HOME SENSORS

In addition to the microphones and cameras in living area (not in the bedroom or bathroom), we plan to instrument the participant’s houses with non-intrusive sensors. As part of our research we aim to identify a set of less intrusive sensors that can give enough information to avoid the need for cameras in future investigations.

**Local Data Aggregator:** Each home will have a local data aggregation system that will help collecting data from all sensors, store some of the data locally in and encrypted and redundant storage and stream some of this data in encrypted form to the project servers at UCSD. We plan to create a separate network from the WiFi already present in the participants’ houses. This will minimize the risk of interfering with participants’ Internet usage and will increase the security of the data we will collect. We plan to use enterprise level networking equipment (known to be more secure and reliable). For example, we plan to use one or more Ubiquiti Networks Unifi 802.11ac Dual-Radio PRO Access Point (<https://www.amazon.com/Ubiquiti-Networks-802-11ac-Dual-Radio-UAP-AC-PRO-US/dp/B015PRO512/ref=sr_1_1?s=electronics&ie=UTF8&qid=1511205328&sr=1-1&keywords=unifi> ore equivalent hardware) to create a dedicated WiFi. We will also use Samsung SmartThings Hub (<https://www.samsung.com/us/smart-home/smartthings/hubs/f-hub-us-2-f-hub-us-2/> or equivalent hardware) to collect data from sensors that use other wireless protocols (such as ZigBee or Z-Wave). Other devices will use bluetooth; because of the limited range of this protocol we will deploy various Raspberry Pi (or similar) devices that will collect bluetooth data and stream it to the local data aggregator via the secure WiFi connection.

All these networking devices will be behind a firewall that will connect to the existing in home internet router. The firewall will protect all study related devices from intrusion both from the existing house network and the Internet.

**Risk mitigation:** The local aggregator will help mitigate many risks. All non-anonymized data will be transmitted locally on a dedicated encrypted WiFi network protected by a firewall. All network connected data storage in the home will be part of this secure network. Only the researchers will have access to this dedicated WiFi network, and only the devices manually added to the network by researches will be allowed, minimizing risks of data breaches. All data will be encrypted and stored in the house. A part of the data that can be streamed to the UCSD servers will be encrypted by devices in the local data aggregator before being transmitted on the Internet. We plan to recover the video by physically collecting the drives with the video recordings in each house; this will mitigate the risk of transmit sensitive video data on the Internet and will avoid overloading the Internet connection used by participants in their homes. All video and sensor data transmitted over WiFi will use a dedicated encrypted WiFi network and will use enterprise grade networking equipment with firewalls to improve security and dependability.

**Android phone**: we plan to replace the TV remote with an application for an Android Phone. The functionality will be the same of a normal remote, but we will be able to identify how the user interacts with it using the 3D touch functionality of the screen and the accelerometers embedded in the phone. This will give researcher periodic information on fine motor control skills. We do not see particular risks in using the phone as a remote control; however, subjects will have the option of using their old remote control if they do not feel comfortable using the phone. GPS track for car? Testing with David? Pair the phone with watch?

**Sleep tracking:** We will use a sleep tracker systems to measure a subject’s heart rate, respiration rate, and movement during sleep. Modern sleep tracker systems, such as the BeautyRest Sleeptracker (<https://www.beautyrest.com/Sleeptracker>) and similar systems, use contactless pads positioned under the mattress in the chest area. Measurements are performed in a non-contact method by analyzing reflections of low-power, high-frequency RF signals from sensors placed under a mattress. The sensors connect to a base station, which provides power from a wall outlet and has sensors to measure ambient conditions (temperature, humidity, noise levels, air quality). The base station is connected to the local Wi-Fi network of the local aggregator. The data collected will be associated with an anonymized subject ID and will be transmitted and stored encrypted.

**Gait and body posture sensing:** while normal cameras help researchers in analyzing gait and posture we will experiment with cameras that gives #D information in addition to standard video feeds. Examples of such devices are Microsoft Kinect (<https://developer.microsoft.com/en-us/windows/kinect/hardware>) and Intel RealSense (<https://software.intel.com/realsense>). We will get its 3D stick figure from the depth camera feed. This figure will be enough to analyze posture and gait of subjects without exposing any identifiable information. Keep stick figure video and its relationship with objects in a home, improving the protection of subjects’ privacy. In this study we will apply the same security strategies used for video recording to depth feeds and stick figures feeds.

Intel RealSense cameras provide both standard video feeds and depth feeds, they are USB 3.0 devices and we will embed them with computation devices that will run intel libraries. Intel libraries for RealSense work on Windows and Linux and support multiple advanced tracking features including: tracking of body movements, tracking people in 3D space, and identifying different persons. There are different cameras that support different fields of view and depths. Depending on the location we will place the camera in each house we may use different cameras. For example, Intel D415 Camera (<https://simplecore.intel.com/realsensehub/wp-content/uploads/sites/63/D415_ProductBrief.pdf>) has a FOV of 69 degrees and a depth up to 10 meters. The standard video feed is 1080p and 30 frames per second while the depth output is at 1280x720 au to 90 frames per second.

All data will be streamed by the embedded device to the local aggregator using an encrypted WiFi network dedicated to our investigation. All video data will be stored encrypted in the subject’s home.

**Pressure mats:** we plan to deploy pressure mats such as Tekscan MatScan (<https://www.tekscan.com/products-solutions/systems/matscan> or similar products) on one or two strategic positions on the house floor (e.g. in front of kitchen and bathroom sinks). The mat is 17.2” x 14.5” x 0.2” and can record a detailed analysis of weight distribution. The data will be relayed over Wi-Fi to local home aggregator. All data will be associated with an anonymized subject ID and stored encrypted.

**Audio recording:** we plan to record audio inside the participant’s houses. To maximize privacy we will not use commercial devices such as Google Home because they send data to the producer cloud outside our control. We will instead create our own device that will record and analyze audio locally and will store the audio only in encrypted form either on the local aggregator or the UCSD project servers. To maximize audio clarity we will use far field microphones such as MiniDSP UMA-8 USB mic array (<https://www.minidsp.com/products/usb-audio-interface/uma-8-microphone-array> or similar devices) and embedded processing units such as the Raspberry Pi 3 (<https://www.raspberrypi.org/> or similar devices). We will run processing on the embedded device and identify things like pauses while speaking, and other environmental sounds such as water running etc. All audio information that will be collected will be associated with an anonymized subject ID and will be transmitted and stored encrypted.

**Video Recording:** we plan to record video from full HD cameras. To this end we will use both video feeds coming from 3D cameras discussed above in the Gait and body posture sensing section, and dedicated WiFi cameras such as DLink DCS-2630L (<http://us.dlink.com/products/connect/full-hd-180-degree-wi-fi-camera> or similar devices). All data will be sent to the local aggregator and stored encrypted in the residence. The Video will be transmitted and stored encrypted, either by a dedicated Network Video Recording device such as DLINK DNR-322L or directly by a computer we will deploy as part of the local aggregator.

**Power Monitoring:** We will instrument electrical connections (e.g. plugs, light sockets) throughout the house to identify what devices and lights are used. Smart plugs, such as WeMo Smart plugs (<http://www.belkin.com/us/p/P-F7C029/>), TP-Link Smart Plugs (<http://www.tp-link.com/us/home-networking/smart-home/smart-plugs>), and similar devices, plug into existing electrical outlets and provide a measure of the amount of power being used by devices plugged into the outlet. Power consumption will be used for activity classification and to determine interaction with devices (e.g. TVs, microwaves, radios). Smart bulbs, such as Philips Hue LED Bulbs (<http://www2.meethue.com/en-us/p/hue-white-4-pack-e26/46677472023>), TP-Link Smart LED Bulbs (<http://www.tp-link.com/us/products/details/cat-5609_LB120.html>), and similar devices, provide information for when a light is being used. All listed sensors except for the Philips Hue Bulbs will transmit information in real time over the local Wi-Fi network to a local aggregator. The Philips Hue Bulbs will connect to the local aggregator using the ZigBee protocol and will interact with the same hub as the other Samsung SmartThings devices. Once received, all data will be associated with an anonymized subject ID and stored encrypted.

**Water Usage Monitoring:** We will use an ultrasonic flow sensor to track water usage of accessible pipes within the subject's home. Sensors, such as Pulsar's Flow Pulse (<https://www.pulsar-pm.com/product-types/flow/flow-pulse.aspx>) and similar devices, perform non-invasive measurement of water by analyzing the refraction of ultrasound waves as they are transmitted through the pipe. The information will be used to classify user actions when interacting with water. The data will be output over a wired connection to a small ADC converter, which will be linked to the home network over a secure Wi-Fi or BLE connection. Once received, all data will be associated with an anonymized subject ID and stored encrypted.

**Smart Home Sensors:** We will use acceleration tags to determine when a user is interacting with an object in the environment and motion sensors to help determine a subject’s presence and movement in a room. Two types of acceleration tag sensors will be used: sensors, such as the Samsung SmartThings Multipurpose Sensor (<https://shop.smartthings.com/products/samsung-smartthings-multipurpose-sensor>) and similar devices, to detect the opening and closing of doors, windows, and other hinged objects; and smaller acceleration stickers, such as the Estimote Stickers (<https://estimote.com/products/>) or similar devices, to detect the movement and vibration of everyday objects, such as chairs, TV remotes, drawers, and small end tables. The open/close sensors have dimensions of 0.6" x 1.4" x 1.9" and separate in the middle to mount on the frame and moving object. They measure acceleration, temperature, and proximity of the two halves of the sensor, permitting the determination of open and closed objects. The acceleration stickers are much thinner with a thickness of 0.02" and only measure acceleration. The Estimote stickers also have BLE beacon capabilities and can be used as an additional input for localization. All acceleration tag sensors have a 1 year battery life and operate on replaceable coin cell batteries.

We will be using passive infrared (PIR) motion sensors to detect a subject’s presence and movement in a room. PIR motion sensors, such as the Samsung SmartThing Motion Sensor [(https://www.samsung.com/us/smart-home/smartthings/sensors/f-irm-us-2-f-irm-us-2/](https://www.samsung.com/us/smart-home/smartthings/sensors/f-irm-us-2-f-irm-us-2/)), Iris Motions Sensor (<https://www.irisbylowes.com/products/iris-motion-sensor/>), and similar devices, measure changes in the infrared spectrum across their field of view. A mask can be applied over the sensor to only sense change in specific regions of a room or at a specific height. The Samsung SmartThing Motion Sensor is 2.0” x 2.0” x 0.8” and has a two-year battery life off of a small coin cell battery. It can detect movement up to 50 feet away.

The Samsung SmartThings sensors will communicate over a ZigBee protocol and the Estimote Stickers will communicate over Bluetooth Low Energy, providing information in real time to the a local aggregator within the home. Once received, all data will be associated with an anonymized subject ID and stored encrypted.

**Indoor Air Quality:** we will use an indoor air quality sensor we developed for the MetaSense project ([http://metasense.ucsd.edu](http://metasense.ucsd.edu/)) to collect information of air quality, humidity and temperature in the subjects’ home. These sensors are small, low power, and do not have any adverse effect. All data collected is under the researcher control. There are no personally identifiable information collected by this sensor. Once the data is collected and stored local aggregator, it will be associated with a subject ID. From that point on all data will be transmitted and stored encrypted.

**Bluetooth tags:** *(Rishi) - use tags and watch to track interaction between people and objects in the home* We will be using Bluetooth beacons to localize users as well as track their interaction with everyday objects. The beacons have a small form factor and are available in the form of stickers which and can be attached to any object or simply on the wall and have a battery life of 5 years. We will be using location beacons from [Estimote](https://estimote.com/products/) (<https://estimote.com/products/>) or equivalent. The location beacons have dimensions of 2.16”x1.49”x0.71”. Monitoring or tracking will be done by an application(designed by us) running on the user's device such as a smartphone or a smartwatch which will scan for advertising packets from these beacons and based on the signal strength from the different beacons, it localizes the user. Once the location is determined, the application will communicate over Wi-Fi the localization information to a local aggregator encrypted. Once received the data will be associated with an anonymized user ID and stored encrypted.

**Smart Watch:** **(Rishi - localization, what watch works; Nicole look into monitor the body component)** We will use smart-watches for indoor localization and for monitoring user’s daily activities like sleep cycles, walking, exercising etc. The user’s interaction with objects will also be tracked by the watches interaction with the bluetooth beacon tags mentioned above. We will be using a Huawei Watch 2 or a Samsung Gear S3(<http://www.samsung.com/global/galaxy/gear-s3/>) or equivalent. Both these watches have heart rate sensors, are Wi-Fi & Bluetooth enabled and have wireless charging capabilities. The Huawei watch 2 and the Samsung Gear have battery lives of 2 days and 3 days respectively with moderate usage. They come with easy to use charging pads which simply require the users to place the watch on top of the pad to recharge their watches. The watch will collect data from its sensors (heart rates, sleep cycle data, motion, interaction with objects using BLE Beacon tags) and transmit data over Wi-Fi to a local aggregator where it’s encrypted and stored. The Samsung Gear S3 sends data to Samsung Cloud over Wi-Fi from where the data will be downloaded to our research server where it would be associated with an anonymized user ID and stored encrypted.

**Wearable Biometric Sensors:**

Our first on-body sensor is a patch that rests on the skin that measures heart rate, activity

posture, and ECG. [VitalConnect](https://vitalconnect.com) is an FDA-approved patch that additionally measures respiratory rate, step count, skin temperature, and fall detection. It is peel-and-stick

and can be worn for short periods of time then thrown in the trash. It has a battery life of 96 hours. [MC10,](https://www.mc10inc.com/our-products/biostamprc) another patch, is worn on multiple locations of the body and is not disposable. It consists of four electrodes, a battery, gyroscope, accelerometer, Bluetooth radio, and memory. It has a battery life of 36 hours and is rechargeable. Either patch should be worn daily. An alternate skin temperature sensor is the [Thromcon DS1922L](https://www.thermochron.com/product/ds1922l-thermochron/) iButton that is ideal for continuous monitoring of those with cognitive impairment as has no extensive wiring, is sterile, and eliminates the issue of cross-talk interface as it is wireless. It should be used daily.

**Car Monitoring:** We will use a passive GPS tracker to analyze a subject's movement patterns outside of the home with a goal of analyzing changes in routes and driving habits that may be indicative of cognitive decline. Passive GPS trackers, such as the Land Air Sea Systems GPS Tracking Key 2 (<https://www.landairsea.com/gps-tracking-key-2/>) or similar devices, record GPS position with frequencies ranging between 1 sample per second to 1 sample per minute. The device is attached to a car with a magnet or can be placed on the dashboard. The device can last for 28 hours of drive time or approximately 3-4 weeks of usage at 1 hour per day. All data is secure on the device and can only be accessed by physically connecting the device over USB. Once downloaded by the researchers, it will be be associated with a subject ID. From that point on all data will be transmitted and stored encrypted.

**Smart Scale:**

Smart scales such as [Yunmai Smart Scale](https://www.amazon.com/Yunmai-Smart-Scale-Composition-Monitor/dp/B01GKDYHGS/ref=pd_sbs_328_7?_encoding=UTF8&refRID=EK2EWQ7X5SNGPGV0BMMQ&th=1) can measure weight, BMI, bone density, heart rate,

water volume, BMR, visceral fat, among a few other and will upload the data wirelessly through an app. The scale itself only shows the weight measurement in a large font size that our participants should be able to read clearly. The scale uses important bioelectrical impedance analysis (BIA) to send an electric current through body tissues to estimate total body water. By measuring changes in total body water, we can identify levels of dehydration which we must account for to ensure that our levels of cognitive decline are not influenced by levels of dehydration. This measurement must be done a minimum of once a day. This scale requires very little setup, is easy to use, and is useful for visualizing trends in body

data.

***Smart home devices:*** *(****Gaurav*** *to figure out what we get out of various samsung devices and how to interact with them - see RPi connection etc.) Other sensors will detect open/closed doors, drawers, or cabinets (with sensors such as Samsung SmartThing Multipurpose Sensor* [*https://www.samsung.com/us/smart-home/smartthings/sensors/f-mlt-us-2-f-mlt-us-2/*](https://www.samsung.com/us/smart-home/smartthings/sensors/f-mlt-us-2-f-mlt-us-2/) *or similar devices) (can be connected to smart things* [*https://www.youtube.com/watch?v=Fepn6pMrtyQ*](https://www.youtube.com/watch?v=Fepn6pMrtyQ)*), motion (with sensors such as Samsung SmartThing Motion Sensor* [*https://www.samsung.com/us/smart-home/smartthings/sensors/f-irm-us-2-f-irm-us-2/*](https://www.samsung.com/us/smart-home/smartthings/sensors/f-irm-us-2-f-irm-us-2/) *or similar devices) (can be used with smart things), and water leaks (such as Samsung SmartThings Water Leak Sensor* [*https://www.samsung.com/us/smart-home/smartthings/sensors/f-wtr-us-2-f-wtr-us-2/*](https://www.samsung.com/us/smart-home/smartthings/sensors/f-wtr-us-2-f-wtr-us-2/) *or similar devices). All data will be deidentified (just connected to a device ID) and will be stored and processed in a dedicated cloud. Depending on the sensors, the data will be transmitted on the researcher WiFi network in the subject home or will be received by a smart home hub (such as Samsung SmartThings Hub* [*https://www.samsung.com/us/smart-home/smartthings/hubs/f-hub-us-2-f-hub-us-2/*](https://www.samsung.com/us/smart-home/smartthings/hubs/f-hub-us-2-f-hub-us-2/) *or similar devices). We will collect the raw sensor data and associate it to a subject ID only when processing the data on our computers to extract information for our study. Once the data is associated with a subject ID will be transmitted and stored encrypted.*