

# Integration of Estimote Stickers into Smart Apartment Technology

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## Introduction

- The Smart Apartment is a network of motion sensors and cameras that is used to monitor the health and everyday functioning of older adults
- Estimotes are sensors that attach to objects (see **Figures 1 & 2**) and send radio signals to smart phones, indicating their motion along the X-Y-Z axis

## Objectives

- Can estimote stickers accurately track motion of objects in use?
  - Compared sticker data collected through smartphones to the real time annotation tool (RAT)
- Test task recognition accuracy for a model trained with data from estimote stickers

## Methods

- Participant Demographics
  - 14 participants, 2 male and 12 female, between the ages of 20-44, obtained through university class and community outreach
- Materials
  - Estimote stickers placed on **broom, dish soap, duster, dustpan, hand soap, medication dispenser, plastic soup bowl, watering can, and water filter**
  - WSU Campus Smart Apartment (4 video cameras, RAT coding system, intercom)
  - 2 iPhones (iPhone 5 in living room downstairs, iPhone 6 in monitoring room upstairs)
- Procedure
  - Participants were instructed to complete 6 activities within the Smart Apartment: **Water Plants, Fill a Medication Dispenser, Wash Countertops, Sweep & Dust, Cooking, and Hand Washing**



**Figure 1:** Estimote sticker on water filter (left)  
**Figure 2:** Estimote stickers in package (right)

## Results

**Table 1:** Number of inaccurate recordings for estimote stickers

Object	False Positive	False Negative	Accurate Fire %
Brita Filter	0	0	100%
Broom	0	0	100%
Dish Soap	1	0	100%
Duster	0	0	100%
Dustpan	0	0	100%
Hand Soap	1	10	15%
Medication Dispenser	0	1	93%
Plastic Soup Bowl	1	0	100%
Watering can	0	0	100%

- False negatives were more prevalent than false positives
  - Rate of true positives is **91.97%** [**sensitivity**]
  - Rate of true negatives (no data when there should not be) is **99.70%** [**specificity**]
- Average time difference between the RAT and estimotes was 9.57 seconds ( $M= 9.57$ ,  $SD= 18.66$ )
- Activity recognition performance
  - 10-fold cross-validation with decision tree classifier on only motion (M) sensor data yielded an average of 94.17% ( $\kappa=0.93$ ,  $\sigma=1.08$ ) recognition accuracy.
- Recognition accuracy on motion sensor data combined with estimote stickers data:

Accuracy	Receiving location	
	Downstairs (DS)	Upstairs (US)
95.83%	95.76%	95.76%
( $\kappa=0.95, \sigma=0.88$ )	( $\kappa=0.95, \sigma=1.05$ )	( $\kappa=0.95, \sigma=1.05$ )

- p-values for 2-tailed t-test for accuracy values between the corresponding data:
- | p-value | DS - US | DS - M                | US - M                 |
|---------|---------|-----------------------|------------------------|
|         | 0.65    | $7.1 \times 10^{-25}$ | $3.95 \times 10^{-21}$ |

## Discussion

- Estimote stickers show potential for tracking object use and being used in a smart home but require additional testing
- High standard deviation means the time differences between the estimotes and the RAT are spread out
- Addition of estimote stickers resulted in improvement in activity recognition accuracy
- While receiving location for estimote stickers had some effect on individual object movement detection, it didn't significantly affect the task recognition accuracy in our setup
- Confounds
  - Experimenter was in charge of marking tasks in the RAT, and humans are imperfect
  - Cameras were on slight delay
  - App used on smartphones to collect and record data from the estimote stickers was a prototype
  - RAT system was made to track a person's activities, not track when a person moved a particular object
  - Some items were not necessarily moved when used
    - Hand soap had a pump in which participants pressed on, with the sensor on the back of the bottle
  - Unsure of effects that heat, cold, and water have on stickers
- Future research
  - How sensitive are estimote stickers?
    - Does the location of the estimote sticker affect estimote sensitivity?
    - Does different environmental conditions affect estimote sensitivity?
  - What is the optimum distance between data receiver and stickers?

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