Indoor Location Detection for Calculating In-Home Exposures in clinical trials of air purifiers (HAFTRAP study)

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Determine minute-by-minute in-home exposures as a function of time and micro-location for each participant using inexpensive off-the-shelf hardware.

Background and Aim

HAFTRAP is a randomized crossover trial of portable air purifiers in homes next to highways. One threat to the benefits of having portable air purifiers is that residents might not spend enough time in the rooms with filtered air[1]. Standard GPS methods do not allow tracking location inside buildings.

We sought to develop a method to track when study participants were and were not in the room with the air purifier. Our solution was to use Bluetooth beacons with an iPhone and develop a custom mobile app which can detect when a participant is at home and in one of the rooms of interest.

Our indoor location data is correlated with other sensor logs (PDM, GPS, temperature, barometric pressure, etc) through algorithms we created in Google Cloud; results are displayed in a Google Sheet that can be easily shared or loaded into other analytical software.

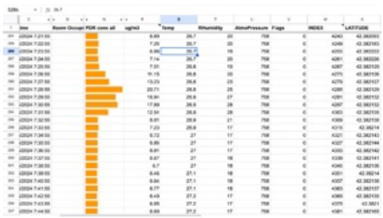

Fig 1. Unified Output from System

For homes with particularly difficult configurations, we also developed a set of standard beacon housings that allow us to "tune" their signal spread so as to better match the geometry of the space and increase accuracy.

Methods

We used off-the-shelf Bluetooth Low Energy (BLE) beacons to mark each room of interest in each participant's home. Participants carried an iPhone running our mobile app. The app automatically logs time spent in each room in real time. Total cost for parts is less than $1000.

Fig 2. iPhone & two brands of commercially available beacons. 9V battery for scale.

Participants also carried an additional set of sensors with them in a small backpack. These included a portable particulate monitor (PDR-1500), a GPS unit (QStarz Q1000XT) and a prosumer air quality sensor (Atmotube PRO). Data were exported from the devices and processed in Google cloud to correlate the logs. The iPhone logs its results to a cloud database in real time, which was also used to verify progress of each trial remotely.

Beacons run on a single battery charge for multiple years. All other devices needed daily charging. Beacons and iPhones can be reused for multiple homes.

Prior to selecting Bluetooth, several technologies were evaluated including GPS and Ultra-Wideband (UWB). GPS does not function within the home and the commercially available options for UWB were not mature enough to be used reliably.

Results

We were **successfully able to collect the times that participants spent in the rooms that we were tracking** in their homes. We were also able to correlate those location data with other sensor data to create a comprehensive time-based exposure picture for each participant.

We were also successful in managing battery life on the iPhone, continually collecting and logging data live to a cloud database. An iPhone 12 Mini was able to run for up to an 8 hour day before needing recharging. We have several options for lengthening this run time, including using later model iPhones with larger batteries.

Results (cont.)

Our limited set of data collected shows exposure patterns and locations that correlate with user interviews and general expectations. Low particulate exposures are seen in the air filtered rooms of the home and increased exposure levels occur outside those rooms. Of particular note were cooking and time spent waiting in traffic at major intersections. Large portions of time in the home were spent outside the rooms with air filtration.

PDR conc all	ug/m3	Temp	RHumidity	AtmoPressure	Flags	INDEX	LATITUDE
	5.85	27.0	11	764	0	2409	42.366495
	6.45	27.0	12	764	0	2415	42.367401
	9.00	27.0	12	764	3	2421	42.369028
	8.33	27.0	13	766	3		2.371825
	6.88	27.0	13	764	0		2.373302
	40.86	27.1	13	764	0		42.37359
	10.85	27.1	13	764	0		2.376473
	7.27	27.2	13	764	0	2451	42.37895
	7.06	27.2	13	764	0	2457	42.379444

Fig 3. Detecting a spike in particulates at a busy city intersection.

Datetime	Event	PDR conc all	ug/m3	Temp	RHumidity
4/9/2024 17:12:39	BEDROOM EXIT		7.79	27.3	12
4/9/2024 17:13:39			7.86	27.3	12
4/9/2024 17:14:39			7.23	27.3	12
4/9/2024 17:15:39			8.90	27.3	11
4/9/2024 17:16:39			137.69	27.4	12
4/9/2024 17:17:39			214.56	27.5	16
4/9/2024 17:18:39			61.84	27.5	15
4/9/2024 17:19:39			56.40	27.6	14
4/9/2024 17:20:39			64.76	27.6	14
4/9/2024 17:21:39			93.82	27.6	14
4/9/2024 17:22:39			46.61	27.6	14
4/9/2024 17:23:39			6.94	27.6	12
4/9/2024 17:24:39			6.83	27.6	11
4/9/2024 17:25:39			6.69	27.7	11

Fig 4. Cooking dinner

Datetime	Room Occupi	PDR conc all	ug/m3	Temp	RHumidity
5/25/2024 9:35:55			6.83	28.5	15
5/25/2024 9:36:55			6.92	28.5	15
5/25/2024 9:37:55			6.92	28.5	15
5/25/2024 9:38:55			7.01	28.5	15
5/25/2024 9:39:55			7.15	28.5	15
5/25/2024 9:40:12	LIVINGROOM		6.86	28.5	15
5/25/2024 9:40:55	LIVINGROOM		6.86	28.5	15
5/25/2024 9:41:55	LIVINGROOM		6.82	28.5	15
5/25/2024 9:42:55	LIVINGROOM		6.72	28.5	15
5/25/2024 9:43:55	LIVINGROOM		6.77	28.5	15
5/25/2024 9:44:55	LIVINGROOM		6.90	28.5	16
5/25/2024 9:45:55	LIVINGROOM		7.24	28.5	16
5/25/2024 9:46:55	LIVINGROOM		7.09	28.4	17
5/25/2024 9:47:55	LIVINGROOM		7.00	28.5	16
5/25/2024 9:48:55	LIVINGROOM		7.01	28.4	16
5/25/2024 9:49:55	LIVINGROOM		7.15	28.4	16
5/25/2024 9:50:55	LIVINGROOM		7.29	28.4	16
5/25/2024 9:51:55	LIVINGROOM		6.84	28.4	16
5/25/2024 9:52:55	LIVINGROOM		7.22	28.4	16
5/25/2024 9:53:55	LIVINGROOM		7.01	28.4	16

Fig 5. Stable environment of air filtered Living Room

Our limited set of data collected shows exposure patterns and locations that correlate with user interviews and general expectations. Low particulate exposures are seen in the air filtered rooms of the home and increased exposure levels occur outside those rooms. Of particular note were cooking and time spent waiting in traffic at major intersections. Large portions of time in the homes were observed to be spent outside the rooms with air filtration.

As for **practicality**, our field testing achieved 1 hour setup (install & calibration) by non-technical field staff for a variety of typical homes. Some unusually complex home layouts required up to an additional hour for successful set up. Removal is completed in under 15 minutes.

Conclusions

More info:
https://bit.ly/haftrap

We have proof in principle that we can practically measure actual time spent in air filtered rooms in order to more accurately characterize the relationship between air purifiers and health indicators[2]. Larger trials are needed to develop statistically meaningful datasets.

Future possibilities include:

- Apply the system in a larger number of homes.
- Expand the system to other rooms of the home where different exposure levels are expected (e.g. in kitchens to catch cooking emissions)
- Potentially leverage the Apple Watch as an alternative to carrying an iPhone as well as a means to automatically collect vitals.
- Integrate collection of GPS data and particulate counts directly on iPhone.
- Further optimize software accuracy and speed of setup.

Acknowledgements

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References

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