

# An open-source system for monitoring activity in a built environment combining edge and fog computing

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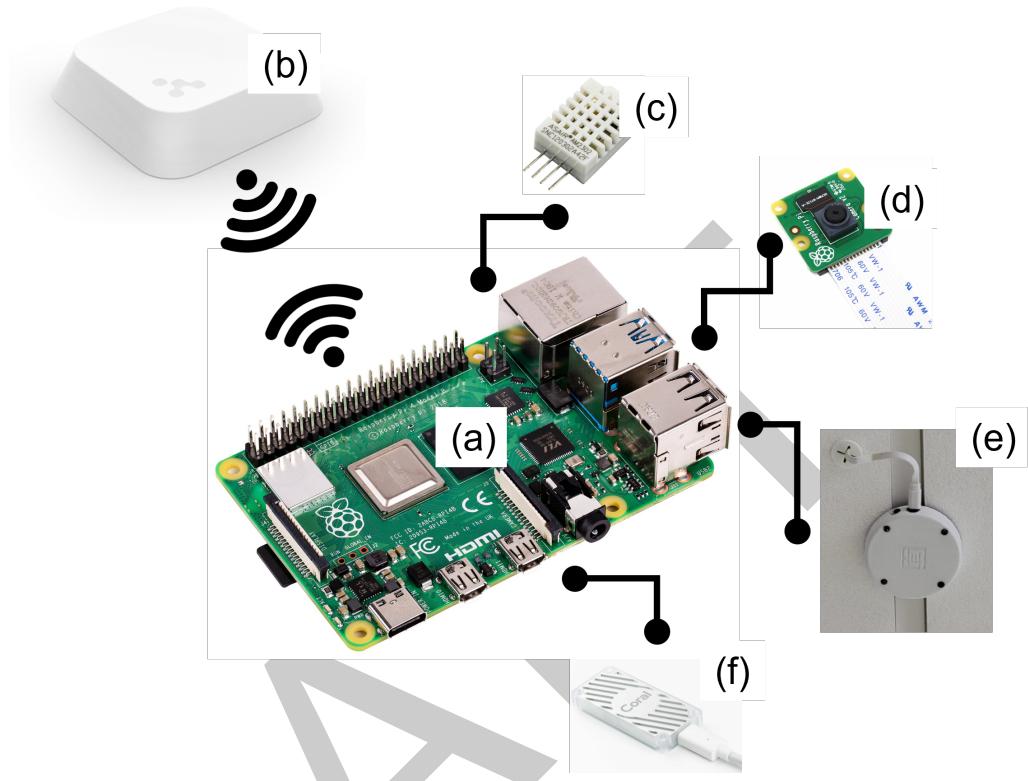
## Summary

Low-cost and non-contact patient monitoring system using edge computing platform enables longitudinal clinical studies in resource-limited settings. Patient monitoring systems need to capture both patient activities and ambient environmental conditions to understand patients' conditions to provide appropriate interventions. In this work, we propose a low-cost indoor monitoring system that uses 39 edge computing systems connected to a fog server layer installed in a built-in environment that can capture multi-modal sensors, including audio, video, Bluetooth strength, temperature, and humidity at multiple locations simultaneously. The system preserves patients' privacy by preprocessing the captured sensor data in real-time using Google Coral USB TPU to extract deidentified features before storing the data. The analyzed patients' activities and ambient conditions are visualized in a dashboard for clinical practitioners to refer for patient care.

## Statement of Need

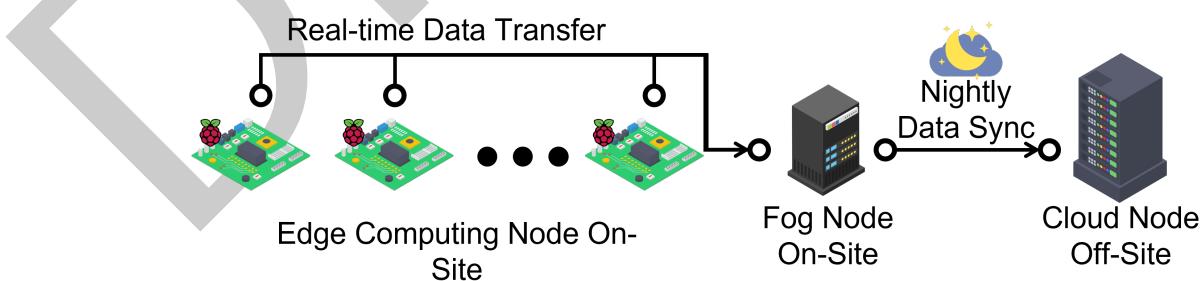
For a distributed sensor network application like this, it becomes very important to ensure that all of the sensors are working faithfully and recording the data. To ensure this, we developed a robust mechanism to check the health of each of the Raspberry Pi ([RaspberryPi](#)) and sensors mounted to it. The results from this upstream system are sourced to the dashboard. We designed our home-built dashboard to answer the following needs in our study which is scalable to other healthcare monitoring facilities/environments : 1. Communicate information quickly. 2. Display information clearly and efficiently. 3. Show trends and changes in data over time. 4. Easily customizable and scalable. 5. Presenting data components in a limited space.

## <sup>30</sup> System Architecture



**Figure 1:** Raspberry Pi attached with sensors. (A) Raspberry Pi v4, (B) Bluetooth sensor, (c) Temperature and humidity sensor, (d) Camera sensor, (3) Microphone, (e) Google Coral USB TPU

<sup>31</sup> The study space is installed with 39 Raspberry Pis (*RaspberryPi*) having multiple sensors,  
<sup>32</sup> as shown in Figure 1. It senses Bluetooth beacon (*Bluetooth*) carried by patients,  
<sup>33</sup> ambient temperature and humidity sensors (*TempHumid*), camera (*Camera*), microphone (*Zuo, n.d.*),  
<sup>34</sup> and Google Coral USB TPU (*Coral*) for acceleration.



**Figure 2:** Overall computer network architectures.

<sup>35</sup> Overall computer network architecture is shown in Figure 2. 39 Raspberry Pis are transferring  
<sup>36</sup> multi-modal sensor data to the on-premise fog computing node in real-time. One day volume  
<sup>37</sup> of data stored in the fog computing node is nightly synced to the cloud computing node for  
<sup>38</sup> permanent data storage. All sensor data is processed in Raspberry Pis on the device in real  
<sup>39</sup> time. The frontend dashboard to monitor preprocessed sensor data are hosted in the fog  
<sup>40</sup> computing node.

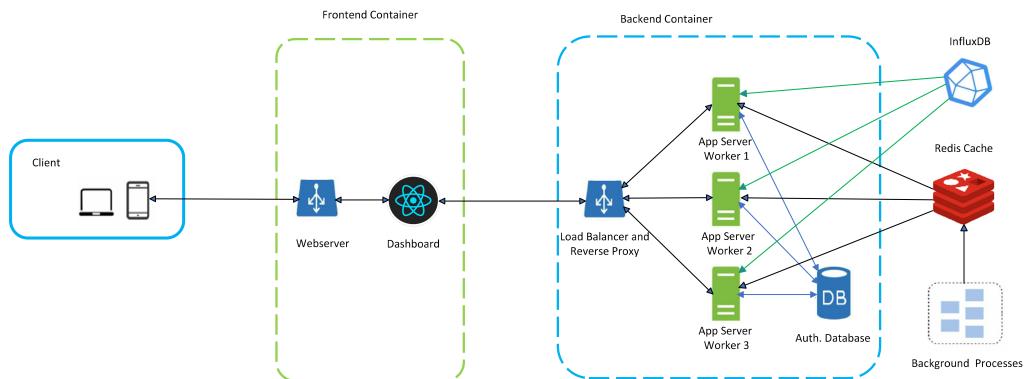


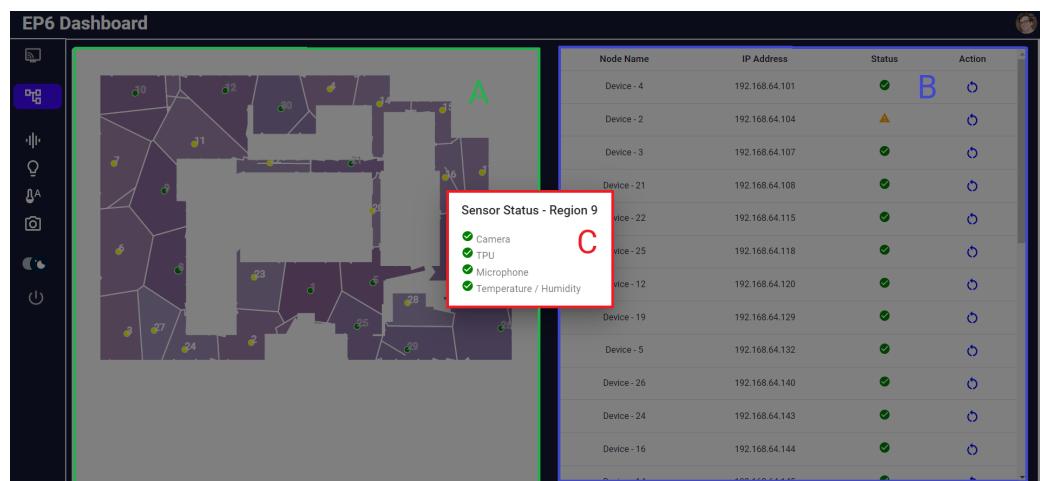
Figure 3: Architecture Diagram of Dashboard

41 To implement the aforementioned system, we have followed a scalable three-tier architecture  
 42 using Flask ([Grinberg, 2010](#)), as shown in Figure 3, as an application server hosted with Nginx  
 43 ([Reese, 2008](#)) as a load balancer and reverse proxy. The frontend is designed with React  
 44 ([Uzayr, 2019](#)) for and served through Nginx as web server. We are using InfluxDB ([InfluxDB, 2013](#))  
 45 as the database for storing the time series data generated by the edge devices. Redis  
 46 ([Redis, 2009](#)) is used as a key-value storage to interact with background python ([Van Rossum & Drake, 2009](#))  
 47 processes, whose output is consumed on the dashboard. MySQL ([Widenius et al., 2002](#)) database is used for storing the authentication and authorization of users.  
 48

## 49 Monitoring the Sensor Network

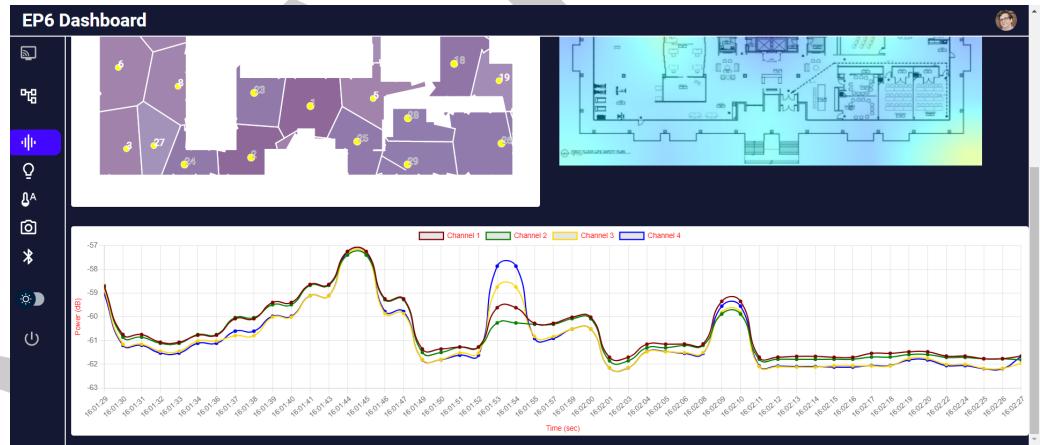
50 The frontend Dashboard is a unified portal developed using python ([Van Rossum & Drake, 2009](#))  
 51 packages and React ([Uzayr, 2019](#)) framework to monitor indoor activities through audio,  
 52 visual, and spatial tracking. It monitors the following activities: 1. Audio 2. Visual 3. Indoor  
 53 Temperature and Humidity 4. Bluetooth

54 Section (A) in Figure 4 represents the position of each Raspberry Pi on our built-in environment  
 55 (18,000 square feet) schematic. If clicked on a particular region, it shows the status of sensors  
 56 connected to that particular Raspberry Pi as shown in section (C) of Figure 4. Lastly, the  
 57 table in section (B) of Figure 4 represents the list of all Raspberry Pi with their status and an  
 58 option to reboot them remotely.



**Figure 4:** Sensor Network Monitoring (A) Schematic of study space defining the positions of Raspberry Pi with region monitored by them (B) Status of each Raspberry Pi with option to reboot them remotely (C) Status of Sensors connected to Raspberry Pi in Region 9

## 59 Audio Pipeline Analysis



**Figure 5:** Audio Channels for a particular microphone array

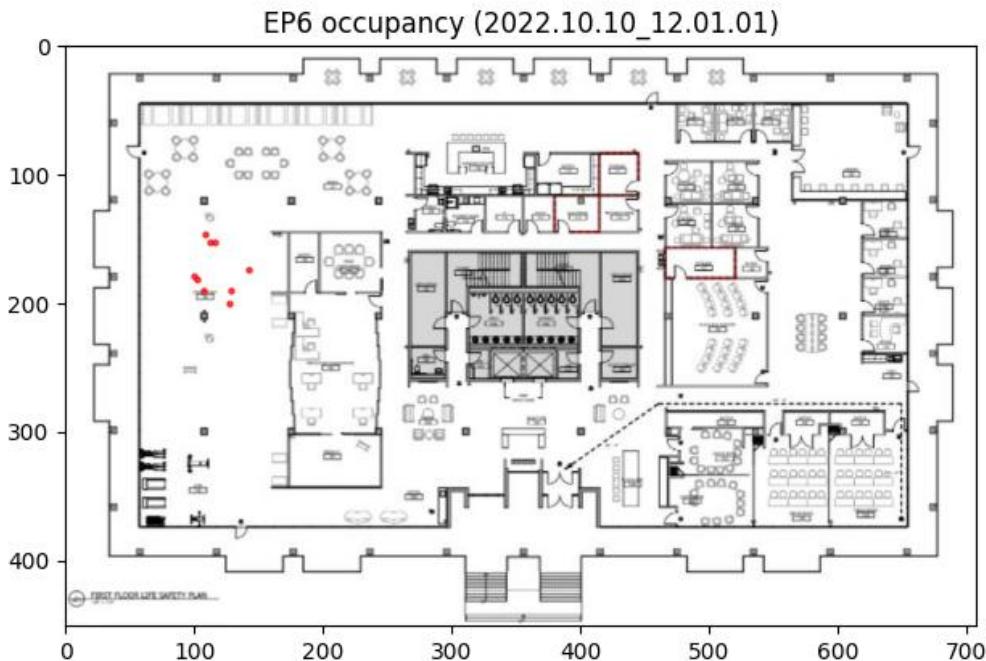
60 As part of the audio capture and analysis pipeline, we collect the environmental acoustic signals  
 61 in a built-in environment through respeaker USB microphone arrays ([Respeak?](#)) placed on  
 62 the ceiling. Since the microphone can capture the conversations of patients, we process raw  
 63 acoustic signals to extract unidentified acoustic features, which are Melspectrogram ([Lederle &  
 64 Wilhelm, 2018](#)) and MFCC ([Lederle & Wilhelm, 2018](#)), to preserve patient privacy. Through  
 65 these features, we perform speaker diarization ([Diarization?](#)) followed by tagging the respective  
 66 participants' groups ([Tagging](#)). Through these, our system can measure conversation or  
 67 environmental audio cues related to ongoing patients' activities. Figure 5 shows the power of  
 68 acoustic signal measured in decibel captured at a Raspberry Pi.



**Figure 6:** Audio Pipeline (A) Study space schematic with the position of microphone arrays (B) Slider to analyze the activity between two specified hours (C) Heatmap depicting the activity level in the study space

With the detected audio activity, we conduct acoustic occupancy analysis, which shows overall conversation activities among the patients in the built-in space. Figure 6 represents the image of Audio section on our dashboard. Section (A) shows the physical location of microphone arrays in the built-in environment. To monitor hourly occupancy, we plot the heatmap of occupancy based on the audio signals captured across our study space, as shown in section (C). The slider in section (B) of Figure 6 can be used to change the particular time range for monitoring occupancy in the space.

## <sup>76</sup> Visual Pipeline Analysis



**Figure 7:** Location of individuals (red dots) within floor plan layout of the built environment

<sup>77</sup> The camera is used to track the movements of the patients in the space. Specifically, we  
<sup>78</sup> detect 2D poses of people captured in the scene by using a state-of-the-art 2D pose estimation  
<sup>79</sup> method (Papandreou et al., 2018) that runs on Raspberry Pi in real-time, which can preserve  
<sup>80</sup> the privacy of patients. The detected 2D poses are projected to the corresponding location in  
<sup>81</sup> the study space, and the movements of patients are displayed in the dashboard in real-time, as  
<sup>82</sup> shown in Figure 7. Monitoring patients' movements in the space over time helps to understand  
<sup>83</sup> the engagement of each patient in social interactions, which gives clues to patients' mental  
<sup>84</sup> health.

<sup>85</sup> Dashboard also displays the processed patient's location data in heatmap. Heatmap, as the  
<sup>86</sup> name suggests, displays the occupancy in terms of heat signature to visualize the population  
<sup>87</sup> distribution throughout the EP6 floor. Combined with the heatmap based on the acoustic  
<sup>88</sup> signal mentioned above, we can tell if the social interactions among patients have led to  
<sup>89</sup> engaging conversations or not. The dashboard also shows the camera location associated with  
<sup>90</sup> Raspberry Pi identifier number to find which camera was capturing the patient's data at a  
<sup>91</sup> specific moment.

## <sup>92</sup> Humidity and Temperature Monitoring

<sup>93</sup> Having temperature and humidity in each partition of the health care facilities could provide  
<sup>94</sup> us valuable information for various studies (Quinn & Shaman, 2017). In this study, we used  
<sup>95</sup> the DHT22 Temperature-Humidity sensor module in conjunction with an RPi to record the  
<sup>96</sup> variation in temperature and humidity. The DHT22 sensor comprised a thermistor and a  
<sup>97</sup> capacitive humidity sensor that measured the surrounding air to provide calibrated temperature

98 and humidity values. The sampling frequency is 1Hz, the temperature range was –40 to 80  
 99 °C, and the humidity range was 0–100% RH.

100 Figure 8 represents the temperature and humidity tab on a home-built dashboard. Similar to  
 101 audio section, user can monitor the hourly occupancy, we plot the heatmap of temperature  
 102 based on the received signal with 1Hz sampling frequency. An slider has been designed so the  
 103 user can access the the desired time frame signal and heatmap. This feature can be used to  
 104 monitor the relative temperature and humidity across the building.

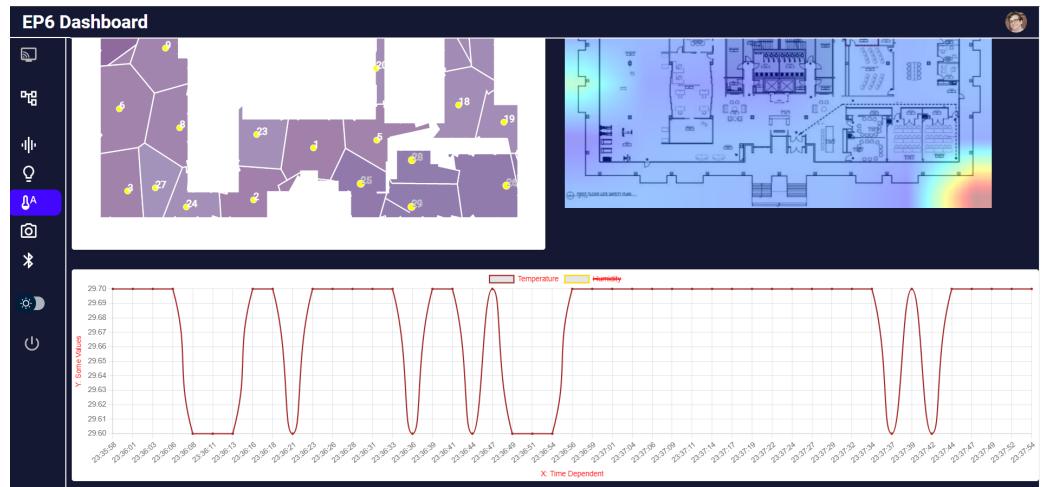


Figure 8: Real-time monitoring of ambient temperature and humidity at a Raspberry Pi location.

## 105 Bluetooth Pipeline Analysis

106 In the Bluetooth pipeline analysis, we gather the BLE signals from the BLE Beacons carried  
 107 by the participants through the Raspberry Pis placed in the ceiling. We only store the  
 108 MAC address and the corresponding RSSI of the BLE Beacons, thus preserving participant  
 109 privacy. Custom real-time algorithms are provided to detect the position of individuals wearing  
 110 Bluetooth beacons moving around a built environment. With the collected RSSI data, we  
 111 perform RSSI-weighted, RSSI-based Trilateration (Yang et al., 2020) to track the movements  
 112 of patients in the study space. Since the patients are equipped with unique BLE Beacons, we  
 113 can associate the patient's location tracked with BLE and camera to identify the exact patient  
 114 that is undergoing social interactions in the space.

115 Occupancy analysis of different areas in EP6 helps us correspond the movements of participants  
 116 and their activities in Figure 8 represents the image of Bluetooth Localisation section on EP6  
 117 dashboard. Section (A) shows the location of Raspberry Pis in the EP6 lab. Section B) shows  
 118 the real-time location of participants in EP6

119 Figure TK by Krishna and Yash

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 122 investment from the James M. Cox Foundation and Cox Enterprises, Inc., in support of Emory's  
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## References

- 124      *Bluetooth*. [Computer software].
- 125      *Camera*. [Computer software].
- 126      *Coral*. [Computer software].
- 127      Grinberg, M. (2010). *Flask: Web Development, one drop at a time*. <https://flask.palletsprojects.com/en/2.2.x/>
- 128      *InfluxDB*. (2013). [Computer software]. <https://www.influxdata.com/>
- 129      Lederle, M., & Wilhelm, B. (2018). *Combining high-level features of raw audio waves and mel-spectrograms for audio tagging*. arXiv. <https://doi.org/10.48550/ARXIV.1811.10708>
- 130      Papandreou, G., Zhu, T., Chen, L.-C., Gidaris, S., Tompson, J., & Murphy, K. (2018). Personlab: Person pose estimation and instance segmentation with a bottom-up, part-based, geometric embedding model. *Proceedings of the European Conference on Computer Vision (ECCV)*, 269–286.
- 131      Quinn, A., & Shaman, J. (2017). Health symptoms in relation to temperature, humidity, and self-reported perceptions of climate in new york city residential environments. *International Journal of Biometeorology*, 61(7), 1209–1220.
- 132      *RaspberryPi*. [Computer software].
- 133      *Redis*. (2009). [Computer software]. <https://redis.io/>
- 134      Reese, W. (2008). *Nginx: The high-performance web server and reverse proxy*. Belltown Media. <https://www.nginx.com/>
- 135      *Tagging*.
- 136      *TempHumid*. [Computer software].
- 137      Uzayr, C. bin, S. (2019). *React : A Javascript library for building user interfaces*. <https://reactjs.org/>
- 138      Van Rossum, G., & Drake, F. L. (2009). *Python 3 reference manual*. CreateSpace. ISBN: 1441412697
- 139      Widenius, M., Axmark, D., & DuBois, P. (2002). *Mysql reference manual*. O'Reilly & Associates, Inc. ISBN: 0596002653
- 140      Yang, B., Guo, L., Guo, R., Zhao, M., & Zhao, T. (2020). A novel trilateration algorithm for RSSI-based indoor localization. *IEEE Sensors Journal*, 20(14), 8164–8172.
- 141      Zuo, B. (n.d.). Respeaker 4-MIC array for raspberry pi. In *seeedstudio*. [https://wiki.seeedstudio.com/ReSpeaker\\_4\\_Mic\\_Array\\_for\\_Raspberry\\_Pi/](https://wiki.seeedstudio.com/ReSpeaker_4_Mic_Array_for_Raspberry_Pi/)
- 142      Nakum et al. (2022). An open-source system for monitoring activity in a built environment combining edge and fog computing. *Journal of Open Source Software*, 0(0), ¿PAGE? <https://doi.org/10.xxxxxx/draft>.