Chapter 1

Introduction
1.1. Overview

The objective of pervasive computing is dictated by the vision of Mark Weiser [Wei 91]. He said that profound technologies disappear by weaving themselves into the fabric of everyday life, thereby allowing people to concentrate on their work rather than technology. His vision is fastly being realized due to the advancements made in the fields of computing and communication in the last two decades. Hardware components are becoming so small and flexible that they can be embedded in any imaginable object. Incorporated with appropriate sensors and wireless communication devices, daily life objects are becoming smart objects that can sense how and when they are accessed, and send this information to their neighbor entities whenever necessary. So, it is now possible to unobtrusively track the way a user interacts with his environment. Using various localization techniques, the different locations traversed by a user can be decided accurately. These developments have spurred the growth of the field of human activity recognition that aims to decide and predict what a user is doing, in order to proactively take some steps to help or guide the user. This has a wide variety of applications limited only by imagination. In the following section a few of the main application areas of activity recognition are explained.

1.2. Activity Recognition Applications

Activity Recognition can be used in numerous applications that range from security to health care and education to entertainment. It can be used in indoor as well as
outdoor environments provided appropriate sensing infrastructure is established.

1.2.1. Surveillance Applications

One of the main applications of activity recognition is surveillance and monitoring. Almost all public places are monitored by video cameras. This results in huge volumes of data that will require tremendous man power to be analyzed manually. Activity recognition systems can be used to analyze such voluminous data and to identify any object or person of interest. For example, suspicious behavior by people in such places can be identified by an activity recognition system and the authorities concerned can be alerted [Cho 02][Mah 04][Geo 04][Jia 06][Zaj 07]. Also, such a system can be very useful in identifying and removing unclaimed objects that may result in danger to the public[Fer 06][Bey 03][Car 08][Van 08]. People caught in dangerous situations can be provided timely help using such activity recognition systems. For instance, an activity recognition system in a swimming pool can identify those who are drowning and can ensure life-saving assistance by alerting the rescue personnel[Kam 02][Lu 04]. Using GPS, the movement trajectory of a user can be monitored and necessary context sensitive navigational instructions can be provided to ensure that the user reaches the destination quickly and easily. Similar technique may be used by business establishments for the safe and cost-effective movement of cargo to the customer sites.

1.2.2. Health care applications

Perhaps the most important area of application for activity recognition is providing health-care, especially to the elderly and those with cognitive difficulties. Falling is one of the frequently occurring problems in the elderly. Timely help after a fall is very important. Fall detection can be done using on-body sensors and an alert call may
be made to the care-givers. Using on-body sensors for fall detection has limitations such as restricted movement area, very few response methods and cost[Dai 10]. These limitations can be overcome by using smartphones for fall detection. Usage of smartphones is unobtrusive and inexpensive[He 12][Mia 06]. Also mobile devices provide greater independence to patients who otherwise would be confined to supervised environments[Loc 12].

Activity recognition systems can be used for effective monitoring of patients and identification of symptoms[Los 10]. Normally care-givers have to rely on data acquired during a short period of medical examination. Some of the principal symptoms may not occur during such examination. In such cases, patients may have to be detained in the hospital for medical observation. Using activity recognition systems, continuous data for long durations about the ailments can be collected without the need for the patient to be in the hospital. Even after treatment the level of recovery can also be monitored by care-givers from a faraway place. Remote monitoring of health conditions is beneficial for both the patients and the care-givers during and after treatment, especially in the case of patients undergoing physical therapy[Lau 10].

Activity recognition can be used for assisting people with cognitive difficulties, like the elderly with dementia, to complete their Activities of Daily Living (ADLs) successfully. Such People may be assisted in their activities by reminding to perform a forgotten step of an activity. For example, successful completion of an activity by such people may be ensured by giving suitable prompting messages whenever the order of the constituent steps of the activity is not maintained[Hoe 05][Mih 04]. Visual cues also may be used for this purpose[LoP 04][Myn 00]. A far away family member or a well-wisher
may be informed about the well-being or otherwise of a lonely patient or an elderly person, thereby ensuring peace of mind and timely assistance[Kat 83][Hea 14].

By providing information at opportune time, people can be persuaded to make corrections in their behavior to attain a predefined goal. For example, to reduce obesity, diet suggestions can be provided when the user is preparing a meal[Int 04]. Activity monitoring devices may offer such data as distance travelled, calories burned, intensity and duration of physical activity, etc. Using these data, fitness applications may recommend changes to be made in the fitness regimen of a user. Positive reinforcement in the form of some kind of reward can also be useful in persuading people to adopt a desired behavior[Con 08][Try 06]. Obviously, all these applications are based on effective recognition of the activities performed by the user.

Activity recognition systems can be used as efficient personal assistants[Tam 98][Hai 02]. Context-triggered actions can be used for popping up location sensitive reminders [Bro 95]. For example, a user can be reminded to buy exhausted provisions when he/she is near a provisional store or to borrow/return books when the library is nearby[Sch 94]. An elderly patient who is alone in a home may be reminded to take appropriate medicines at proper time[Cha 04][Oht 02].

Activity recognition can be used for providing luxurious services such as automatic adjustment of lighting and cooling facilities, proactively adjusting other ambient features like getting the required gadgets ready according to one’s working schedule and presenting information in appropriate form depending upon users’ situations (e.g. when driving, reading out a message instead of displaying).
1.2.3. Workplace Applications

Efficiency and cost effectiveness can be greatly improved by using activity recognition systems in workplace environments. Energy could be saved by devices like motion activated lights. Whereabouts of employees could be traced using context-aware activity recognition systems, especially in hospital environments where this information will be of immense help in case of emergencies [Fav 07]. Messages and answers to queries could be displayed in the systems that are in the vicinity of the current location of a mobile recipient in a vast campus. Fine-grained location awareness throughout a building might be used in dynamic power management of devices [Har 08]. Current energy saving devices such as motion activated lights tend to be disabled by occupants because they may be annoying. By understanding more of the local context, and the habits of the users, it might be possible to build systems that match better the expectations of the people in the building [Wre 06]. Best practices may be encouraged during work by observing activities of the employees [Sna 14]. For instance, a driver who meticulously follows safety and fuel efficiency instructions may be given discounts on his insurance payments.

1.3. Different Approaches to Activity Recognition

Like any other data processing system, the first step in the realization of an activity recognition system also is acquisition of relevant data. For this, the place - be it indoor or outdoor - where the activities are going to be performed, must be furnished with suitable data collecting devices. For activity recognition, the suitable data collecting devices are the myriad types of sensors that vary in capability from taking a sequence of pictures of users to collecting their vital parameters and other environmental aspects.
such as temperature, pressure, light and sound. As shown in Figure 1.1, approaches to activity recognition can be divided into two broad categories mainly based on how the required data is collected[Che 11]. They are sensor based and video based approaches. The sensor based approach is further divided into wearable and environmental sensor based approaches depending on where the sensors are mounted.

1.3.1. Sensor based approaches

Information about the users’ activity and environment are monitored using various sensors. The sensor data collected are usually analyzed using data mining and machine learning techniques to build activity models. These models are then used to recognize the activities performed by users.

Wearable sensor based approach

In this approach, output signals of sensors worn by the person under observation are analyzed and using different mathematical models the underlying pattern is identified. The wearable sensors may be inertial measurement units such as accelerometers,
gyroscopes and magnetometers, or vital sign processing devices or Radio Frequency Identification (RFID) tags[Tur 08]. Activities like walking, jogging and climbing up/down, which consist of very small number of constituent steps that get repeated in some order, may be accurately and effectively recognized using this approach[Lee 02][Bao 04][Pat 05][Huy 08]. Also the wearable sensors are relatively inexpensive.

But there are two main drawbacks of this approach. First, the user may feel uncomfortable and be unwilling to wear the sensors. Second, this approach is inadequate to recognize most of the activities of daily living other than physical movements.

**Environmental sensor based approach**

This is also known as object based activity recognition. This is based on the observation that activities are characterized by the objects that are manipulated during their operation [Phi 04][Tur 08]. Smart environments are created by embedding objects in the environment with appropriate types of sensors that fire output - usually on and off - signals, whenever the user interacts with the objects[Phi 04][Cha 08]. For example, a reed switch attached to a door will generate binary signals whenever the door is opened or closed. A switch sensor in the bed may indicate if the user is sleeping. Pressure sensors embedded in floor mats can be used to track the movement of the user in the environment. Thus by observing the status of the sensors embedded in the environment, the set of objects used by the user and his/her movements can be easily identified. Using the set of objects and the order of their usage, the activity performed by the user can be inferred. The system, then, can make necessary adaptations and provide just-in-time context aware assistance to the user as required by the application[Tur 08]. This approach is feasible and effective in recognizing ADLs of users. Unlike wearable
sensors, ambient sensors pose fewer restrictions and hence simplify overall system design. Since this approach is infrastructure dependent, it may be very expensive and time consuming for monitoring user activities in outdoor environments. In multi-user environments, it may be difficult to differentiate between users unless some wearable sensor is used.

1.3.2. Video based approaches

In these approaches, the objective is to automatically recognize the activity that is being performed in a sequence of images with one or more persons performing an activity[Tur 08]. The sequence of images is captured using one or more video cameras installed at strategic locations in the place of the activity. Computer vision techniques are used to analyze the visual observations for pattern recognition[Tur 08][Bod 03][Fio 08].

This approach is more challenging in real life environments as it is more sensitive to changes in lighting and angle of viewing[Bod 03]. Also, cameras are expensive and not scalable and reusable. Moreover, users may not prefer cameras as their privacy may be compromised. Nevertheless in applications related to security of public places, this approach is better suited than the others.

1.4. Structure of Activities of Daily Living

In the literature terms like ‘activities’, ‘events’ and ‘actions’ are used by different authors to mean different concepts. So to avoid ambiguity, in this work the terms ‘events’ and ‘activities’ are used with specific meanings. An event is a simple operation that may get completed in a few seconds. For example, opening a door, sitting on a couch and lighting a stove are events as they take a few seconds and they by themselves are not complete. After lighting a stove the user must proceed with a sequence of events.
like placing a vessel on the stove and pouring something into the vessel for cooking. An activity is a sequence of events, which may last for a few minutes to several hours. For example, preparing dinner is an activity. Obviously this involves several events and may require several minutes to get completed. For an activity there can be more than one possible sequence of events, as an activity can be performed differently by different users or by the same user at different times. Some authors use the terms ‘goals’ to represent activities. In this thesis ‘goals’ and ‘activities’ are used interchangeably.

1.5. Research Focus

A number of methods have been used by researchers for activity recognition. Use of finite automata is one among them. To recognize activities like walking and jogging using finite automata, the earlier works require the automata to be created manually. Recognition of other ADLs like cooking, cleaning, etc. using finite automata is not considered by many researchers. Given the power of finite automata in recognizing strings with some structure and the possibility of representing activities as a string of events justify exploration of methods for automatic construction of finite automata to recognize ADLs. The fact that users tend to perform activities differently at different times dictates the need of fuzziness in the constructed automata. So in this thesis the following questions are answered with respect to activity recognition.

1. Can finite automata be automatically constructed to recognize activities from sensor data obtained in a smart environment? There should be no need for the designer to manually specify the states or transition rules for the automata constructed for recognizing any activity. Also fuzziness in the constructed
automata should be incorporated so that variations in the manner of performing the activities can be dealt with efficiently.

ii. When using automata, classification is done depending upon the state reached after scanning the end of the given string. This will not be suitable for online recognition of user activities. So, how can the constructed automata be modified so that on-line recognition of activities can be achieved?

iii. In real life, users tend to do multiple activities by concurrently performing or interleaving activities. Any activity recognition system, to be useful in real life environments, must be able to recognize concurrent and interleaved activities. How can the automatically constructed automata be used for recognizing concurrent and interleaved activities?

iv. It is important to decide how well a user performs an activity. This capability will be useful for guiding and assisting the elderly and people with cognitive disabilities to lead an independent life. So can a simple method for deciding if a user has successfully completed an activity or not, be devised?

The subsequent chapters explain the solutions suggested to these questions one by one in the order of the questions given above.

1.6. Contributions

The main contributions of the research work are five different algorithms as given below.

i. Auto-Fuzzy Automata Algorithm (AFAA): The purpose of this algorithm is to automatically construct a Fuzzy automaton for recognizing user activities in a
given data set. Using the SL-infer algorithm[ Fer 09], a Deterministic Finite Automataon (DFA) is constructed to accept the preprocessed data. By including appropriate functions for membership value calculation and multi-membership resolution, fuzziness is incorporated in the DFA. The Fuzzy automaton so constructed is used for activity recognition.

ii. Online Recognition Algorithm (ORA): To recognize user activities at every time step, the AFAA is extended to identify and store the labels of activities, in each state of the constructed automaton. To resolve ambiguities, the number of occurrences of an event in the activities and the number of times an activity follows each of the other activities are used.

iii. Location Based Composite Activities Recognition Algorithm (LBCAR): This algorithm is used to recognize concurrent and interleaved activities performed by a user by identifying his/her location in an indoor environment. Along with an automaton constructed using the ORA, the algorithm uses a stack and an input buffer to recognize composite activities by simple push and pop operations.

iv. Object Based Composite Activities Recognition Algorithm (OBCAR): For recognizing interleaved ADLs using the sequence of used objects, this algorithm uses an automaton constructed using ORA. Then by maintaining a table of the activities pursued by the user, the algorithm efficiently identifies the interleaved activities.

v. Algorithm for Detection of Abnormal Activities (ADAA): This algorithm identifies the abnormalities, if any, caused by missing out events or changing the
order of events, in the activities of a user. Events that are essential for an activity and the required order of events are identified by a simple and novel method.

1.7. Overview of Chapters

Chapter 2 gives a detailed description of the literature survey. Earlier works related to the contributions of this thesis by different authors have been listed under subheadings each related to a specific focus area.

The basic concepts and definitions necessary to automatically construct an automaton are given in chapter 3. The SL-infer algorithm[Fer 09] which constructs a Deterministic Finite Automaton (DFA) to recognize a given set of strings is reproduced for the sake of completeness and easy reference. The data set, experiment conducted and the results obtained are also given in detail.

Chapter 4 explains the proposed algorithm for online recognition of user activities. It contains description of the experiments and the obtained results. The results obtained are compared with that of an earlier work from the literature.

Chapter 5 explains how concurrent and interleaved activities can be recognized using automatically constructed finite automata. The data set used, experiment conducted and the findings are also described.

Chapter 6 provides the alternate method proposed for activity recognition. It also illustrates how abnormal activities can be identified using the proposed method. Description of the data set used, tests performed and performance evaluation are included.
Chapter 7 serves as conclusion of the thesis by listing the limitations of the proposed activity recognition algorithms and incorporates the recommendations for future study.

1.8. Conclusion

In this chapter, the basic ideas that led to the concept of pervasive computing are introduced. To achieve the vision of pervasive computing, activity recognition is essential. Ability to recognize user activities in a smart environment has tremendous potential to improve the living standard of all kinds of users. To illustrate this, some of the activity recognition systems that have been developed for surveillance, care-giving, health-maintenance and workplace-assistance are enlisted. The different approaches used for activity recognition are introduced. The basic terms viz. ‘event’ and ‘activity’ are defined and examples are given. The scope of this research is defined by enumerating the questions for which solutions are given in the subsequent chapters. A brief overview of the contributions is presented and organization of the chapters is described.