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Object Classification Utilizing Commodity 2.4 GHz Radios

Investigating the possibility of commodity radios use in object identification has been an exciting project. Part of why it's so fascinating is the combination of network engineering, machine learning, computer vision, and general physics involved in advancing radio object classification accuracy.

Previously, object classification with radio signals was accomplished with high-end radios, or with limited classification power. Prior examples of this type include: ultrasonic, ultra-wideband, infrared, and other methods. Granular data, such as how much water a plastic bottle in a luggage bag contains, or the dimensions of small metal objects which are surrounded by various other materials in luggage is often too noisy for consistent classification. Recently, there has been an ongoing investigation into the potential use of commodity radios. Perhaps there are low cost, low power use cases for the growing multitude of devices with 2.4 GHz radios. The growing IOT movement will present an opportunity to use data from ubiquitous hardware, such as 2.4 GHz radios, to solve problems that were previously expensive or undefined.

Huang et al. (2014) demonstrate a proof of concept for using the reflection of objects between a transmitter and receiver to produce an image mapping. Using their proprietary 'Wision' algorithm, which I believe just maps signal reflection onto a 2d heatmap, Huang et al. are able to stronger return signals to identify more dense and reflective objects. I think the next award winning paper drew heavily from this paper, especially with reflections in the identification of the shape of metal objects.

Wang et al. (2018) presented cutting edge object detection research that won the best paper award in IEEE's 2018 Networking Conference. In their paper, Wang et al. show CSI complex data, including both phase and amplitude information, as well as reflection information can be used in detailed object classification. The experimental setup is similar to the one I use, however, material was put between multiple transmitters and receivers. A key component of Wang et al.'s experiment was the use of multiple antennas and subcarriers in their transmitter and receiver setup (3x 6dBi omnidirectional dual band rubber ducky). Multiple antennas, use of subcarriers, detailed CSI data with phase and amplitude, and evaluating signal reflection contributed to a rich feature space from which ML/Statistical tools such as SVMs, Neural Nets, KNNs, and Regression could be used to reach a high level of classification accuracy.

Bluetooth now offers up to 39, 2-MHz channels, more channel data than used in Wang et al. (2018). Classically, bluetooth offered 79, 1-MHz channels. I believe 2x channels may make legacy bluetooth useful for nearby object classification. Since Channel State Information made the feature space of Wang et al.'s neural network classifier, additional state information may allow for more accurate object size, shape, and material prediction. An experimental setup with 5 or more MIMO BLE transmitters and receivers costs less than Wang et al.'s setup and may provide significantly more data for detailed classifications.

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Ohara et al. (2017) use the idea of object detection with wifi to interpret the current state of multiple household objects. The experiment setup also used multiple radios to transmit and receive, as well as CSI data. Open doors, fridge doors, and other room events were detected by wifi, demonstrating crude wifi based detection. Limitations of this experimental setup include the use large AP transmitters that may too mostly to emulate in a commodity setup.

Zhao et al. (2018) demonstrates the case of wifi imaging in the field of computer vision. Because the human body reflects wifi signals, studying the reflection as Huang et al. suggested in 2014 allows for tracking human movement outside of line of sight. In computer vision occlusion to natural light presents a significant limitation. Limbs are often hallucinated with a significant drop of accuracy. Using wifi in human limb pose estimation offers a solution unimpeded by loss of vision. This method is similar to the reflection procedure used in both Wang et al. and Huang et al. Wifi reflection proves useful in classification and computer vision.

I investigated the possibility that using different protocols using the same 2.4 GHz radio would allow for object material type classification. BLE and wifi RSSI values were taken transmitting through a few material types to attempt object classification. The multi-protocol approach made this experiment unique from current other current research being done. While my model could clearly differentiate between no material and material, it had difficulty in separating objects with similar attenuation. More complex data was needed to build a robust machine learning classifier and additional antennas, reflection data, subcarriers, and CSI data would have been instrumental in creating an accurate narrow-band 2.4 GHz classifier. Also, there were too many degrees of freedom in my experimental setup. For example, Wang et al.'s 2018 award winning paper focused on three clearly differentiate categories for wifi scanning luggage: 1) Paper, cloth, plastics, 2) Metal, 3) Liquid. Narrowing the scope of material classifications also augments machine learning classifiers.

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