**Experimental Results**

Data collection on a single resident for the baseline method occurred over 14 days in February 2014, shortly followed by 14 days of data collection with CARL running in February and March 2014. The resident was instructed on disabling CARL if the system started malfunctioning or there would be guests in the apartment, and did so for a 6 hour window when entertaining guests one evening. Data from the window was removed to ensure comparison of single resident behavior only between the baseline method and CARL. Ultimately, the primary goal is to determine how much energy savings can be achieved by using CARL. However, human factors need to be considered as well. As a result, CARL is evaluated on a number of different performance measures. These measures include: total time, watt hours, RMSE, and NRMSE.

数据的采集分为两个部分：1）基准方法的数据采集，从2014年2月开始持续14天；2）使用CARL系统后的数据采集，从2014年2月到3月之间持续14天。居民被告知关闭CARL系统的方法。当系统异常运行或者公寓中有其他客人时，居民会关闭CARL系统。但是，有其中一天晚上，居民忘记操作，留下了6个小时的招待客人时候的家庭数据；该数据被移除，以确保分析中仅仅比较单个居民在使用基准方法与CARL系统之间的差别。最终，目标是得出使用CARL可以节省多少能耗。并且，人机交互的因素也要考虑。因此，CARL在许多不同性能参数上被进行评估。这些参数包括：设备整体使用时长，设备能耗，RMSE和NRMSE。

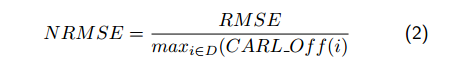
Total time measures the sum total time that devices are on. Watt hours measures the sum watt-hours of power that are used by a particular method (CARL or the baseline method of no automation) combined over all of the devices that could be controlled in the residence. Power data from other devices, refrigerator, stove, heater, etc. were not included in the calculations. The RMSE (Root Mean Square Error) is computed to indicate the error in CARL’s automation due to being too aggressive (turning off devices when the resident needed them) or too conservative (not turning off devices when they were not needed). The too-conservative case occurred twice. In both situations, this was due to the smart home infrastructure not detecting the request to turn off a device. The too-aggressive situation was more common and was typically due to errors in recognizing the current activity. The errors were indicated by button taps by the resident and are therefore measured using this feedback, as shown in Equation 1. In this equation, D represents the number of devices, CARL\_Off(i) represents the number of times that CARL turned off device i, and DoubleTap(i) represents the number of times that the resident indicated an automation error via a double tap.

Total time表示设备开启的总时间。Watt hours表示总能耗，该能耗为在某数据采集阶段（使用CARL或未使用的14天）采集到的公寓中可以控制的设备的能耗总和；冰箱，火炉，加热器等设备的能耗不在能耗量测中。RMSE（均方根误差）被计算，用来指出CARL自动化控制中的错误。错误有两种类型：1）太积极造成的错误（在居民需要使用设备时候关闭设备）；2）太保守造成的错误（在居民不需要使用设备时候未关闭设备）。实验中，太保守的情况出现过两次。在这两种错误场景中都是由于智能家居基础设备没有检测到关闭设备的请求造成。太积极的错误出现得更寻常，并且，是由于当前活动的识别错误造成。错误可以通过用户对开关按钮的轻敲反馈获得，均方根误差计算公式如公式1所示。在公式中，D表示设备个数，CARL\_Off(i)表示CARL关闭设备i的次数，DoubleTap(i)表示居民通过双次轻敲按钮暗示自动化控制错误的次数。

 (1)

The NRMSE (Normalized RMSE) is computed in order to better interpret the RMSE values. This is obtained by dividing the RMSE result by the maximum possible error. The resulting value ranges between 0.0 (no error) and 1.0 (maximum possible error).

 (2)



为了更好地解释RMSE（均方根误差）的值，NRMSE（归一化的RMSE）被计算。NRMSE通过RMSE的结果，除以最大可能的错误数得到。结果的范围在0.0（表示没有错误）到1.0（表示全是错误）。

The results comparing total time and watt hours for CARL-based automation and no automation are summarized in Figure 3 and Table 1. As the figures indicate, there is consistent reduction in energy consumption and unnecessary device utilization through activity-aware automation. Most of the energy reduction is due to turning off lamps when they are not needed (e.g., when the resident is not at home) and turning off speakers when the resident is not in the living room listening to music or watching television.

使用CARL方法前后的能耗、性能比较，在Figure3和Table1中呈现。从图表中可以看出，在使用基于活动感知的自动化系统后，通过关闭无用设备可以从一定程度上减少能耗。大多数的能耗减少都是因为：1）关闭不需要的灯（比如，当居民不在家的时候），2）关闭扬声器（在居民不在卧室听音乐或看电视的时候）。

|  |  |  |
| --- | --- | --- |
|  | Baseline | CARL |
| Total Time (minutes) | 19, 826.04 | 13, 867.64 |
| Consumption (watt hours) | 25, 297.85 | 18, 352.27 |
| RMSE | 0.00 | 11.15 |
| NRMSE | 0.00 | 0.15 |

Table 1: Reduction and accuracy results for CARL.

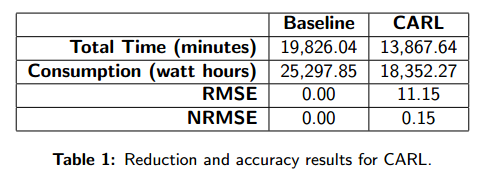


Table 1 summarizes the reduction and accuracy results. There is a significant (p < 0.01) reduction in both energy consumption and total time using activity aware automation. This automation does come at the expense of occasional overly-aggressive device control. This is reflective of the almost 3% error reported earlier for recognizing the targeted 17 activities in real time. Error is also influenced by the rate at which the resident switches between different activities, a resident with a stronger, deliberate routine will have less activity recognition errors than a resident who switches between several activities quickly and often. As activity recognition becomes more robust this error will be further reduced.

Table 1概括了能耗减少和控制精确度的结果。在使用基于活动感知的自动化控制系统后，能耗和设备使用时间有显著减少，尽管CARL会带来一些偶尔积极错关涉笔的控制。错误率还与人在不同活动的切换有关，一个拥有更规律的日常生活的人家中部署该系统将会有更少的活动识别错误。随着活动识别程序更加健壮，错误也会进一步减少。