAC) industry. But to adequately expose the students to the many inter-related aspects of this broad industry in such a short time is a challenge.

As reported in the literature[1], faculty in the BEST program have been using the computer for many years to facilitate students' understanding of aspects of the HVAC industry. With vastly improved computing speed and output quality, a Basic program that produced jerky black and white animations of moving blobs[2] is now a Java-based, smooth, multi-colored interactive teaching tool for psychrometrics[3]. With the advent of the internet, this tool can be made available to students and faculty anywhere, any time.

The internet also allows faculty access to Shareware tools that can be incorporated into the classroom experience. One of these tools is a nifty shareware software package that allows you to produce animated gifs[4] very easily. Unfortunately, it is still a rather time consuming process. My best estimate based on the work reported in this paper is that an experienced user can expect to spend at least an hour to produce a simple ten-second animation.

But why use music? My experience is that a majority of the engineering and technology students relate well to music. I choose familiar tunes that most students will recognize. I would like to think that when they hear a particular tune in the future, their minds will connect with a technical concept. But pragmatically, I use this method because of my long experience with the Boy Scouts of America. Their teaching philosophy is that you should make learning fun. When students are having fun, they will retain more knowledge, because they will spend more time on that particular task. Perhaps this theme is the most important message within this paper.

The Process

Discussed below are the steps to follow to develop your own musical animations. Since I would like to be able to say that it is as easy as One-Two-Three, I had to start with a zero step, which is very important, but really must come before the actual process of making the animation.

Step Zero - Develop an Idea

Perhaps the most difficult step is to simply come up with a problem that needs a solution and to select an appropriate musical background. Virtually any process or cycle that involves movement can be animated to music. Thermodynamic loops (especially boiler and refrigeration loops), chemical processing, electrical power, and even feedback control loops are candidates for fun applications.

Selecting appropriate music is the second issue that must be addressed. The tune must be familiar to the student and readily available. Generally, popular instrumental pieces seem to work best for me, but classical music can also be used. For example, the William Tell Overture seems perfect to track an electron or water molecule through a generator or boiler respectively. The 1812 Overture might represent charge building up in a capacitor until it arcs through a spark plug. You could have lots of fun with Beethoven's Fifth Symphony. The list of possibilities is endless once you get into that frame of mind.

Step One - Build an Animated Gif

Once you know what you are trying to accomplish, develop the series of images required. I have always used Microsoft Paint to develop bitmaps, but you can use any graphical format that can be translated into gifs. Generally try to develop the final picture or background image first, because the earlier images can be quickly developed once you know where you want to go. When moving a dot through a loop, I generally use four images to track with the beat of the music. Keep the step increments as small as possible to provide a smooth motion in the final product.

The use of bright colors and shading is important. I try to use colors that match the conditions (e.g., red is hot and blue is cold). Often the first few images have objects outlined in shades of gray. These objects switch to color at the appropriate time in the animation.

Each image is saved as a separate bitmap. When all images in the sequence are completed, open the software tool and simply select them in order to link them into the proper sequence. After several seconds of processing, your animated gif is ready for viewing. It can be saved and used as a normal gif with a size of about 50kb. However it takes an advanced browser such as Netscape 4.0 to view the animation.

Step Two - Link it to the Music

Getting the selected music track into your computer is obviously the first step. There are free web sites that include hundreds of midi files. These are generally not high quality, but they can quickly be transferred over the internet. You can also use recorded music off CDs, or even do a karaoke thing with your own voice over. Processing these signals into the length and quality that you feel is appropriate for your product can be done using any sound package that you have access to and are familiar with.

The next step is to link the music to the animation. The key here is to make the animation transitions occur at the appropriate point in the music. The software allows you to define transitions to a hundredth of a second. My personal quality standards and my ear for music are nowhere near that close. While you could use the graphical output from your sound processor to determine exactly when to make transitions, I tend to rely on the traditional method of trial-and-error for this step. This is also where having a dedicated work-study student with lots of patience comes in handy. She spent many hours listening to each of these tunes over and over until the images appeared at the right time in the music.

Step Three - Publish it on the Web

The final step is to make the animation available to the student. The internet is the perfect media for this presentation, but there is one more thing that needs to do be done to make it useful. A web page on the front end that explains what is going on must be written and published along with the animation. Since there are usually lots of symbols used in the animation, you will need to explain what the student will be observing. If the browser is set up right, the student can be reading this information while the gif and audio files are still downloading. The only difficulty that I have found with this process is that often the gif and audio are not in synch with each other. Generally pressing the refresh button locally can cure that problem.

The Results

Currently a series of four musical animations are available at my website. These are discussed below in the order that they were developed.

TBDBITL

You are probably familiar with the story of the blind men who touch various parts of an elephant and then describe the whole animal. They wonder aloud how all these different parts can possibly be related. Since my HVAC students have expressed frustration about trying to understand how the many sub-systems and components that we discuss in class relate to each other, I felt that I needed a better way to demonstrate these inter-relations. As an undergraduate at Ohio State, I had the opportunity to play sousaphone in the OSU Marching Band. In one popular concert number, each instrument's part is highlighted sequentially for the first phrase of the school fight song. Then the instrumental voices are all combined at the end into a rousing chorus. I thought this musical animation might help them better understand the big picture.

We start with the basses as the lowest instrument in the band to represent the refrigeration loop, which has the lowest temperature in the building. A four-step animation shows how the compressor pushes the refrigerant through the loop. The baritone voice represents the chilled water loop as the second coldest system. This loop delivers the "coolth" to the Air Handling Unit (AHU). The trombones represent the air loop through the AHU. These are followed in turn by the alto horns, flugel horns, 2nd trumpets, 1st trumpets and e-flat trumpets, which represent the exhaust vent system, makeup air system, energy recovery loop, cooling tower and boiler loop respectively. The drums represent the control system that communicates with all the represented

loops. As a finale, each of the systems is animated in turn with their respective brass voices until the entire building comes alive.

2001Theme

Several factors contribute to the cooling load on a building. Lighting, people, forced ventilation and solar gain through windows to provide adequate Indoor Air Quality (IAQ) are major contributors to this cooling load. Understanding how multiple chillers can be managed to efficiently meet these varying cooling demands is confusing. Students entering the industry must understand the system management concept of swinging the lead unit and base loading the remaining chillers. Minimum cooling capacity of each chiller to avoid surge conditions is also a concern that must be addressed.

In this animation, the four load sectors are each ramped up sequentially as the music builds. Each chiller in turn ramps up to match the increasing load. Once it passes its most efficient operating condition sufficiently to avoid surge in the next unit, it pulls back to this optimum operating point, and the next unit cycles on as the lead unit. Under design conditions (represented by the climax at the end of the music), all four chillers are operating in an overload condition. This is to remind the students that while they must design systems to operate sufficiently under worst case conditions, the system also needs to operate efficiently during the many hours that the system will spend under part load conditions.

Pink Panther

How building mechanical systems respond to varying weather conditions throughout the year is an important concept to grasp. Obviously the boilers run during the winter heating months, and the chillers operate during the cooling season. But how does the ventilation system respond, and when does this crazy concept of an economizer cycle kick in?

The various operational phases are simply matched to the musical phrases of this familiar tune. The animation walks the student up the building thermal load profile starting with the winter design condition. The heating load decreases until the balance temperature is reached and the load requires neither heating nor cooling. Since the outside air (OA) is still cold, the percent of OA is simply ramped up to meet the increasing cooling load during these shoulder periods. When 100% OA cannot meet the cooling load, the chillers cycle on. When the enthalpy of the OA rises above that of the return air, the dampers return the airflow to the minimum OA position, which remains until the maximum cooling design condition is satisfied.

Dueling Banjos

Another difficult concept for HVAC students to understand is how control systems communicate throughout the building. We talk about sensors, processors and actuators, but integrating them into control systems is confusing. To add to the confusion, in a VAV reheat system for example, we adjust air flow through the VAV box to control space temperature and water flow to the reheat coil to adjust humidity levels. These adjustments echo back to the operating conditions of the fans, chillers and boilers. Understanding how all these signals ripple through control loops is confusing.

This animation uses the banjo and guitar voices as a conversation between the sensors and the actuators respectively. The messages are displayed in the message box with arrows connecting the communicants. It starts with the room thermostat telling the controller "I'm hot", and the response from the controller to the VAV box to increase the flow of Supply Air. These conversations continue between various sub systems. When the musical chorus is reached, the messages appear rapid and random, just as they would in an operating building control.

Conclusion

Students learn more when they are having fun. One way to make learning more enjoyable is to stimulate more student senses. Four examples of musical animations developed to improve student learning have been presented. The three process steps required to build a typical musical web page have been discussed. The first step of matching a process with appropriate music is the most difficult.

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