Chapter 7

Conclusion
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7.1. Introduction

Activity recognition is essential for pervasive computing applications. Many different models have been used by researchers for recognizing user activities in smart environments. Finite automata are one among the models. However, earlier works using finite automata required manual construction of the automata. For activities such as walking and jogging that involve limited number of repetitive constituent steps, automata can be manually constructed relatively easily. For other activities of daily living like cooking, cleaning, etc. manual construction of automata is very tedious. So in this work, algorithms for automatically constructing automata from sensor outputs and to recognize online and composite activities are presented. Also an algorithm for detecting abnormality in the performed activities is presented. All the proposed algorithms were tested with established and publicly available smart environment data sets.

7.2. Research Contributions

Following are the contributions of this research work.

I. Auto-Fuzzy Automata Algorithm (AFAA) - This simple and efficient algorithm is proposed for automatically constructing finite automata from sequences of sensor inputs to recognize ADLs. Fuzziness is incorporated in the constructed automata to deal with variations in the order of constituent events of the activities. This algorithm will spare the
implementers the onerous task of manually constructing finite automata to recognize activities in a smart environment.

II. *Online Recognition Algorithm* (ORA): Online recognition of activities is important for real-life assisted living environments. It must be possible for the system to decide which activity is performed without waiting for future inputs. So, an algorithm named Online Recognition Algorithm (ORA) is proposed for deciding the corresponding activity on the arrival of an event input.

III. *Location Based Composite Activities Recognition* (LBCAR) & *Object Based Composite Activities Recognition* (OBCAR): People frequently perform two or more activities in a concurrent or interleaved manner. This fact necessitates the ability to recognize composite activities. To facilitate online recognition of composite activities these two algorithms are presented. As the names imply, LBCAR identifies activities by tracking the location of the user; OBCAR uses interaction of the user with objects in the environment to decide the currently pursued activities.

IV. *Algorithm for Detection of Abnormal Activities* (ADAA): Ability to decide how well a user has performed an activity will be very useful in providing guidance and help to people with cognitive difficulties. This algorithm locates abnormalities in the performed activities due to missing out of constituent events, changing the order of events and occurrence of irrelevant events.

Table 7.1 summarizes the contributions of the thesis.
Table 7.1. Summary of the Proposed Algorithms

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Name of the Algorithm</th>
<th>Purpose of the Algorithm</th>
<th>Data Set Used</th>
<th>Number of Sensors and Activities in the Data Set</th>
<th>Evaluation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.</td>
<td>Online Recognition Algorithm (ORA)</td>
<td>Online Recognition of Activities using a Fuzzy Automaton</td>
<td>Kasteren, et al. [Kas 10]</td>
<td>14 sensors, 10 activities</td>
<td>By calculating Precision, Recall, Accuracy and F-measure</td>
</tr>
<tr>
<td>3.</td>
<td>Location Based Composite Activities Recognition (LBCAR)</td>
<td>Recognition of Composite Activities using a Finite Automaton</td>
<td>Chai and Yang [Cha 05]</td>
<td>3 Access Points, 11 events, 8 activities</td>
<td>Percentage of recognition</td>
</tr>
<tr>
<td>4.</td>
<td>Object Based Composite Activities Recognition (OBCAR)</td>
<td>Recognition of Foreground and Background Activities for each time step in a data set</td>
<td>Patterson, et al. [Pat 05]</td>
<td>60 sensors, 11 activities</td>
<td>By calculating Precision, Recall, Accuracy and F-measure</td>
</tr>
<tr>
<td>5.</td>
<td>Algorithm for Detection of Abnormal Activities (ADAA)</td>
<td>For identifying errors in performed activities</td>
<td>CASAS data set [Coo 09]</td>
<td>39 sensors, 5 activities</td>
<td>By counting the number of errors identified</td>
</tr>
</tbody>
</table>
All the proposed algorithms are implemented in Java using JDK1.6.0_04 and tested with frequently cited and publicly available data sets. All the algorithms except LBCAR and ADAA were evaluated by calculating precision, recall, accuracy and F-measure values. LBCAR was evaluated by calculating percentage of recognition. ADAA was evaluated by counting the number of abnormalities located in each of the observed activities. The results obtained are highly promising and relatively better than those of earlier works in this area.

7.3. Limitations

All the proposed algorithms in this thesis assume the following:

i. **User activities are monitored using outputs of sensors embedded in the environment:** User activities may also be tracked using video cameras and on-body sensors such as accelerometers and gyroscopes. But usage of video cameras may be objectionable to many users due to privacy concerns. On-body sensors may cause inconvenience to the users. Sensors embedded in the environment do not have these demerits. Also, more of the ADLs may be easily monitored using environmental sensors than on-body sensors.

ii. **The data sets are fully annotated or activity-wise segmented:** It is easy to extract the sensor event sequences corresponding to the observed activities if the data set is annotated. Effective segmentation methods are available to identify event sequences from unannotated data. So, it is assumed in this thesis that fully annotated or activity-wise segmented data sets can be acquired in real-life environments and only such data sets are considered.
7.4. Future Work

Following are some of the possible future research, in continuation of the work presented in this thesis.

- In this thesis, fuzzy automata are used for dealing with variations in the number and order of events in an activity. Suitability of other types of automata such as probabilistic automata and pushdown automata for activity recognition may be studied in future.

- As such, the proposed algorithms are applicable to data sets that are acquired using sensors embedded in the environment. Data sets from on-body sensors (such as accelerometers and gyroscopes) and video cameras are not considered. All the considered data sets except the CASAS data set which is used to evaluate ADAA, contain binary sensor outputs. CASAS data set contains outputs from few analog sensors for monitoring the use of faucets and a stove burner. In future, methods for making the algorithms suitable for any type of sensors may be explored.

- All the proposed algorithms assume that there is a single user in the monitored environment. Obviously this is rarely the case in real-life situations. So, ways of extending the proposed algorithms for multi-user environments can be studied in future.

- Users tend to do even the same activity differently at different times. Mostly the number, order and duration of events of an activity vary each time the activity is performed. The Auto-Fuzzy Automata Algorithm deals with variation in the number and order of events by calculating the
membership value of active states. Duration of each constituent event of an activity may also be monitored in future works. This may be useful in deciding how well an activity is performed.

- The Algorithm for Detection of Abnormal Activities locates abnormalities in the performed activities due to missing out of an event, out of order events and irrelevant events. There are other reasons for abnormality such as spending too much of time in an event and unnecessarily repeating events. ADAA may be extended to identify abnormalities due to such reasons.

- The presented algorithms may be tested in real-life situations in future.

7.5. Summary

Activity recognition is an area of pervasive computing with immense potential to enhance the living standards of each type of users. The recent advancements in sensing, computing and communicating capabilities of various devices have opened up new avenues of applications which are limited only by imagination. This thesis has contributed algorithms that can be used to automate the process of recognizing users’ activities from sensor event data with minimum human intervention. By taking measures to overcome the limitations, the performance and utilization value of the proposed algorithms can be improved in the future.