Makerspace Utilization Report

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1 Team Formation

The Makerspace Utilization Project was originally conceived by David Russell. He had previously spoken with Liesl Ulrich-Verderber and Matthew Hawthorn about a system to understand the usage patterns in the Studio, and was interested in revitalizing this idea in the new Makerspace. David contacted the rest of the team, Damon Gwinn, Adam Romlein, and Nikolas Lamb, because of their in-depth and complementary skill sets. David, Damon, and Nikolas have previous experience with machine learning and data manipulation and were able to construct a proof-of-concept which produced space utilization maps. Adam has significant knowledge in embedded computing and was integral in setting up our computer, the NVIDIA Jetson, to capture images using a webcam addon and process the data with a open-source software. Damon also set up a website to allow remote data visualization and processing. Finally, Nikolas contributed a 3D model of the candidate space on which to superimpose the heatmaps for more intuitive visualization. Especially when it came to presenting the work to a broader audience, these varied perspectives were invaluable in creating high quality results.

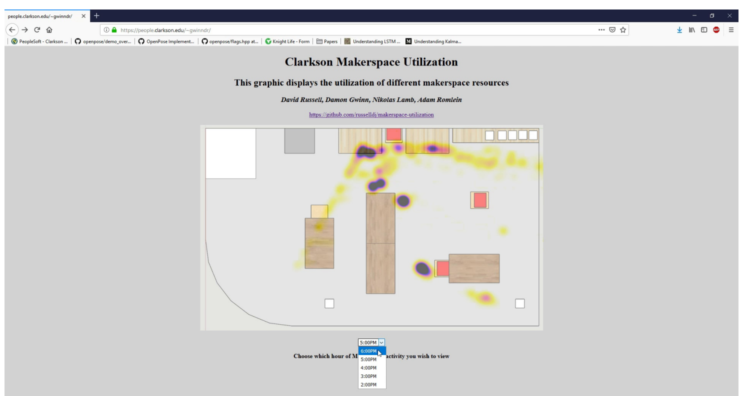

Figure 1: A screenshot of our website showing the utilization patterns for a period of one hour.

2 Target Users

Our system provides an interface showing the utilization of a given space over a specified period of time, Fig. 1. This is indented to provide as much data as possible to University administrators who are tasked with purchasing and organizing student resources, and to give students an introductory understanding of computer vision applications. Student resources, like 3D printers, hand tools, computers and even study areas, are extremely important in cultivating a productive and enjoyable campus environment. Determining the overall utilization of current resources will allow these curators to make more informed budgetary decisions, form a better understanding of student interests, and tune the availability of current resources to better accommodate students' schedules.

An ideal environment in which to test our system is the new University Makerspace, which includes 3D printers, raised tables, soldering tools, a 3D scanner, hand tools, a digitizing table, and an axidraw system. These tools represent an investment of at least $25,000 in the campus community, and their variety is ideal to test what type of work students would like to use the space for. But without automated data collection methods, making broad conclusions as to the tools' collective popularity and utilization over time, as may come into consideration as administrators look to purchase additional items in the future, will be generally subjective.

Additionally, this information could help students inform their own choices, such as what might be a good time to use a specific resource. We hope for this system to be involving for students and university administrators alike, allowing students to see a first-hand application of computer vision, and enabling administrators to better design and utilize their resources. Since we have provided our source code, this represents an ideal microcosm to learn about machine learning, data privacy, and sustainability.

3 Innovation

3.1 An Overview

Our system runs on the NVIDIA Jetson TX2, a small computer board which has a powerful graphics processing unit (GPU) and is targeted at edge computing applications. During operation, this device is mounted in a corner of the target space and set to collect and process video. Processing is done using OpenPose [1], a computer vision algorithm that identifies human body skeletons from video. We use the skeletons generated by OpenPose, along with a CAD model of the target space, to estimate the 3D location of each person within the space at a given moment. This data is recorded and uploaded to a website, `https://people.clarkson.edu/~gwinndr/` shown in Fig. 1, where it can be viewed by anyone. In addition, the system can accommodate additional IoT cameras to extend the view of the space. During initial data collection, we were able to add 3 additional Raspberry Pi cameras to obtain an almost 360-degree view of the space at any given time.

3.2 Cost

The NVIDIA Jetson TX2 has a retail price of approximately $600, which includes the integrated camera, though a one-per-student educational discount reduces this cost to $300. Additional Raspberry Pi B3 cameras cost $50 per camera. All the software that runs on both devices is either open-source (in the case of OpenPose) or was created by our team. Given the extremely small size of our system's data packets, almost any computer can act as a server to store collected data. Our system currently uploads data to Clarkson's adweb file storage. Given the potential to avoid buying costly resources or using unnecessary energy, we believe these costs could be easily justified in a number of locations.

3.3 Existing Solutions

Other utilization systems exist, most of which are marketed as workplace efficiency monitoring systems [2]. However these systems are unable to give precise location data, only more general "utilization percentage." In addition, though our central processing until is more expensive than most solutions, our additional IoT sensors are significantly cheaper.

3.4 Ethical Concerns

To allay privacy concerns that come with collecting video of a public space, we anonymize all data by retaining only human body skeletons after processing. This ensures that, though we can still pinpoint the locations every person inside the space, we cannot provide information as to their appearance or identity.

4 Impact

4.1 Community

We will use the new Clarkson Makerspace to demonstrate the effectiveness of our system, though we hope to apply the system more broadly to the Clarkson campus in the future. In the Makerspace, we will observe the utilization of the 3D printers, raised tables, soldering tools, 3D scanner, hand tools, digitizing table, and axidraw system. From this data we will identify those tools that are being over and under-utilized, and more broadly those times that are more and less popular for students to visit the space. This data can be used to adjust the times that the space is open, or to recommend purchasing more of a specific tool. By making these adjustments, the space will better serve the members of the Clarkson community.

4.2 At Scale

While this system is only being tested in the Makerspace, we believe the goals of the project are broadly applicable to many shared spaces, especially when they are being set up, or changes are being considered. To facilitate an easy adoption of our methodology, we have made code for this project is publicly available online at `https://github.com/russelldj/makerspace-utilization`. It is licensed under the GNU General Public License v3.0, which encourages usage and improvement by the community. As we refine the system, we will generate a manual which describes suggested best practices, such as avoiding keeping raw video or other personally-identifiable information on-hand. Additionally, it will describe the hardware setup we use and potential alternatives. Because of the large volume of data, which requires processing, generated by additional cameras, we will limit the number of additional cameras to three. Each new location will require a model by which points can be generated in 3D; during setup this will be collected as several photographs and measurements of identifiable objects.

5 Feasibility

5.1 Testing

At this stage we have a well-developed prototype of our system. During a Makerspace mentor training event, we set up the Jetson in a corner and recorded video. Then, we used the Jetson process this video to yield the skeletal keypoints for every frame. In this situation we processed the data after the fact to extract the skeletons from all frames, but we have also shown that the system can run in realtime at a rate of 1.3 frames per second. We took an overhead floor plan of the space, from a 3D model we generated, and a frame from the video. Then, a user selected correspondences between points in the image and the floorplan. Using a well-know computer vision technique, we computed the homography, or warp, which relates the points in the image to the points in the floor plan. Then, for every detected person in the video, we algorithmic ally selected their lowest joint and assumed this to be resting on the floor. Using the homography, we were then able to compute their location on the map. This data was aggregated for several minutes, and a heatmap was developed by marking each location with a Gaussian distribution and summing them to yield a representation of the total activity. Then we selected sections of the data to represent different periods in time and placed them on the Polaris server where they can be accessed through our web page.

5.2 Implementations

While this system is currently functional, there are some additional improvements we would like to make. One of the first is to set the system up permanently in the Makerspace, as we previously only captured sample data. This will require creating a mount and clearing the project with appropriate administrators. Once we have access to this data in real time, the system will automatically upload data to a remote server. The data currently on the website is only a demonstration; once more current data is obtained this will be udated as well. To protect the anonymity of people in the space, we will only upload the aggregate heatmaps, discarding both the the raw images and the keypoint skeletons. As a final step, we will look into setting up multiple cameras in the space. With this data we will be able analyze more areas of the space, in addition to triangulating peoples' skeletons to provide a more reliable understanding of space utilization and group dynamics.

Given the rapid pace of our initial development, we believe that we can accomplish these tasks relatively quickly. We estimate that a full functional system with a single camera will be in release by the end of the semester, and with multiple cameras by early fall semester. In parallel with this effort, we will seek to improve the quality of our code and documentation and respond to questions and requests from members of the community.

6 Sustainability

Broadly, this system will help reduce resource waste by indicating those tools, spaces, or amenities that are going unused or are overused. If a lounge area is expensive to maintain but very infrequently used, it should be replaced by some student resource that would be better utilized. If a Makerspace is overcrowded on Thursday but empty on Friday, the operation hours should be adjusted to better make use of paid student staff and energy resources required to operate it. Our system also provides the data to inspire action when things are underutilized. Because our system generates human density heatmaps, this data can also be used to make some inferences as to which regions of spaces have the highest and lowest through traffic. Regions with high traffic are more ideal places for garbage and recycling receptacles, and also for sustainability signage.

Our system is composed of several small compute units with extremely long lifetimes, provided they're not often tampered. A single system should last a number of years without deteriorating or slowing, and because of the development platform any errors that appear are easy to fix. Additionally, the NVIDIA Jetson is specifically designed to operate on minimal power and it runs on a very reasonable 15 watts.

7 References

[1] `https://github.com/CMU-Perceptual-Computing-Lab/openpose`

[2] `https://workplaceoccupancy.com/#occupancy`