Ensuring Privacy and Sharing Framework for Pervasive Logging

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Abstract

The advancement in the storage and capturing capabilities of today's digital devices has promoted the idea of pervasive logging. Pervasive logging captures a variety of information without any human intervention. This data is logged by means of pictures, audio clips, location and activity logs and commonly known as lifelogs. The lifelogs help to recall the past events occurred in one's life. However, there are a few major problems which prevent pervasive logging from becoming widely accepted among common people.

It is necessary to address these problems to make pervasive logging popular, since it has a potential to be exploited in a number application areas. At first, we must consider the privacy of people who are captured during pervasive logging if they are not willing to be a part of some one's lifelogs. Second, the lifelogs must be retrieved instantly and relevant to the current situation of a user. Finally, the user may be able to share the lifelogs with friends in such a way that the friends may take advantage of these lifelogs in their respective lives.

We ensured privacy in pervasive logging by proposing a *lifelog privacy framework* by which a person may easily input his or her privacy consent on the lifelog device. The privacy consent is a geo-temporal privacy policy which consists of a restricted location and time duration, where and when the user does not want to be recorded by neighboring pervasive devices. A user of the system may select the type of sensors on which restrictions are to be applied, and at the same time, allow selected friends and family members to capture while denying anonymous people. The privacy preferences set by the user are shared among neighboring devices present at a place and the lifelog sensors are suspended from logging when the user with active privacy settings is in front of another user. We designed a prototype lifelog device and implemented our privacy framework in such a way that the users may easily inscribe their privacy preferences on the device. Our approach is better than computer vision based privacy (in case of images), because it does not allow the sensors to log the person on the first hand, whereas, computer vision based technique applies privacy after capturing. The proposed system performed very well during evaluation and the users were able to hide themselves from unwanted logging of neighboring participants.

We also proposed a lifelog retrieval method by which the users may have access to those past lifelogs which are relevant to their present situation. The lifelog device is a smart phone on which this mechanism is implemented. We recorded images and audio clips as

lifelogs and captured three key elements together with the lifelogs. The key elements are people nearby, object context and present location of the user. A user may exploit any one or all the key elements together to retrieve most relevant lifelogs to the present situation. This approach is very useful as the users do not have to enter any past information to retrieve lifelogs , and moreover, they are able to see their past information instantly on the device. We compared our system with Vicon Revue device and found that our proposed lifelog system is better than Vicon Revue device. Finally, our *lifelog sharing framework* recommends a method to share lifelogs with friends based on their current location. The user may share lifelogs by declaring one of the three sharing strategies which are, particular street, city and location free sharing. Again, a smart phone is configured to capture lifelogs in the form of images and audio clips. Only those lifelogs are shared with friends which are selected by the user himself and the friends may view the shared lifelogs when they visit the location where the lifelogs were generated. Sharing lifelogs based on the location may keep the friends away from viewing the lifelogs which are not useful or related to them. The system evaluation further strengthened our idea of sharing lifelogs with friends based on the location and the participants of the experiment found the shared lifelogs useful for their current location.

In summary, pervasive logging will be widespread in near future. Our research work highlighted the problems and presented valuable frameworks and methods to resolve the issues in the current techniques for achieving privacy, retrieving and sharing lifelogs in the course of pervasive logging. Furthermore, the experiments conducted for evaluation confirmed that our proposed techniques are practical and efficient. Incorporating these techniques in the future lifelogging devices will draw more people towards using a system that is able respond to their privacy concerns, retrieves the lifelogs relevant to their present situation and allows them to share lifelogs with friends who may find these lifelogs informative.

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Chapter 1

Introduction

The increasing use of digital devices has produced a surge of digital personal data including electronic mail, photos, blogs posted, visited locations, performed activities, etc. With such diverse set of information, one may like to maintain digital archives pervasively without any human intervention. The digital collections of information about individuals are termed as lifelogs.

The lifelogs may contain data from various sources and this data is processed into a meaningful and retrievable information which may be very helpful for the purpose of reminiscence. The burden of recording lifelogs has reduced with the advancement in acquisition and retrieval capacity of the modern wearable devices such as smart phones and other gadgets which are capable of logging life events pervasively. The whole process of capturing, storing, processing and organizing of data happens by default, requiring no active input by the lifelogger, that is the reason lifelogging is also termed as pervasive logging. Since the activity of pervasive logging is an evolving field, therefore a generally accepted definition of pervasive logging is yet to be defined. Lifelogging has played a significant role for treating people with episodic memory impairments [1], at the same time, it is also becoming popular among ordinary people to serve a variety of aspects in human life such as, personalized services, behavior modification, health benefits and tele-medicine [2], [3], [4], [5].

1.1 Pervasive Logging

Pervasive logging has been a prominent research concern in recent years with the invention of wearable life capture gadgets embedded with a variety of sensors. The lifelogs generated by these devices are in the form of images, audio records, location traces, health records, activities performed, social interactions, etc. These lifelogs assist in the course of recalling the past events in one's life. Several attempts have been made by the researchers to digitize day to day activities, thus, increasing the social acceptance of personal lifelogging. Among them, "My life bits" [2] project by Gemmell et al. stored a variety of media including conversations, meetings, sensor readings and computer activity and supported manual annotation for the purpose of easy retrieval of past information. In [6], Kim et al. used body worn sensors including audiovisual device, GPS, 3D-accelerometer and processed logged information to create metadata for easy retrieval afterwards. A system was proposed in [7] to trigger episodic memories of past by recognizing the context with infrared beacons that are placed in rooms; attached to persons and objects. Shaikh et al. in [8] inferred human activity from environmental sound cues and common sense knowledge, which is an inexpensive and alternative way to the traditional sensors. They employed hand-held devices to achieve a seamless integration between the physical and virtual world.

In [9], the authors designed a new wearable compound omni-directional sensor comprising a hyperboloidal mirror and multiple paraboloidal mirrors. This sensor recorded visual information in all directions around the user and classified captured objects as foreground or background according to their distance. Lee et al. attempted to capture third person viewpoint while logging people when they interact with smart objects [10]. They made three smart objects, a mirror, a kiosk and a step machine and logged the people who interacted with these objects. A framework was proposed to capture and share personal digital memories in [11]. With this framework, the system records a user's movements throughout the day periodically and collates photos, physiological and environmental data to create an accurate timeline of the user's day. This data could be shared among other users who are in the same vicinity. A cloud-based lifelogging framework was proposed by Albatal et al. in [12]. They designed "Senseseer" tool for personal health monitoring, location tracking, lifestyle analysis and tourism and their system design offered three services, which are, My Health, My Location and My Social Activity.

Among various research subjects, this study focuses on the privacy concerns evolved while using pervasive devices for lifelogging. We proposed a lifelog system which incorporates privacy consent of users and allows them to avoid unnecessary logging by neighboring people. Furthermore, we also highlight the issues of retrieving lifelogs for the present situation of a user and sharing them with one's friends in this dissertation. In this chapter, the detailed motivation of this study is explained by clarifying the importance of privacy in pervasive logging devices, retrieval of appropriate lifelogs for a particular situation as well as sharing of lifelogs among friends to make the best use of one's past experiences.

1.2 Motivation and research goal

In this research, we emphasized upon two major issues in pervasive logging and proposed methods to resolve them. We discuss these issues one by one in the following subsections.

1.2.1 Privacy in pervasive logging

In general, the purpose of pervasive logging devices is to capture everything so as to recall previous events, for instance, the people met in the past or topic of the discussion in a gathering. In future, the popularity of such devices might evolve privacy concerns among people at public places when someone wearing a lifelog device captures them indefinitely. Such an action will make the people more vigilant if they will come to know that they are being recorded by another person. In a study by Dubey et al. in [13], it is shown that if a human being is being observed continuously, this may alter their usual behavior.

A survey conducted by Karkkainen et al. in [14] supported the idea that people were content with lifelogging when they had the authority to share the photos and videos taken by the lifelog device, but showed utmost care in case of neighbor's pictures as no proper privacy mechanism was available to deal with such situations. Nguyen et al. surveyed to gain feedback about the use of SenseCam device [15] revealed that most of the people preferred to be informed and asked before any recorded data was to be shared [16].

In the light of the above mentioned problems, a mechanism is required to restrict pervasive logging device from capturing the people who may want to avoid anonymous logging and do not like to be a part of some one's lifelogs. Lifelog devices may become very popular if we develop a method that encourages pervasive logging given that an individual has already approved to be recorded by the people wearing the lifelog device. There are several challenges in the course of developing such a lifelog system that need to be addressed. First of all, the preferences of a person seeking privacy from neighboring users need to be well prescribed on the lifelog system. Second, sharing of those preferences among neighboring devices and finally, refraining the lifelog device sensors from logging the person with active privacy settings.

As a solution to above mentioned challenges, we proposed a lifelog system which permits users to inscribe their privacy consent on their respective logging devices. This system shares users' privacy preferences among neighboring devices and ensures privacy by suspending the lifelogging sensors. In order to ensure privacy from neighboring devices, each user must wear the proposed lifelog system. If the users do not wear the given system, their privacy cannot be guaranteed. The users are urged to input the privacy in the form of restricted locations and time intervals on the lifelog device so that privacy may be activated at those locations and time durations.

1.2.2 Retrieval and sharing of lifelogs

With the advancement in storage capabilities of computing devices, storing of events occurred over a life time in digital format is closer to becoming a reality than previously expected. The pervasive devices allow a user to transfer the lifelogs on a computer for viewing and recalling past events. As the amount of data grows, it is at a risk of becoming meaningless and unmanageable. Moreover, searching for the lifelogs of a particular situation becomes challenging, since people tend to forget the key details of their past life. A user needs to input exact date and particulars of the past experiences in order to access these lifelogs. At the same time, the lifelogs are not instantly accessible to the users when they are distant from the computer where the lifelogs were originally stored.

The lifelog project by Gemmell et al. [2] generates data at tremendous rate, making it impossible to retrieve appropriate logs if manual annotation is not performed. As well as lack of comprehensive context associated with the logs makes the process of retrieving appropriate logs time consuming and boring. The term context can be defined here as location, identity of people around the user, time of the day, temperature, etc. [17], [18]. A study by Sellen et al. in [19] explained that the ability of a user to relive past experiences based on automatically taken images decreased rapidly after only three months, leading to doubts regarding their effective support for long term recollection.

The data gathered by the lifelog devices during lifetime increases rapidly since this information is collected with the intention to assist the user in reminiscing past experiences. In the light of the above mentioned problems, we need to develop such a lifelog system that may capture contextual data in conjunction with the lifelogs. This context may be exploited to retrieve only those lifelogs that may help in the present situation of the user.

We designed a lifelog system that identifies people and objects situated infront of the user as well as records user's location simultaneously while capturing the lifelogs. In this way, the system assists the user to retrieve past lifelogs related with the current location of the user along with people and objects nearby the user at present.

People usually share their significant life experiences with friends via email or mobile phone. Today, social networks have become the most popular way to share life experiences with friends. These systems do not restrict information sharing to friends only, as with default settings, social networks share information to everyone. Talking about lifelog devices, they amass a variety of life experiences and an individual may like to share these experiences with others. However, sharing of life contents with all the friends is inappropriate, as some of the friends may not find the shared information useful. On the other hand, it is very difficult to identify the target audience who may find one's shared life experiences valuable. In addition, lifelog data is personal and it is inappropriate to share all its contents with public.

Serveral researchers have focused on sharing lifelogs with people. A sharing model was proposed by Rawassizadeh et al. in [20] for secure sharing of lifelogs with people for a limited period. In another research, Zheng et al. tried to use location history to develop social network and offer travel recommendations. They named the system "GeoLife" [21] which records GPS traces of people and the travelers make use of these travel sequences to obtain information about most popular places to visit as well as the most feasible transportation mode to travel. In [22], the authors created augmented personal episodic memories which were shareable. With their system, the user needs to specify privacy constraints to make the sharing of these memories possible. Exploitation of one's lifelogs with the aim to assist friends in their respective lives has never been discussed before.

Based on the above mentioned issues, a mechanism is required to ease the process of sharing lifelogs with specific friends who may find one's shared life experiences in their best interest. Here we proposed a location based lifelog sharing strategy where users are permitted to select and share lifelogs with friends who visit the same location where these lifelogs were originally generated. With this approach, we achieve the goal of allowing only concerned friends to view shared lifelogs, whereas, rest of the friends are denied from viewing these lifelogs. Furthermore, the friends viewing the shared lifelogs may better understand their current location they are visiting for the first time.

1.3 Dissertation organization

This thesis is organized as follows. In chapter 2, we introduce the lifelog system, which ensures privacy of users from neighboring pervasive logging devices. Chapter 3 introduces a method to retrieve relevant lifelogs with the present situation of the user and describes sharing of lifelogs based on the location. Finally chapter 4 provides conclusions.

Chapter 2

Privacy in Pervasive Logging

2.1 Importance of privacy in pervasive logging

Privacy is a state or situation of being free from being observed or captured by other people. Pervasive logging devices are passive in nature as they record indiscriminately including people in the vicinity. As these devices are directed towards bystanders instead of the owner, therefore, in an environment where majority of people appear to have these devices, some of them shy away at the thought of being logged by someone else due to privacy concerns [23], [24]. In such situation, we need a mechanism which encourages pervasive logging, provided that the anticipated logging is consented by those who wish to be in the personal records of the people wearing the lifelog device.

Privacy is a major hindrance in making the lifelog device successful among common people. The DARPA (Defense Advanced Research Projects Agency) program of lifelogging was also canceled in 2004 after criticism from civil libertarians concerning the privacy implications of the system [25]. It is known that lifelog devices also record vital data including one's location traces, activity details, and health records to recall the past, however these lifelogs are personal information and cause no privacy risk to the neighboring people. That is the reason, capturing of such lifelogs is beyond the scope of this study. In this research we focused only those lifelog sensors (at present camera and microphone) that efficiently record the people in the surrounding and developed a mechanism by which a passerby's consent is considered before capturing them by our proposed lifelog device.

In this chapter we put forward a privacy framework by which the wearer of the lifelog device is authorized to set their privacy concerns. The camera and microphone sensors are employed for lifelogging and the user may restrict any one or both of these sensors of the lifelog devices worn by the neighbors. Furthermore, the lifelog device is made competent to first identify the person in sight and capture only if permitted. To make our privacy mechanism work, we assume that everyone wears our proposed lifelog system in order to avoid anonymous logging. Since, wearable gadgets have become popular in recent years and logging of daily life events has become easier, it is necessary to make a lifelog device with a privacy mechanism. We developed a system incorporating the privacy framework together with the lifelogging function. If a user does not wear the proposed device, the privacy from neighboring lifelog devices cannot be achieved. We believe that in near future, people will need such privacy mechanism to hide from bystander's lifelog devices.

We focused on two challenges to ensure privacy:

Challenge 1: The privacy preferences of third parties should be well described in terms of the restricted locations and time intervals.

Challenge 2: The mechanism to suspend logging should effectively avoid logging a person with active privacy settings.

To address these challenges, we setup a lifelog device that allows the users to elicit their privacy concerns on their respective device by inscribing restricted places and time durations. When a privacy concern of a user is sent to other lifelog devices in the neighborhood, at that moment the receiver of this privacy consent respects the privacy of the user by avoiding to capture, thus ensuring the privacy of that user. As it is difficult for any lifelog device to understand when the privacy is required by a user, so by allowing the user to select a specific location will activate the privacy on the device automatically when the user arrives at that location. Employing location for declaring private places is very useful because, people acquire knowledge about the spatial layout of the places they experience and understand the locations, distances and directions [26]. Similarly, declaring privacy for a specific time duration will trigger privacy during that period only and let the neighboring devices know about the privacy concerns of the user. A user may either select location, time or both to specify restrictions for neighboring lifelogging devices.

2.2 Our proposed privacy framework

Our proposed privacy framework offers an exclusive method to restrict neighboring pervasive logging devices from logging a person at a particular place, during specific time durations or both, the restricted place and time. At first, we categorize the type of logs generated by a lifelog device. Considering the task to preserve the actions confined to the owner of the device in the form of health logs, location traces, body actions, etc, we name these lifelogs as personal logs. The research presented in [27], [28], [29] and [30] shows the most suitable examples of personal logs generation. On the other hand, the lifelogs that comprise of surrounding data either in the form of picture or audio recording are marked as neighbor logs. These lifelogs are potentially responsible to impair the privacy of the people in the vicinity of the lifelogger. Our proposed framework [31], [32] is concerned with lifelogs produced by the neighbor log generator component of the lifelog device. The framework has the competency to constrain the neighbor log generator of the device wearer with Geo-temporal privacy. An overview of our proposed framework is shown in Figure 2.1.

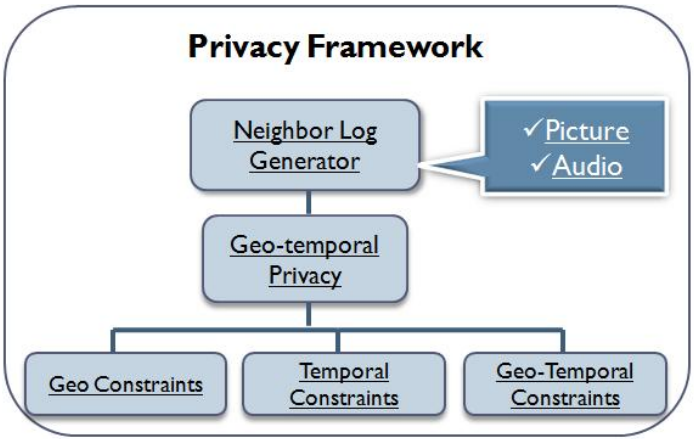

Figure 2.1: Proposed privacy framework to ensure privacy from pervasive logging devices.

2.2.1 Geo-temporal privacy

The Geo-temporal privacy is to be pre-defined by people who wish to hide from others. A user of the system may declare Geo-temporal privacy on the lifelog device by means of three different ways. When privacy is required at a precise location, the user may select that location by composing a geo constraint. If a user needs privacy for specific time duration, in such case, a temporal constraint must be created. However, there as some extraordinary circumstances where both location and time parameters are essentially required to activate privacy, so a geo-temporal constraint is created in such situations. These constraints are triggered automatically corresponding the present location and time of the lifelog device wearer. The proposed privacy framework is very useful to the people who require privacy from neighboring lifelog devices and they may convincingly apply the privacy policies in order to prevent neighboring devices from logging.

2.2.2 Comparing with other geo-temporal systems

The concept of exploiting geo and temporal parameters is not new and it has widely been used in several studies for visualizing [33], [34] and structuring [35] of data. Moreover, this concept has also been used to enhance privacy in geo-social commerce [36]. Our privacy framework is novel in the field of pervasive logging, since we attempt to instill privacy before capturing rather than using post capture distortion (in case of images) in the lifelog [37], which is incompetent if the algorithm fails due to poor light conditions [38].

2.2.3 Privacy policy

A user who desires for suspension of neighboring lifelog sensors has to set values for 'Sensor Type', 'Policy Validity', 'Accessibility' and 'Provision' collectively named as privacy policy on their respective lifelog device (see Figure 2.2). Every privacy policy is stored on the owner's lifelog device in the form of a tuple which stops a user from being recorded by pervasive logging devices in the neighborhood. A Geo-temporal privacy tuple looks like,

(sensor type, policy validity, accessibility, provision)

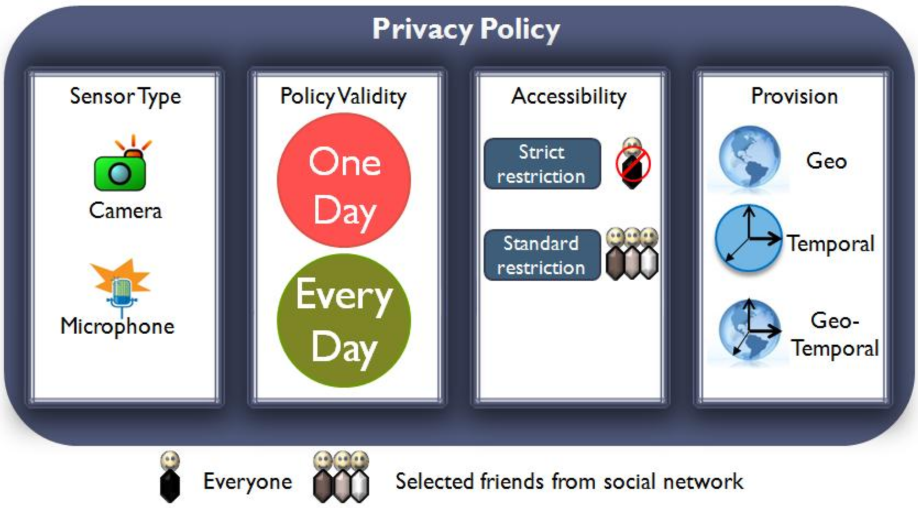

Figure 2.2: Parameters to inscribe a privacy policy on the lifelog device.

By Sensor type, we mean Camera or Microphone worn by people in the user's vicinity and the user can restrict either camera, microphone or both from logging. Policy validity declares the life time of a constraint and the user can choose to prolong it either for one day or let it be an everyday schedule. A policy declared as Everyday remains in the system as long as user requires such privacy plan. Unlike Everyday policy, a 24 hour policy is automatically removed from the system at the end of the specified day. Therefore, a user needs to be extremely careful while deciding the validity of a policy.

Accessibility reveals the restriction level for the Geo-temporal privacy. We define two levels of restriction, Strict and Standard. Strict restriction does not allow anyone to capture the constraint creator, whereas, in standard restriction, the user is provided with the personalized friendlists from their social network to select friends and authorize them to capture that user in their respective devices even during the imposed privacy policy. Social networks have become the most convenient way to determine friendship between two persons. Thus, we employ social network services and let the user pick those friends whom they feel comfortable with and permit them to record during active privacy settings, but at the same time, deny the rest of the friends as well as anonymous people from logging. Standard restriction may be useful in situations for instance; an individual invites friends and family to a party at home. If one's lifelog device is able to distinguish family members from friends when they are in sight, the person may set different privacy policies for various groups of related people depending upon his/her privacy preferences. There are possible situations where the lifelog device users may like to impose strict restrictions and deny being logged by others. For instance, in a place like restaurant or cafeteria, people may avoid anonymous lifelogging. However, we are not always facing a stranger while eating at public places. The lifelog camera or microphone only stops for short duration when the person is facing a user with active privacy settings. It resumes logging as usual when there is no one in front of the lifelog device wearer or when the time duration of log suspension ends.

Finally, the user has to declare the provision in terms of a specific place; for definite time duration or by selecting both, location and time to stop the sensors worn by people in the vicinity from logging. The provision is inscribed with any one of the constraints that best suits their requirements. A Geo constraint is created when a user selects a restricted location to control privacy. For example, a person is at a private clinic for a health check and desires to avoid neighboring peoples' lifelog devices. In this scenario, that person is uncertain about the time extent of their presence at the clinic, so they may select that place as a private location (l) exclusive of any time restraints. Alternatively, selecting some time interval (t) to ensure privacy during these moments in time is labeled as a Temporal constraint. These constraints may help in situations, such as, people who dislike by-standers to take picture while eating in public may select lunch and dinner time as private timings in spite of their location. There is one more privacy constraint for those requiring privacy in terms of both time and location. This constraint is called Geo-temporal constraint where a user has to define a private location and also declare time restriction (l, t) corresponding to the defined location in order to hide from unwanted sensing by the neighbors' devices. For example, a person may favor Geo-temporal constraint because he or she desires to avoid pervasive logging by mates in the office during working hours, but feels contented if captured outside the office during leisure time. When a Geo-temporal constraint is defined, then the user's present conditions have to be met in the following order for the policy to function.

- The Geo-temporal constraint will come into play the moment the user checks into the specified location given that the restricted time slot also commences.
- If the user checks into the restricted place before commencement of the restricted time duration, the privacy policy remains inactive.
- The policy expires once the restricted time duration is over, regardless of the user's location.
- The policy becomes void even if the user departs from the restricted location before the time of entire duration of the policy lapses.

We came up with four basic parameters which can determine user's privacy preferences in a proper manner. While designing the privacy policy parameters, firstly, we considered the sensors on which the restrictions can be applied. Secondly, we allowed the user to set policy expiry duration in terms of its validity period. The user was also given the option to allow some people while restricting others from logging. Finally, the provision in the form of constraints assisted the user to restrict anonymous logging at specified location, time or both. In Figure 2.3, we demonstrate few of the privacy policies defined by a user which are stored on their lifelog device as tuples. The policy P1 is based on a Geo constraint consisting of a location selected by the user as a restricted place in the form of latitude and longitude coordinates. This policy is made by the user to avoid logging by people except family members and it is self activated when the user's current location is within a 100 meter radius of the location of a social gathering. The policy is disabled when the distance from the user's present location is more than 100 meters from the restricted location. Likewise, policy P2 is a Geo-temporal constraint consisting of a restrict location and time interval set by the user. This policy is active when the user is at the restaurant during lunch time in order to evade logging by everyone around. For the policy P2 to stay active it must satisfy the conditions discussed above. Policy P3 stops neighboring microphone sensors to stop logging during a meeting in the morning of the present day. Policy P4 is set by the user at gym where only gym friends are allowed to log that user in the evening time.

In the evaluation, the users successfully avoided neighboring logging sensors, thus, proving that our privacy policy is efficient to ensure privacy while logging. Our current system incorporates the functionalities of both, capturing lifelogs and ensuring privacy in a lifelog device. We can make available only one function and configure a lifelog stopper device to incorporate our privacy framework. The lifelog stopper device can be used to achieve privacy and stop neighboring lifelog devices to capture. This device can be used by the people who are not interested in lifelogging but require privacy from neighboring lifelog devices.

P1

<camera, 24 hours, standard: Family, Geo (36.1117176971,140.075543148) >

P2

<both, Everyday, strict, Geo-Temporal (36.1217174352, 140.065544892, 12:00~ 13:30) >

P3

<Microphone, 24 hours , strict, Temporal (9:00~ 12:30)>

P4

<both, Everyday, standard: Gym Friends, Geo-Temporal (36.1523433281, 140.0211549778, 17:00~ 18:00)>

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Figure 2.3: Example privacy policies stored on the lifelog device.

A policy is assumed to be weak and it may be overlapped by a stronger policy when their geo and temporal values have a collision. Let us consider a situation where a user has created two policies, whose locations overlap with each other. In such case, their accessibility and validity parameters are checked. If the accessibility of one of the policies is 'strict', it is considered as stronger policy, and consequently, preferred over weaker policy. Similarly, if the validity of one of the overlapped policies is '24 hours', it is regarded as stronger policy and favored over weaker policy. In the next subsection, we explain our prototype system designed for incorporating our proposed privacy framework.

2.3 System setup

2.3.1 Hardware and software

A prototype of our system has been implemented on a Nexus S smart phone with Android 4.1 installed. We exploit the built-in capabilities of the smart phone such as, integrated camera, microphone, GPS and Bluetooth to make our prototype work as a lifelog device with the aptitude to execute our privacy framework. The camera used for recording has no zoom-in function and it captures everything which is in the sight. The purpose of Bluetooth is to share a user's privacy consent with people situated at a particular place. The approximate range of Bluetooth communication for smart phones is 50 meters [39].

Apart from that, we utilized a 5mm round infrared LED (model no. TLN110) as a transmitter which emits unique infrared ID intended for a person's identification. This transmitter is a consumer infrared sensor [40] which is usually used in remote controls and switches. It is capable of transferring data at bit rate of 120 bits per second using a variety of protocols, but for our prototype system we used Sony protocol [41] to transfer 12 bits code. The infrared receiver (model no. PL-IRM2121-A538), as shown in Figure 2.4 (a) is further employed to acquire reception from the adjacent transmitters and send those signals to the smart phone for identifying human proximity. The receiver module helps in detecting the signals arriving from a maximum distance of 8 meters at an angle of 30. We pursue a similar wearable system designed by Choudhury et al. and named as Sociometer [42] to identify people in close proximity and understand face to face interactions between people. The infrared sensors are the best means to identify the person who is engaged in a talk with the user wearing lifelog device. Other approaches like Bluetooth may identify people situated in any direction, however in case of infrared sensors, the transmitter and receiver must face each other to obtain reception.

We also used Arduino Mega ADK Board [43] (see Figure 2.4 (b)) for communicating with the above mentioned sensors smoothly via smart phone. This board is supplied with 9 volts external power source (battery) to serve the functions of emitting infrared signals and sending all the received infrared signals from neighboring devices to the attached smart phone.

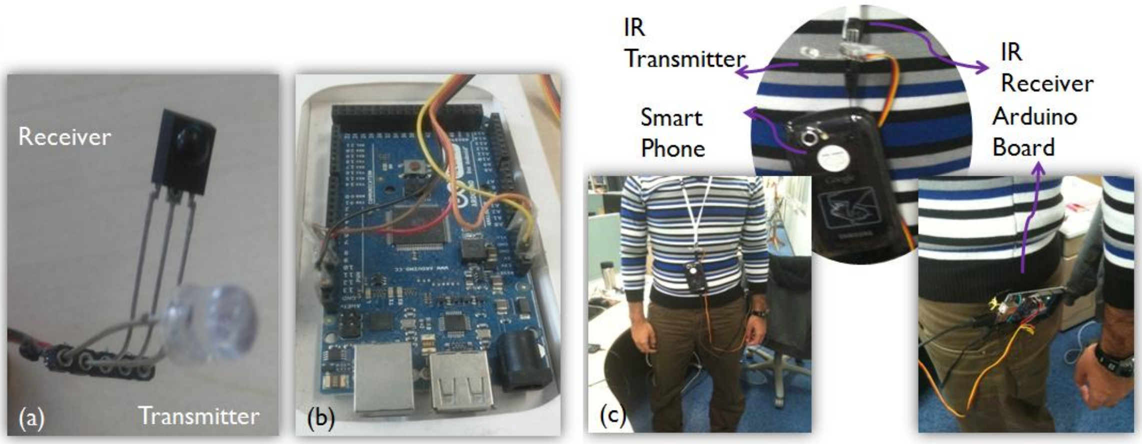

Figure 2.4: (a) Infrared receiver and transmitter, (b) Arduino Mega ADK board and (c) the prototype system.

The prototype system is worn with the help of a 15 inch long neck strap and infrared sensors are fixed to it while the microcontroller board is attached on the waist of the user as shown in Figure 2.4 (c). The prototype device takes one picture and records 10 seconds of audio every minute unless interrupted by another lifelog device with enabled privacy settings. A user may view the image or listen to the audio straight away on the device or else transfer all the data to a computer for viewing later. Since it is a smart phone, the quality of image and audio is compromised, as the main focus is on the privacy mechanism offered by the prototype lifelog device. Regarding the software, Google maps API for android is employed to select private/restricted locations, whereas, facebook API [44] is exploited to pick friendlists consisting of people who are given the permissions of logging. Table 2.1 illustrates the purpose of device sensors and APIs that are employed to put together our prototype system.

2.3.2 Privacy policy inscription

We designed a friendly policy input interface for the users with diverse background since some people may not be well aware of how to impose a suitable privacy policy for a given situation. Here we refer to a condition/action rule based approach as modeled by Kelley et al. in [45] where they allowed the user to maintain control of their privacy policy.

Table 2.1: Sensors and APIs used by the prototype

Sensors	Purpose
Camera	Capture logs in the form of images
Microphone	Capture logs in the form of audio records
GPS	Sense the current location
Bluetooth	Share user's consent with others
Infrared Transmitter	Emit appropriate infrared signals to neighboring devices
Infrared Receiver	Receive infrared signals from neighboring devices
APIs	**Functions**
Facebook API	Obtain customized friendlists
Google Maps API	Choose restricted location for Geo-temporal privacy

Our privacy input interface (see figure 2.5 (a)) incorporated a rule based system which determines a user's current privacy preferences by asking the following questions.

Q1. Do you want privacy from lifelogging devices at only one location?

Q2. Do you want privacy from lifelogging devices for specific time?

Q3. Do you want to hide from the camera sensor of others' lifelogging devices?

Q4. Do you want to hide from the microphone sensor of others' lifelogging devices?

Q5. Do you want the policy for today only?

Q6. Do you want to deny all the neighbors from logging?

A user may exploit this interface and define Geo-temporal privacy on the lifelog device. This policy is saved in the SQLite database as a constraint with a user defined name and constantly being checked for privacy activation. All of the previously defined constraints are also made viewable to the user for inspection, alteration or deletion purposes. To begin with, the user first answers to Q1 and Q2. Q1 and Q2 are responsible to decide the provision parameter of the policy. For example, in case of Q1, if user says 'Yes', then a geo constraint is created. If user replies 'Yes' to Q2 as well, then a geo-temporal constraint is created. Again, if the user says 'No' to Q1 and 'Yes' to Q2 then a temporal constraint is created. On the contrary, a geo constraint is created if the answer to Q1 is 'Yes' and Q2 is 'No'. Q3 and

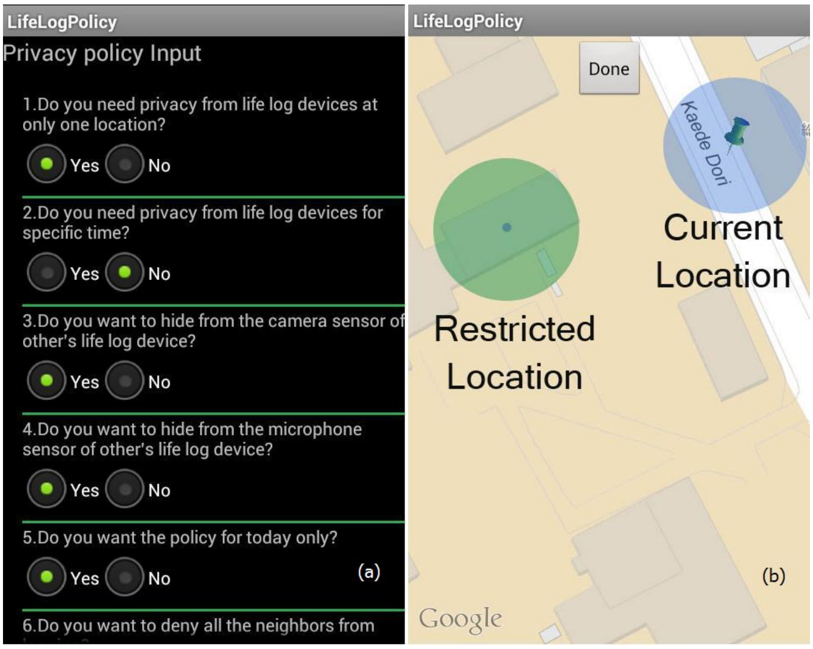

Figure 2.5: (a) Policy input interface and (b) Location selection for privacy.

Q4 are concerned with the type of sensors and replying 'Yes' to both questions denies both of these sensors of nearby lifeloggers from logging the user. The validity of the policy is decided by Q5 and accessibility is determined by the answer of Q6. If the user replies 'Yes' to Q6, the accessibility level will be set to 'Strict'. A complementary approach appears when the user answers 'No' to Q6 which makes the accessibility parameter as 'Standard'. As a result, the facebook API is exploited to fetch user's customized friendlists and the user is permitted to choose one or more friendlists and allow them to take records even during activation of this privacy policy. In this manner, anonymous lifelog device wearers and those not included in the allowed friendlists are refused to log when a user with activated privacy is in close proximity with them.

Finally, the user has to set the geo and temporal values based on the answers of Q1 and Q2. For a geo constraint, a map is shown with the current location (see figure 2.5 (b)) and the user may select a location to declare it as restricted. This location is selected by touching any place on the given map and is represented by latitude and longitude coordinates. Once the restricted location has been selected, the privacy policy is activated around a 100 meters radius of that location. In order to precisely calculate the distance from the user's current location to the selected private location, we use 'Inverse Formula' by Vincenty in [46]. For geo-temporal constraint, the user is allowed to select the restricted location and then choose the duration for privacy at that location via the time preference control. The user is required to set the start and end time of privacy activation for the selected location. In regard to temporal privacy policy, the user has to define only the time duration for once to declare the privacy activation duration. We have so far taken privacy inscription step into consideration, which is solely dependent on users' prerequisites, thus making them competent at hiding from unwanted sensing at specified locations or at times when they desire to be off the record. When the user defines a geo-temporal privacy policy, it is activated depending on geographical and time data obtained from the device. Currently, the privacy policy of the user must be shared between lifelogging devices in the neighborhood. We discuss privacy activation and sharing of privacy policies in the following subsection.

2.3.3 Privacy activation and sharing of users' logging consent

While sharing users' logging consent we presume that the lifelogging devices worn by people are capable of communicating with each other. The lifelog device in our approach employs the built in Bluetooth, thus making the prototype well suited for correspondence or sharing one's privacy consent within a certain range. When two or more users wearing the prototype device meet at a place, their lifelog devices dynamically compile an Access control list (ACL) for the present location. The contents of ACL include the name and infrared ID of the people in the vicinity, including the name of the sensors and the privacy settings (i.e., permissions to allow logging at that time and place). The infrared ID is a unique identification of person wearing the prototype device. A fresh ACL is created for each location visited by the prototype device wearer as well as for the locations re-visited later on the same day.

We explain the process of privacy activation and sharing of one's logging consent based on their activated privacy policies with the help of an example scenario. Let us assume three users of the prototype system (User A, User B and User C) who are frequent visitors of a library. Among them, User A and User B are friends with each other on a social network but User C is neither related to User A nor User B. Both User A and User B are privacy vigilant; therefore, they have made a geo constraint by selecting library as the restricted location and enabled this privacy policy for everyday on their prototype device. User C has no concerns of being logged by anyone in the library, so has not set any privacy policy for the library. Figure 2.6 illustrates the privacy polices defined by the users before arriving at the library. User A and User B have restricted both; microphone and camera sensors of neighbors from logging them but their accessibility settings are different from each other. User A has set 'Strict' restriction which means that nobody is allowed to log him/her in the library. On the contrary, User B has set 'Standard' restriction and listed some friends including User A, allowing them to log while denying all the rest.

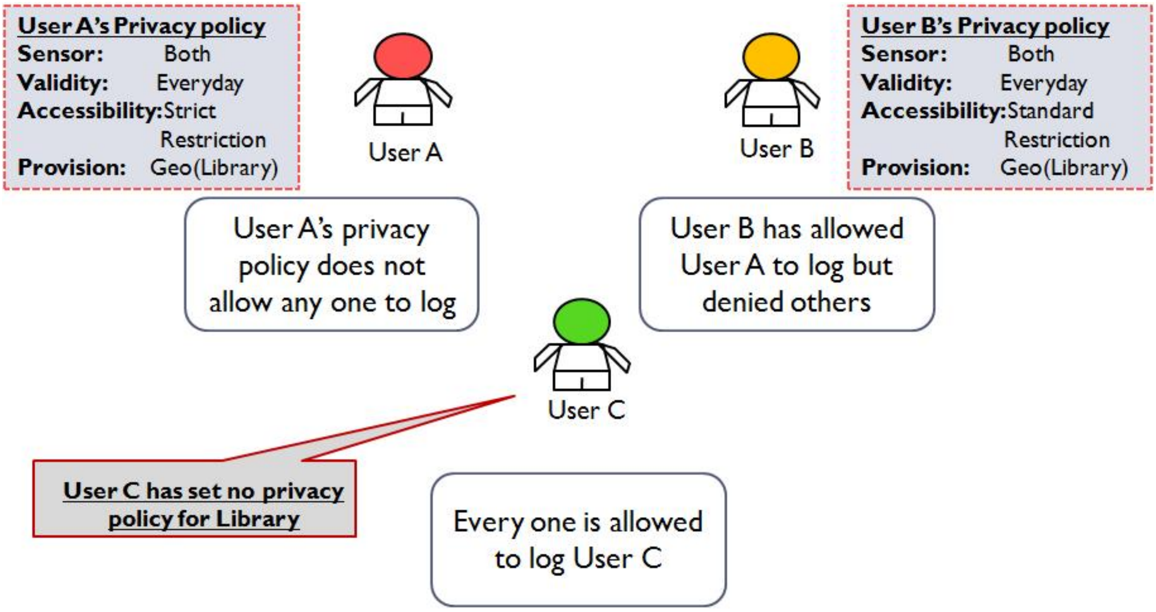

Figure 2.6: Privacy preferences of users for the library.

The geo constraint on the lifelog devices of User A and User B is self-activated when either of them arrives at the library with the device. Once a privacy policy is turned on, the accessibility parameter is examined for that policy and if it is 'Strict', a text message is compiled consisting of i) user's social network name, ii) unique infrared ID emitted by the attached transmitter, iii) the permission for logging and iv) name of restricted sensor for the activated policy, and sent via Bluetooth to the logging devices of all the neighbors. As noted earlier, the accessibility parameter of User A's activated policy appears to be 'Strict', therefore, the text message is compiled as {User A, AAA, Not Allowed, Both} and sent via Bluetooth to the logging devices of User B and User C. The lifelog devices of User B and User C compile an ACL and enlist User A's provision by which they are not permitted to log User A in the library premises. Alternatively, the accessibility parameter of User B's activated policy is 'Standard' and for that reason, a text message compiled with only social network name of User B is sent to the neighbors. At the same time, the neighbors wearing lifelog device and within the range of Bluetooth also share their social network name with User B. After receiving the name of the person nearby, it is compared with the names of the allowed friends in the social network's friendlist of User B for the activated privacy policy. Upon finding the name in the allowed friendlist, the neighbors are answered with a text message from User B as {User B, BBB, Allowed, Both}. But if the name is not found in the allowed friendlist, then they are replied with the message {User B, BBB, Not Allowed, Both}. In our example case, User A's name is included in the allowed friendlist of User B; as a result, the lifelog device of User A receives the consent, allowing to log User B, and saves it in ACL for the location 'Library'. On the contrary, User C is anonymous to User B, therefore, not permitted to log via any logging sensor and this consent is saved in User C's ACL. Since, User C has not set any privacy policy for library, as a result, shares {User CCC, Allowed, Both}, allowing everybody to log him/her at the library. The privacy policies of the users assist in compiling ACL on their lifelog devices (see figure 2.7).

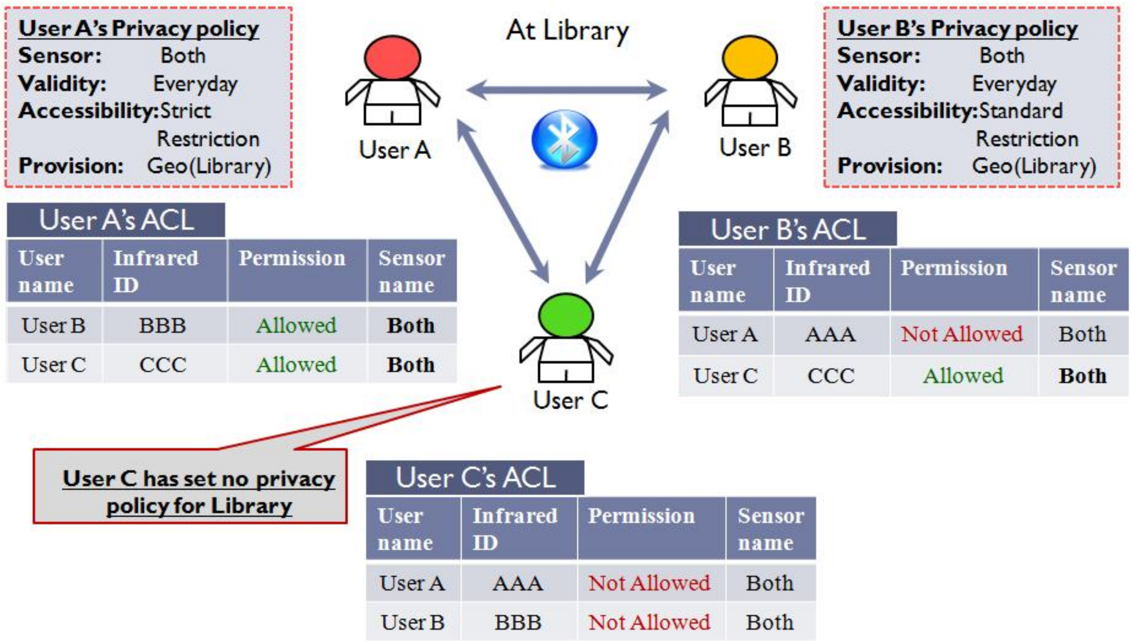

Figure 2.7: Privacy preferences and ACL of the users at the library.

We acknowledge that User A and User B are friends on a social network in the given scenario. Nonetheless, User A's privacy policy has refrained User B from logging via microphone and camera in the library. User B's privacy policy has allowed User A to capture in the library whereas anonymous people such as User C is not permitted to log user B. In spite of their diverse perspective in terms of privacy from pervasive logging devices, both (User A and User B) users have attained their required level of privacy by exploiting the proposed Geo-temporal privacy method. In the next subsection, we discuss the algorithm for lifelog suspension based on the ACL and recognized human proximity by the prototype device.

2.3.4 Lifelogging suspension algorithm

We explain the mechanism to stop lifelogging sensors of a lifelog device worn by a person in one's neighborhood with the help of an algorithm. The suspension of logging is dependent on the human proximity observed as well as the privacy consent already shared and saved in the prototype device in the form of ACL (discussed in the previous subsection). Each user plants an infrared transmitter as a mandatory part of the prototype device with a receiver facing towards others in order to detect and identify the people in sight. The infrared transmitter of each user emits unique infrared ID of 12 bits on a 40 kHz carrier wave with 5 seconds interval. Therefore, as soon as the infrared receiver at the other end detects a signal, it is decoded in the form of an infrared ID and sent to the user's prototype device as an input where ACL is checked for the user's current location. The received infrared ID is referred with the ACL in order to obtain the logging consent of the person in sight of a user. If the received infrared ID matches the one stated in ACL, the permissions for that infrared ID are assessed. For 'Allowed' permission, the sensor name is not verified and both the camera and microphone of the user's lifelog device are signaled to log the person in sight without any disruption. On the other hand, for 'Not Allowed' permission, the restricted sensor name is verified for the received infrared ID. The sensor name can either be 'Camera', 'Microphone' or 'both', and as a result, either one or both of the user's lifelog device sensors are deactivated and not allowed to log for 150 seconds starting from the present time and they become active again unless there is another request for logging suspension. There is a possibility when the received infrared ID has no match in the ACL, which means that the person in sight is not recognized by the user's device; therefore the lifelog device of the user keeps on recording without any disruption.

The presented algorithm is intended to suspend extraneous sensing by pervasive logging devices of neighbors in the vicinity of an individual without any intervention at the given moment but depending upon the pre-defined constraints set by that person. Thus, the passerby's lifelog device is obliged to work in accordance with the consent of the user in sight.

2.4 System evaluation

2.4.1 Purpose

We evaluated the proposed privacy mechanism with the purpose to ensure privacy of an individual from those people who wear the lifelog device. We need to determine whether our privacy input interface makes it easy for the users to describe their privacy concerns. In addition, we also need to confirm the effectiveness of our proposed privacy mechanism. In the next subsection, we explain about the experiment setup and tasks to be performed by the users.

2.4.2 Experiment 1: Convenience of the privacy input interface

We set up an experiment to analyze whether a user is able to inscribe privacy policy on the lifelog device using the proposed rule based interface. We made five privacy situations and asked the users to create policies for the given situations on the proposed lifelog device in order to assess Research Challenge 1 (see section 2.1). The situations are given below,

Situation 1: Activate privacy when waiting for a train at train station

Situation 2: Activate privacy at the work place during working hours

Situation 3: Activate privacy while meeting with a friend

Situation 4: Activate privacy during shopping at a mall

Situation 5: Activate privacy at a gym while exercising

At the end of the experiment, we evaluated the inscribed privacy policies set by the users to determine whether they had accomplished the given tasks, and asked the users to comment about their privacy preferences. We mainly focused on the answers of Q1 and Q2 of the policy, as these determine whether the privacy policy will be geo, temporal or geo-temporal.

2.4.2.1 Participants

We recruited ten participants to perform the given tasks of making privacy policies for 5 different situations on the lifelog device. The users (4 female 6 male) aged between 21 and 54 with mean age of 37.1 (sd = 8.82). The participants were professionals including businessmen, doctors and engineers. Each user was thoroughly explained the benefits and weaknesses of a lifelog device and how the proposed system helps to achieve privacy from the neighbors wearing lifelog device. The users were encouraged to take their time and understand each situation properly before making privacy policies on the lifelog device.

2.4.2.2 Preferred policies for the given situations

The policies inscribed by the users for the given situations were reviewed and it was found that the users opted for geo, temporal and geo-temporal policies according to their own requirements (see figure 2.8). For instance, in situation 1, 50% of the users created geo constraint while arguing that they are habitual of shopping at the station and do not usually care for the train time. The rest of the users said that they were certain about the exact time they will take the train so chose temporal constraint instead. For situation 2, 50% of the users commented that they used to commute during working hours, therefore, preferred temporal constraint rather than choosing any other constraint. Remaining users selected geo-temporal constraint to avoid logging for this situation since they worked at a fixed place for definite time period.

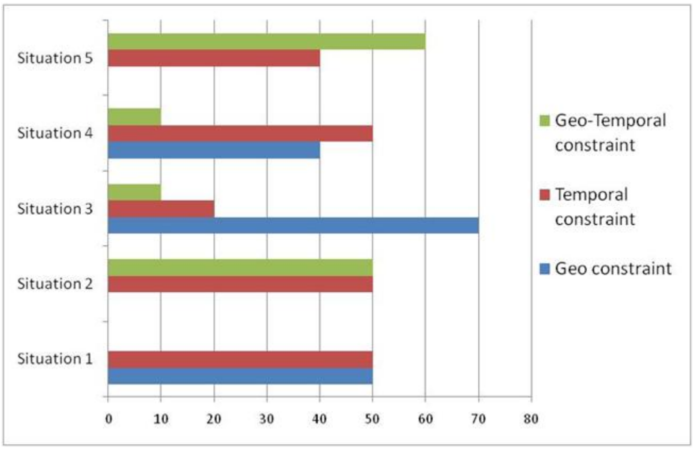

Figure 2.8: Preferred privacy policies by the users for the given situations.

Geo constraints were favored by 70% of the users for situation 3, as they were certain about the location where they were going to meet a friend. On the other hand, 20% users confirmed that they often gather with their friends for specific time period but no fixed location. One user said that, he usually meets with his friend at the coffee shop in the break, therefore, selected geo-temporal constraint for this situation. For situation 4, 50% of the users stated that they sometimes watch movies in the multiplex within the shopping mall, hence preferred temporal constraint and specified shopping time only. Additionally, 40% of the users made a geo constraint and said that they usually go for shopping at a specific mall.

Finally, in case of situation 5, majority of the users (60%) selected geo-temporal constraint as they required no body to capture them in the gym at the time of exercise. However, 40% of users chose a temporal constraint and argued that they would only specify their exercise time as restricted as they liked to be recorded rest of the time by their friends at the gym.

These results show that the users understood the situations well and built the constraints based on their own preferences. The mechanisms to achieve privacy, while being logged by specific users, were appreciated by the participants, and they were intrigued by the idea that privacy constraints on their lifelogging device can suspend the camera and microphone of neighboring devices. The simple and user-friendly interface made it easy for the participants to describe their privacy settings.

2.4.3 Experiment 2: Evaluating the lifelogging suspension mechanism

We carried out a second experiment in order to measure the system's efficiency in achieving our Research Challenge 2 (see Section 2.1). We configured four identical prototype devices and provided them to the users to wear during the experiment. We devised two study locations and observed the behavior of the prototype device at these locations for two weeks. Location 1 was a computer science laboratory where users already had a fixed work place and location 2 was a cafe where they have their lunch. Each user was asked to perform privacy activation tasks on their lifelog device at the study locations as shown in table 2.2.

Table 2.2: Tasks performed by participants at devised locations

Tasks	Location	Time
Multi-user case: Set up a privacy setting to avoid logging from lifelog device camera of all the participants	Fixed Location: Computer science laboratory	During working hours
Single-user case: Create a privacy policy that authorizes only one friend but denies all the rest to log	Varied Location: Cafe	During lunch time

2.4.3.1 Participants

Four users were invited to wear the proposed prototype device at the devised locations. They were given the option to put off logging during their private time, such as, in the rest room. All the participants were students (1 female 3 male) with ages between 26-31 years. They all belonged to computer science laboratory and were well aware of privacy in terms of pervasive logging. Each participant was trained and briefed for 30 minutes regarding the means of specifying Geo-temporal privacy and its consequences on the neighboring lifelog devices. The participants were given the prototype devices (see figure 2.9) to wear while performing these tasks. All of the participants were encouraged to accomplish the given tasks at the study locations.

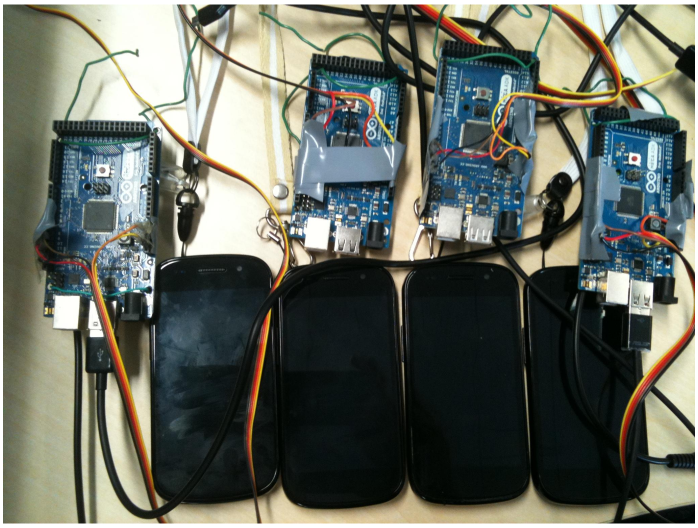

Figure 2.9: Prototype devices worn by the participants.

2.4.3.2 Results and observations

We summarize the results of the given tasks performed by the participants at the given locations. In order to accomplish the requirements of multi-user task, the users need to restrict every participant from logging during their stay at the laboratory. Because each user's daily schedule of staying at the laboratory was inconsistent, therefore, they inscribed more than two privacy policies for multi-user task in a single day. We observed that each user made privacy policies with 'Strict Restriction' to avoid logging from the rest of the participants and selected validity of '24 hours'. The users preferred temporal constraint over geo-temporal constraint at some situations and selected the time intervals of their stay at the laboratory. One of the reasons for inscribing a temporal constraint for this task was that at many occasions the users made a fixed schedule of their stay in the laboratory and had no plans to move to any other place during that period. The policies made by User D are more than the other participants because he had to go for a part time work for 3 days in a week. The mean number of policies required by a user to accomplish this task is 2.4 per day.

Table 2.3: Privacy policies inscribed by the users on the lifelog device

Users	Multi-user Task		Single-user Task	
	Geo-temporal constraint	Temporal constraint	Geo-temporal constraint	Temporal constraint
User A	11	14	0	10
User B	10	12	0	10
User C	13	08	0	10
User D	10	18	0	10

For single-user task, the location and timing was not fixed as the participants chose different places for lunch every day. However, they all went together at one place to complete this task. Each participant inscribed a fresh temporal privacy policy daily with validity of '24 hour' and selected lunch time to accomplish single-user task. This policy was applied on the camera sensor and expired at the end of the day. Because of 'Standard Restriction', each participant had to select one user to grant permission of logging. Their selection of eligible user for logging was random. We observed that each user created 10 privacy policies for this task in total during the two weeks period and they were all successfully activated during lunch timings regardless of their present location. In Table 2.3, we show the total number and type of policies made by each user during the two weeks period. The mean time required in inscribing a privacy policy for multi-user and single-user task is 39.07 seconds and 36.37 seconds respectively.

The efficiency of our privacy method can be observed with a fairly small number of false logs while performing the given tasks. By false log we mean, logging of a user (either via the camera or microphone) with activated privacy settings by a neighbor participant. In figure 2.10, we show the comparison of valid and false logs captured by each user while performing the given tasks at the study locations. The proportion of false logs by all the participants is 2.8 % in multi-user task, but it increased to 10.5 % in single-user task.

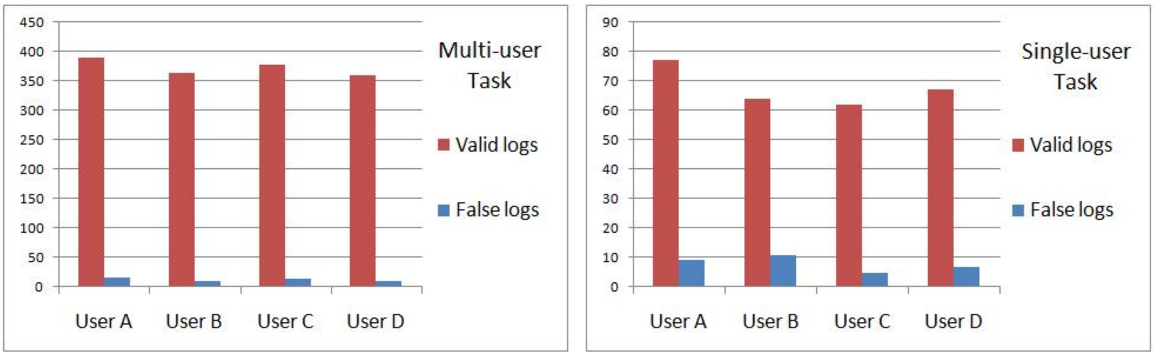

Figure 2.10: Valid and false logs by each participant during the tasks.

In multi-user task, the 'Strict restriction' set by all the users has given no opportunity to the neighbor's lifelog device to capture, however, the mean value of 4.4 false logs per day were observed during this task. The most common reason for false logging was because some of the participants had a habit of moving their hands while talking. The presence of any object or thing in front of the infrared sensors interrupted both incoming and outgoing signals.

The objective of the single-user task was to allow one friend while denying the rest of the users during lunch time. The mean number of false logs captured by all the users during this task is 3.2 per day. The loose fitting of infrared sensors with the smart phone caused false logs while performing this task. At some occasions the infrared sensors were directed towards the permitted friends while the camera was facing the users with active privacy settings. We observed this inaccuracy at the end of the day by viewing the lifelogs of each participant's device. This imprecision can certainly be eradicated in the commercial device by embedding infrared sensors with the system so that the camera and sensors are aligned in the same direction.

We also calculated mean error percentage by the users while performing the given tasks. For multi-user task, the mean error percentage is 3.6%, 2.4%, 3.1% and 2.1% for User A, User B, User C and User D respectively. However, for single-user task, the mean error percentage increased to 9.3%, 14.0%, 6.6% and 9.1% for User A, User B, User C and user D respectively. In figure 2.11, we show the mean error percentage together with the respective standard deviations. These results are appealing and indicate that the above mentioned approach is promising in achieving privacy from pervasive devices even if there are more than two users at the same place with different privacy settings.

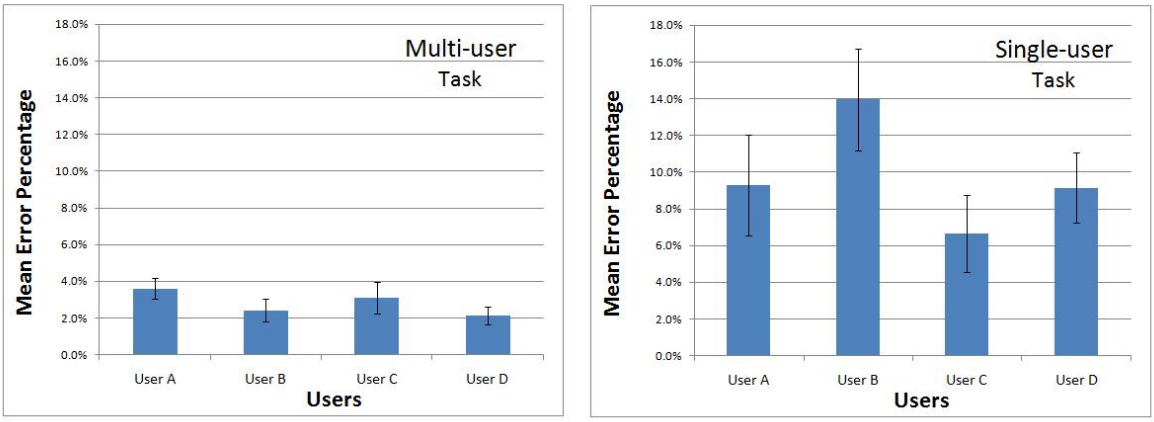

Figure 2.11: Mean error percentage by each user for the given tasks.

2.4.4 Experiment 3: User's experience of the proposed privacy mechanism

In this experiment, we aim to determine the need of a restriction mechanism in pervasive logging and to find out the effectiveness of the proposed mechanism. We asked the users to wear the device for one day and at the end of the day we put forward four questions. The uses had to respond these questions in 'yes' or 'no'. The questions are given below.

1. Does the user wearing lifelog device literally amend the neighbor's behavior if the restriction policies are not in function?

2. Does the user feel satisfied when s/he has the trigger to the lifelog sensor of the person in sight?
3. Are the contextual parameters, in this case, geographic location and time allocation for privacy constraints, enough or is there a need to add another parameter?
4. Is the proposed mechanism influential in eradicating the threat of anonymous logging?

2.4.4.1 Participants

We asked 16 users (12 male 4 female) to wear the system for one day. All users were students and among them, 12 were from computer science department while 4 were from other departments. They were explained the purpose of the experiment and briefed about the use of lifelog devices and the way these devices cause privacy concerns among the neighboring people.

2.4.4.2 Results

In response to question 1, all the users denied being captured by a stranger and most of them agreed that they would intentionally change their behavior in case they knew they were being photographed.

In the next step, the users were asked if they had the authority over the remote control of the camera shutter directed towards them. In response to the second question, 14 users replied 'yes' and explained that the decision of allowing/disallowing would depend upon their mood and situation. This conclusion strengthens the idea of creating a mechanism which may protect from anonymous logging.

In answer to question 3, 12 users warranted that the geo and temporal constraints are enough to ensure privacy and that the system is very easy to operate. Four users claimed that there can be some other contextual parameters apart from geo and temporal constraints, two of them had no other option in mind at that time. One user asserted that an option of broadening and curtailing of the restricted area should be supplemented in the prototype, which positively allots more authority in the hands of the user. The other user replied that while performing a certain activity we may switch off being logged by neighbors.

Finally for question 4, 7 users made a privacy policy and refrained their partner from capturing them, while the remaining users allowed their partner to log them at their current location. The users who made the privacy policy were all satisfied with the working of the system, because they were cloaked from the sensors of the partner, and the only information being logged was their name, time and location. According to them, it was easy to inscribe a privacy policy and apply restrictions over the passerby's lifelogging device. The system worked successfully all the time due to the fine range of the infrared LED and receiver that helped in instant detection of human proximity.

2.4.5 Benefits and limitations of the prototype system

The proposed privacy approach is promising in varied situations, especially when people are close to each other during a discussion, and the face is not in the view of the camera but voice is clear and audible to the device. If there were a privacy system with face recognition as a tool to recognize people, it would fail to do so because the faces would not be visible in the situations like the one mentioned above, and the device may continue to log the voice regardless of the privacy setting of users. Moreover, computer vision based technique is not feasible for a lifelog device because huge power is consumed to run these algorithms on a portable device as studied by Anuar et al. in [47]. Our technique does not require execution of complex algorithms, thus, it is viable in a commercial lifelog device where power consumption is considered as one of the significant factors.

The system was able to detect the person in sight from 0.15 meters up to 6 meters accurately when both the users were facing each other. However, in some settings, the infrared transceiver system may be deliberately or accidentally obstructed and, as a result, logging of users with active privacy settings may occur. This weak spot can be prevailed over by embedding a light sensor with the device that may stop it from logging if there is no significant light change near the device for a threshold time. In this manner, the person trying to obstruct the infrared signal to acquire false logs may not be able to log further.

With the current prototype system, the neighboring lifelog sensors are deactivated for 150 seconds when there is a person in sight with active privacy settings. The logging suspension duration is lengthy and can be annoying in gatherings where one person activates privacy and denies logging while majority of people have no issue with being logged by the neighbors. To solve this issue, the prototype device can be configured to resume logging as soon as there is a person in sight with permissions to log. Furthermore, in case of audio recording, the user wearing prototype system can record a person with active privacy setting even when he is behind that user. The reason is that unlike camera, microphone can record sound coming from all directions. But, using our system the sensors are suspended only when the users are facing each other. To resolve this problem, we suggest that for specifically audio sensor, Bluetooth must be employed to suspend audio recording instead of infrared based human proximity method. In this way, a person with active privacy setting may suspend audio recording by all neighboring lifelog devices at a place without being in their sight.

2.5 Related work

The lifelogs of a person are highly vulnerable in a sense that if they are disclosed, then there is a high potential of incivility, emotional blackmail, exploitation in other wrong means as mentioned in [23]. In the light of our privacy approach we split the related work into three categories: sensors based privacy, computer vision based privacy, privacy frameworks and methods employed during the process of logging.

2.5.1 Sensor based privacy

In [48], Makino et al. developed a tactile sound based lifelogging system employing a piezoelectric device on finger nail and recording the touch sound propagating through a fingertip. They attempted to enhance privacy by avoiding camera, microphone and GPS sensors; however, their approach lacks rich lifelog data to assist in the course of reminiscence. If we hold the idea for the moment that avoiding camera and microphone may reduce privacy concerns then, several systems had been proposed using merely RFID tags [49], [50] or accelerometers [51] to recognize daily activities. Nevertheless, lifelogging requires diverse information, thus, the research presented in [52], [53] and [54] employed the above mentioned approaches in conjunction with the camera and microphone to enrich lifelogs with contextual information and focused on remembering the past events efficiently. However, the privacy of nearby people being captured accidentally was not considered. Our approach ensures privacy while incorporating camera and microphone sensors which are foremost in the course of pervasive logging.

2.5.2 Computer vision based privacy

Privacy issues while capturing video or recording voice were discussed by Chaudhari et al. in [37]. The wearable lifelog system attempted to protect the privacy of lifelog video recordings in real time. They used face detection, tracking and blocking algorithm to obfuscate the faces of the subjects with solid-color block, but this approach is vulnerable to missed detection in bad light conditions. Furthermore, the system depends upon skin color detection algorithm, which fails even with a tiny movement of the shoulder where the camera is mounted. The audio identity of the subject is distorted using a time-based pitch shifting algorithm. The prototype performs processing on a Micro PC; therefore, it is a bad candidate to be used as a lifelog device with privacy protection. Various methods have also been proposed to induce privacy in video surveillance systems. One of them is [38], in which CCTV footage was encoded and privileged users were given access to the original video where as ordinary users were provided only statistical information about the objects contained in the video. However, this approach produces errors such as missed detection and false alarm. Therefore, the post capture privacy techniques may reveal personal information if failed. In our approach, we presented the mechanism which at first identifies the neighboring users, and allows capturing only if permitted by them.

2.5.3 Privacy frameworks and methods

A privacy exposure controlling approach was proposed by Giang et al. in [55] in which they employed pre-defined privacy policies based on trust values in ubiquitous environment. They estimated trust via peer recommendation and time-based past interactions with people and assigned three possible states, trusted, public or distrusted to the requester of their personal information. Hara et al. suggested that the information captured by lifelog devices be categorized as either public or private. For example, web browsing habits, geo data or emails, can be stored in a personal knowledge base, while public domain information, including personal information that the user has deliberately exposed on social networking sites, can be stored separately [3]. A security algorithm was proposed in wireless sensor networks for lifelogging purpose in [56]. They used the compressed sensing [57] principles in order to apply joint compression and encryption on logged data to achieve high secrecy and decryption fidelity.

Rawassizadeh et al. in [20] addressed post privacy concerns after the lifelogs are being captured via various sensors. They categorized lifelogging in three stages and developed a sharing model in which the logged data is shared with an expiration policy. Though, they emphasized the use of smart phone for lifelogging in [58] and made the logs private once captured on the phone via encryption, their approach fails to consolidate the privacy of bystanders who are in the range of the logging device. Petroulakis et al. in [59] elaborated security and privacy issues of lifelogging in smart environment and proposed a lightweight framework. Their main focus was the interconnectivity of lifelogging devices worn by people and sharing of personal preferences and habits. They studied energy consumption by a communication model, an attacker model and an experimental test-bed while secure sharing of lifelogs under different scenarios. Thus, retaining privacy in the course of lifelogging has been of great concerns with evolving technologies and prevailing gadgets. Our approach is novel as it incorporates an individuals consent before allowing the pervasive devices of the people to log.

2.6 Summary

The extensive use of lifelog devices in future may necessitate privacy mechanisms to keep oneself from continuous observance of neighboring devices. We have employed android based smart phone to work as a lifelogging device while incorporating user's privacy consent of being logged by neighbors at a place. Our proposed technique facilitated the user to set Geo-temporal privacy by specifying restricted locations and time slots and at the same time permitting selected friends to log.

The evaluation results have proven that the proposed approach is promising to comprehend user's privacy preferences by refusing neighboring pervasive devices from logging. Besides, we have drawn attention to the benefits and limitations of the prototype lifelog device which must be considered for the next generation lifelog devices. We plan to extend our privacy framework and also consider additional contexts for enabling privacy settings apart from geo and temporal constraints.

Chapter 3

Retrieval and Sharing of Lifelogs

3.1 Motivations and design goals of retrieving lifelogs

As discussed in the last chapter, lifelog devices gather data by means of various sensors and assist in the course of recalling the past events in one's life. The advancement in acquisition and retrieval capacity of the modern gadgets has led to the development of lifelog systems. The devices such as Sensecam [15] and Narrative [60] can passively capture everything but are not competent in identifying an individual or objects present around the user wearing these devices. In addition, the lifelogs are organized by date and manually tagged information, making it practically complex to explore and search for lifelogs specific to the present situation of a user. One needs to input accurate details of the past to get back needed information but people have the tendency to forget the exact point in time or particulars of their past experiences. Furthermore, lack of comprehensive context associated with the logs makes the process of retrieving appropriate logs time consuming and boring.

Research has already begun to visualize life experiences on different interactive platforms such as smartphones, tablets and desktop PC [61] and applications have been designed to access lifelog data in explicit environments [62], [63], [64]. However a person who owns a lifelog device, also requires a swift procedure to repossess or gain back past experiences when needed for instance, past lifelogs of discussion with a friend when talking with him in the present situation. Sellen and Whittacker argued that the lifelog system should support the user to capture and retrieve valuable data [65]. If the lifelog device is made capable to autonomously identify the people and objects interacted by the user together with the usual logging activity, the required lifelogs can be easily retrieved based on the people and objects currently present near the user. Likewise, the lifelogs related to the present or user defined location may also be directly accessed if the lifelog device possesses the records of any previous visits to that place. To achieve this purpose, we developed a lifelog system that automatically links captured logs at a particular moment with the key elements, that is, nearby people, object context and present location. By exploiting one or more present key elements, the user may get back the most appropriate logs which may help to recall similar situation of the past. A recent study by Peesapati et al. in [66] concluded that people are more leaning to reminisce about persons and things rather than places or experiences. We also believe that logs of social interactions with people are significantly important as they may help a person to remember the details of past meetings with a person. At the same time, logs related with objects are also essential to recall past interactions with them. Our prototype system recognizes the people and objects nearby the device wearer besides taking logs and recording location. Hence a person requiring past logs of gatherings with a friend has to actually meet with him to access these logs. Similarly, the objects must be present in order to get back the past logs related with them. Moreover, the lifelogs of a particular location may be obtained by selecting that place via a map or actually re-visiting that place.

Figure 3.1: Retrieving past logs of objects carried in the bag.

Identifying people and location is useful in a variety of situations, for example, a couple eating in a restaurant for the third time may require their past dinning order logs in that restaurant to choose their present day's feast. Likewise, recognizing objects in the surrounding may easily retrieve logs of past interactions with the objects currently present nearby the user. Let us imagine a person who is planning his next camping trip, but forgets the tools and gadgets he carried at the previous trip. In this situation, past lifelogs related to camping may be helpful for short listing the items to be taken to this trip. The user scans the bag and a few items of the camping gear, such as, a flashlight or rope using the prototype device. He gets back his past camping logs consisting of the objects carried in the bag which can assist him in packing the bag again for this trip (see figure 3.1).

By making use of more than one present key element concurrently, one can access the precise lifelogs for their current situation. For instance, a user willing to retrieve logs for the current location, nearby people objects will retrieve accurate lifelogs of past meetings with those people and past interactions with the objects around the user at the present location. These logs may help the user to recall the event that happened in the similar situation of the past. We further explain about our proposed lifelogs retrieval mechanism in the following section.

3.2 Proposed mechanism to retrieve lifelogs

3.2.1 Contents of lifelogs

Our proposed mechanism involves capturing of lifelogs and, at the same time, enriching them with a variety of context. The reason for recording the context together with lifelogs is that the user may easily recall these lifelogs later by providing the present context or key elements. Our lifelog device captures three key elements in conjunction with the lifelogs. We will first discuss the contents of lifelogs captured by the system and then we will explain the process of detecting key elements in detail.

The lifelogs consist of pictures and audio clips recorded by the prototype device once in every minute. The audio recording is a short clip of 10 seconds for each minute. The pictures are shrunk to 320 x 240 in order to reduce the overall internet load while loading both audio and pictures to and from the cloud storage. Once the data is uploaded to the cloud, their URL links are obtained to reclaim them afterwards based on the captured key elements.

3.2.2 Capturing key elements

We attempt to capture three key elements which are, 1) identity of the people in sight of a user wearing lifelog device, 2) context of the objects/things in the neighborhood of a user, and 3) the current location of a user. The most primary key element supported by the prototype device is the person's identification who is in close proximity or engaged in any activity like, talking, gaming, etc. with the user. In addition, the textual information describing three-dimensional (3D) objects in the neighborhood is also taken into account while perceiving the present location coordinates of the user. Each log URL is associated with the detected key elements, i.e., identified people, recognized objects, and location coordinates for the given time (t). There can be multiple people and objects but only one location associated to a single log URL as shown in figure 3.2. We further illustrate a log URL at time (t) as follows

URL^t {Person(A,B,..,Z),Object(A,B,..,Z),Location}

Here, Person and Object represents the people and objects distinguished by the prototype device whereas Location is the GPS sensor reading at the time (t) of log capture. Consequently, a user may acquire a particular log URL by providing one or more present key elements that are identical to preceding elements.

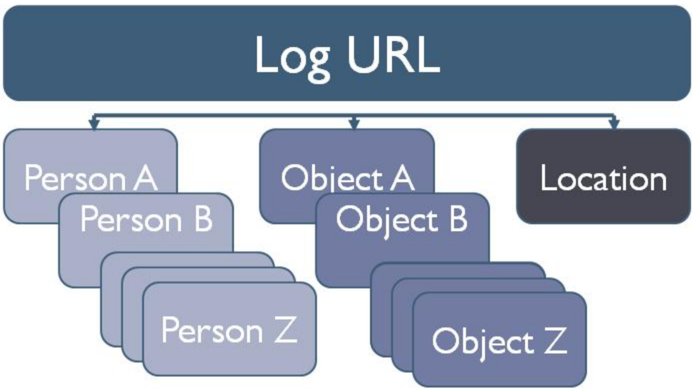

Figure 3.2: Associating Log URL with key elements.

If we look at the research conducted in past, an attempt was made to create metadata by fusion of sensor data from a set of heterogeneous sensors by Kim et al. in [6]. They recognized the person in sight by post processing on the logged video but this technique consumes a lot of time and processing power. Furthermore, they identified only those objects which were tagged with RFID. On the contrary, our approach identifies the people via infrared sensors, recognizes the objects by employing image recognition engine efficiently and quickly. We store these key elements together with the captured logs. Accordingly, whenever there is a request from a user for lifelog retrieval, at that moment the lifelogs are retrieved based on the present key elements or we can say the present situation of the user. In this manner the past experiences can be retrieved instantly and may help to tackle the present circumstances efficiently.

3.2.2.1 Key element 1: People nearby the user

The identity of the people situated nearby is noteworthy and may help to recall and review past meetings with them. Our idea is also supported by Cosley et al. in [67] as stated by them, “Well I’d say it was usually about people. And it is also partially about places but the places are important probably because of the people”.

Our proposed lifelog system recognizes one or more persons involved in a conversation with the user, consequently assisting to recall the past information linked with them instantly without inputting any details, for instance, date or location etc. Here we mainly focus on face to face interactions between people and refrain from taking into account the person present behind the user at a location. By doing so, we avoid retrieval of irrelevant logs at a crowded place as the lifelog device will only retrieve logs related to those people who are present infront of the user.

To understand the process of identifying an individual situated in close proximity, we visualize two users, User A and User B situated at a crowded place, wearing the prototype lifelog device and talking to each other. In order to perceive that User A is only interacting with User B among a group of nearby people, we attached infrared transmitter and receiver with their lifelog devices. The transmitter emits an infrared ID of 12 bits on a 40 kHz carrier wave in every 5 seconds so that the people receiving this ID via infrared receiver may identify the individual in their sight. But before initiating this process, Bluetooth is used to share the user’s name and unique infrared ID with the people in the vicinity. Consequently, when an infrared ID is received, it may be compared with the ones already shared and saved on the device. Once the person in sight is perceived by a lifelog device, the lifelogs generated at that instant are linked with that person. We pursue a similar wearable system designed by Choudhury et al. and named as Sociometer [42] for identifying human proximity and understanding face to face interactions between people.

We also address the situation where multiple users gather at the same place for an activity such as a seminar or party. In such a case, the lifelog device of each user initializes a proximity vector for that place and populates it with the people who were involved in a colloquium. We further explain the benefits of applying this context with an application scenario.

In figure 3.3, two class mates (User A and User B) are present in a seminar room of the university campus and discussing to submit a research paper. But User A is unable to recall a few salient propositions that were summarized at the end of prior meetings with User B. Since, User A's lifelog device can recognize User B, as a result, all the past logs that involved User B can be retrieved and viewed on the lifelog device of User A. In their 1st meeting User A and User B were in the campus library where user B was showing a reference book to assist in the making of the prototype system. Their 2nd meeting logs were at the campus laboratory with the initial version of the prototype where user B is suggesting some feedback system for the prototype. Our proposed system helped user A to recall the past meetings with user B and based on the comments on his research work, User A was able to polish up the system and draft the paper.

Figure 3.3: Exploiting friend's proximity to obtain past lifelogs involving that friend.

3.2.2.2 Key element 2: Context of objects

Recognizing the context of objects/things around a person in real time can effectively be used in terms of lifelogging to retrieve past logs associated with these objects. Context has been well explained by Brown et al. in [17], however in regard to an object, context is any information that can be used to categorize an object. We can describe an object with some textual details to elaborate the means of use of that object but the actual problem is to make an object distinguishable from the rest of the objects. There has been an extensive research in the field of computer vision to recognize 3D object from 2D images [68], [69], [70]. At present, it is possible to recognize objects via smart phones and several image recognition engines such as, Moodstocks [71], VisionIQ [72], ClickPic [73], etc. are available to offer image recognition from millions of sample images in real time. We acquire the services of Moodstocks API for real time 3D object and barcode/QRcode recognition.

We stored sample images of few objects along with the tags on the Moodstocks server to identify them via the smart phone's camera. We are very optimistic that, in near future, the image recognition engines will be competent enough to recognize any and every object around the user. We consider the annotation of an object via Moodstocks API as a key element and associate it with the lifelogs captured at that moment. In this manner, the objects present in the vicinity are recognized simultaneously and the user may find out their past lifelogs associated with these objects. In figure 3.4 we show a user capturing image logs of some objects and sending them to the Moodstocks server in order to obtain the context of objects.

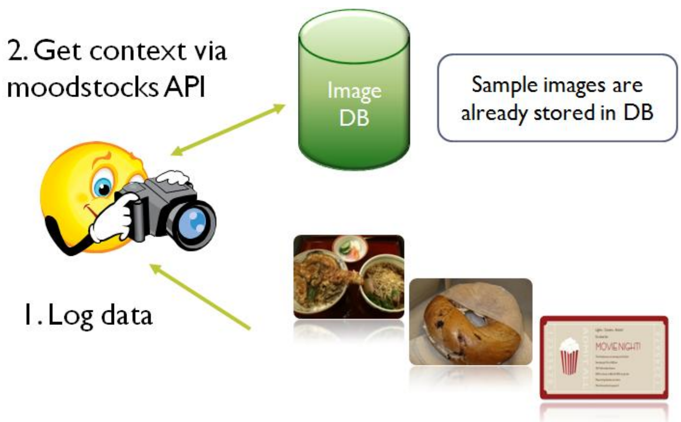

Figure 3.4: Moodstocks API for obtaning objects context.

3.2.2.3 Key Element 3: Location of the user

The user's location is significantly important and may effectively assist in the retrieval of logs pertaining to a particular place. The study conducted in [74] and [75] emphasized upon the significance of location in lifelogs retrieval process. A mobile based reminiscing tool was developed by Tang et al. where they utilized GSM towers to locate a user and associate their lifelogs with that place [76]. We employ built-in GPS sensor of the smart phone to grab the user's location and save it as a key element. Each location is represented in the form of latitude and longitude coordinates. When a user arrives at a place, all the lifelogs generated at that moment are associated with their current location. Later on, if the user goes back to a previously visited location or selects that location manually on the map, the lifelogs within 100 meter radius of that location are fetched. For accurate calculations from the user's current or selected location to the past visited location, we use 'Inverse Formula' by Vincenty [46].

Figure 3.5: Retrieving logs at a cafe to trace the lost book.

Retrieving lifelogs based on the location are well suited for those situations when a user who has already been to a location in the past is requiring logs related to that location for reminiscence. Let us consider an example shown in figure 3.5 where a student has lost his book at a cafe in the university campus a day before. He requires previous day's lifelogs to aid him in finding the misplaced book. He may return back to that cafe or select the cafe on the map to retrieve the logs that were generated in the vicinity of that cafe. The retrieved logs related to his presence in the cafe confirmed that the book was with him at the entrance but he put it on the counter and never picked it up.

3.2.3 Exploitation of all the present key elements for retrieval of lifelogs

Retrieving lifelogs on the basis of any one key element widens the range of the retrieved data; conversely, making use of all the key elements at the same time narrows down the search and fetches precise logs to the existing state of the user. We explain the advantage of exploiting all the key elements simultaneously to recollect accurate past lifelogs with an example scenario.

A user meets with a friend at a super market and requires lifelogs pertaining to a prior encounter with him at the same place but cannot recall foremost details such as the exact date and a few grocery items suggested by that friend. The user may employ the prototype lifelog device to obtain the logs of that meeting by simply providing the present location, people and objects in the neighborhood (see figure 3.6). Making use of all the present key elements will retrieve the precise logs related to that friend at the market which may assist to remember the details of the previous meeting with him. However, if the user's friend was not present at that moment, then based on the location and objects around, the obtained logs will consist of all the previous visits to that super market by the user. Our example scenario clarifies that by using multiple key elements, the number of retrieved logs will be reduced and, at the same time, most suitable lifelogs will be fetched that may help the user with their present situation.

3.3 The prototype system for retrieval of lifelogs

The prototype system used for retrieving lifelogs based on user's context is identical to our previous proposed system for ensuring privacy in pervasive logging. In addition, we used Dropbox API [77] to store the logged data permanently in the cloud for future retrieval. In this prototype system Moodstocks API is also used to recognize 3D objects in the vicinity of the user which are scanned by the user. In the present implementation, the user has to upload all the generated lifelogs to the cloud storage using the given application.

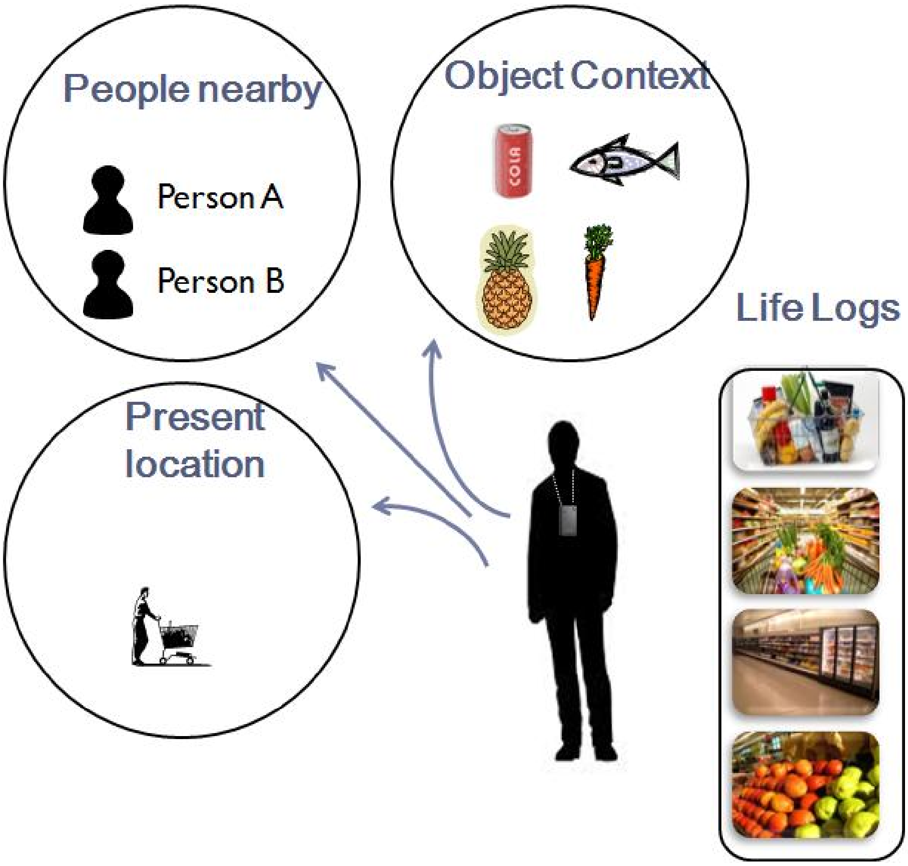

Figure 3.6: A user at the market retrieving logs based on all key elements.

We are considering automatic transfer of lifelogs to the cloud storage at regular intervals in the prospective prototype.

3.3.1 Capturing and storing lifelogs with key elements

We designed an application that works on the smart phone incorporating the features of logging life events and, at the same time, attaching meaningful context to these logs. The application runs persistently as presented in a snapshot of the prototype device in figure 3.7. The screen of the device shows the live camera view and some form widgets. The key elements detected by the device are listed under the label 'People Nearby' and 'Object Context', while the images and audio clips are recorded in the background. The current location of the user is also monitored as a background process and not displayed on the screen. The prototype system detects an individual in sight of the user when there is an infrared reception. The objects and barcodes scanned and recognized by the prototype lifelog device are exposed on the device's screen. The lists consisting of the identified people and objects are refreshed every minute as well as following any change in the user's current location. All the detected key elements are acknowledged for the lifelogs generated at that instant and saved as distinct listings on the lifelog device until the user uploads the lifelogs to the cloud storage.

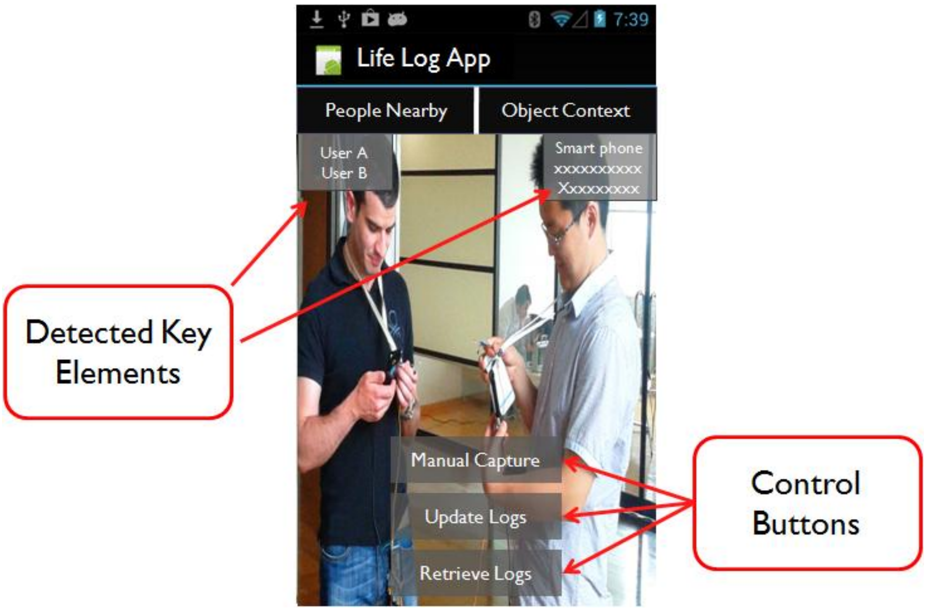

Figure 3.7: Live camera view showing captured key elements.

We also provide three control buttons to manipulate the lifelog device. The 'Manual Capture' button triggers the camera and microphone to record purposely when required by the user, despite of the routine logging in every minute. Another button is captioned as 'Update Logs' which sends all the captured logs to the cloud storage and obtains their log URLs. Each log URL is associated with the date and time stamp of capture because it is unique and may work as a reference ID. The listed key elements are also linked with this reference ID and pushed to a designated server. We configured this server with MySQL database to store URLs of the lifelogs together with all the apparent key elements recognized by the prototype device. At later stage, the user may inquire the server with the intention of retrieving appropriate logs by offering the present key elements. The 'Retrieve Logs' button serves this purpose and hands over one or more present key elements selected by the user to the server. The server compares the given key elements with the past key elements and returns the matching logs to a user wearing the lifelog device. We will discuss about retrieval of lifelogs in the following section.

3.3.2 Retrieval of lifelogs associated with the present key elements

In contrast to an ordinary lifelog device where a user needs to transfer all the data to a personal computer to view it, the users of our proposed system may retrieve past logs while on the move even if they do not exactly remember the trivial details of their past. We take advantage of the user's present key elements to find the information that may best fit their present circumstances and help them recall similar events that occurred in the past. A user may select one or more present key elements based on their requirements which will reflect the resultant lifelogs that will be retrieved after querying the server. The interface shown in Figure 3.8(a) allows the user to select 'People Nearby', 'Object Context' and 'Current location' or 'User defined location' to retrieve appropriate logs. On selection of a single key element, the server will return all the past logs matching the preferred key element by the user.

For example, if the user selects 'People Nearby', all the lifelogs related with the people currently present infront of the user would be retrieved. Alternatively, when all the key elements are selected by the user, the server at first filters the lifelogs based on the current or selected location of the user. Once, all the lifelogs pertaining to that location are sorted, the people and objects associated to these lifelogs are compared with the key elements that are presently identified by the device. Finally, the user may receive the past logs on the lifelog device matching the current situation. There can be a situation where the prototype device may identify several persons and objects concurrently. In such case, the lifelogs associated with all the recognized people and objects are retrieved and displayed on the device.

On the basis of selected key elements, the lifelogs are retrieved on the prototype device. The retrieved logs are shown in Figure 3.8(b) as images with resolution of 320 x 240 along with date of log generation, objects context and names of those people who were perceived at the moment when those pictures was taken. These lifelogs were retrieved by selecting 'People Nearby' and 'User Defined Location' as the key elements. The 'Locations' tab displays a map marking the exact places where the logs were captured. An audio clip is also attached to each image that may be listened by clicking the desired image. Hence, we

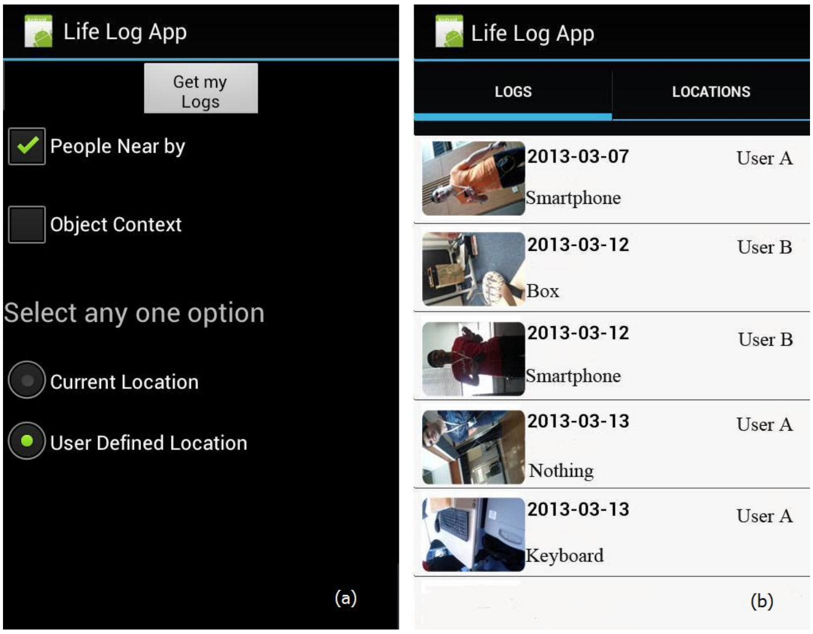

Figure 3.8: (a) Selecting key elements for retrieving lifelogs and (b) Lifelogs displayed with date taken, context attached and associated people .

simplify the procedure to acquire the specific lifelogs that match with the present situation of the user and, at the same time, prevent the user from mentioning particular details of their past event.

3.3.3 Application scenario

We highlight a situation where a student at the laboratory is requiring lifelogs of his past interaction with microcontrollers, specifically the arduino board. The student forgets some tips given by his lab mate to initiate an application on the smart phone automatically when it is connected with the arduino board as well as the method to interact with an ordinary remote control. In the absence of his mate, the student employs the prototype lifelog device and scans the arduino board and remote control as shown in figure 3.9(a) to obtain the past logs generated at the laboratory related to these objects. Eventually, the past logs related with the arduino board and the remote control are acquired even though one of the key elements, that is, the mate proximity linked with these logs is not available at that particular time. The retrieved lifelogs comprise of images taken by the lifelog device's camera, the date of capture, people and objects nearby that were associated with these logs (see figure 3.9(b)). The student makes use of the retrieved lifelogs and configures the smart phone to initiate the application automatically based on the program loaded on the microcontroller. Hence, the proposed lifelog system helped the user to overcome this awkward situation by fetching precise logs which were required by him even though his lab mate was not present at that time.

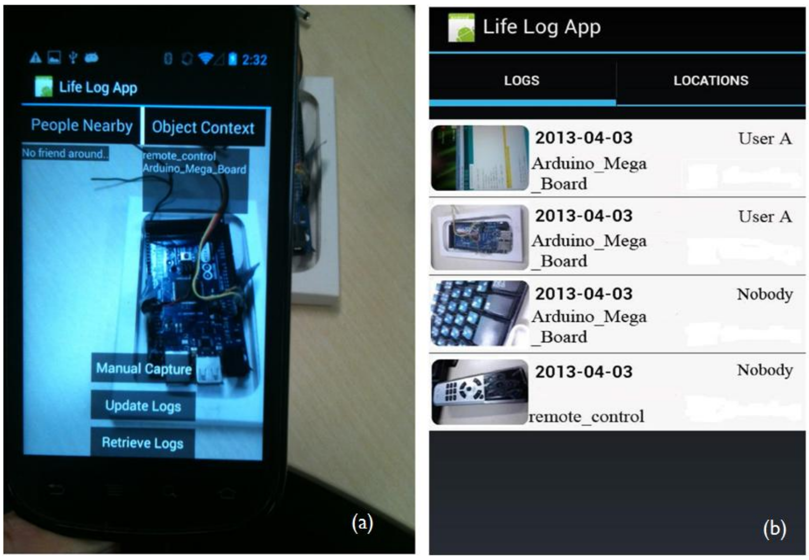

Figure 3.9: (a) Student scanning Arduino Board and (b) Retrieving logs based on present key elements.

3.4 Significance of sharing lifelogs

Lifelogging is an activity that captures a variety of user's day to day experiences. Some of these life trails are worthy to be shared among known friends, benefiting both parties, the one who shares as well as those viewing the shared logs. A person sharing past logs may obtain useful comments or feedback on his previous experiences, where as, the friends may exploit the shared past experiences in their respective lives. Most of the research is focused on capturing useful information to be labeled as one's lifelogs [2], [6], [53] and [54]. Researchers also proposed models [78], [20] for sharing of lifelogs, but less attention is bestowed upon how to select the people who may appreciate or utilize this huge data reserve.

The recent advancement in the technology has aided the people to share their life events instantly via mobile phones and social networks in the form of digital media (images and videos) along with the location and time stamp to let the viewers know where and when the media was recorded. However, people are shy when it comes to sharing lifelogs among masses because of the private data that may be exploited and manipulated without their awareness. Lifelogs contain critical data such as location traces, health information, vidoes etc and when given the option to pre-select the particular content, the people are more open to sharing their lifelogs. Also, people would like to limit the lifelog sharing to their friends and family members only. A recent study by Olsson et al. in [79] focused on the guidelines for sharing life memories with others. One of their design implications was that "the users must have the power to decide whether to share entire library of lifelogs or not". They came up with a concept prototype of a mobile service where users can easily share content by forming events of the media items and sharing the event to a certain user or groups of users.

In [80], the authors concluded that the social and emotional influences play an important role in media sharing behavior and people are more influenced towards sharing photos more than other media. We believe that if the people share the entire contents of lifelogs, then most of the times, this data would be irrelevant and useless because lifelog devices collect huge amount of data. Similarly, if people share lifelogs with all the friends, then some friends may find these lifelogs inappropriate in their present context. Therefore, we came up with an approach in which the user selects specific lifelogs and defines a location based sharing strategy. This provision allows sharing of lifelogs at multiple location levels and the data is not visible to unknown people but only to the friends. First is, sharing at street level, whereby friends visiting a particular street may view the logs of the user who previously visited the street. Second is sharing at city level, where logs are made available to only those friends who currently reside in the city or visit it. Third is location independent sharing, where logs are accessible to all friends regardless of their location. Hence user's friends must fulfill the condition of location to be able to view the lifelogs. In this manner, the friends not only find the shared information suitable to their present location, but they are also free from the hassle of sifting through the entire library of someone else's lifelogs. This system also allows user's preference to come into play, and the user is not obligated to pre-select the friends with whom one might share lifelogs.

We developed a prototype device to capture the lifelogs in the form of images and audio. The lifelogs are shared with only those people who are friends of the user on a social network. The user may select individual logs and share them with friends by specifying a location scope. In addition, we also employ Moodstocks API [71] to read QR-code, barcode as well as identify objects nearby the user in real time and attach meaningful context to the captured logs. We believe that every place has certain characteristics, for instance, a super store is a place to buy grocery and other house hold items. Therefore, sharing lifelogs including campaigns and super sale information at the super store with a family member who may visit that store in future will assist and indicate them about what else to buy from that store. Sharing context related information has the potential of supporting people to perform their activities efficiently [81]. Our approach for sharing of lifelogs based on the locality may automate the process as to whom one's lifelogs would be viewable.

In summary, this sharing framework prohibits sharing of entire lifelogs with friends and keeping them from going through non-relevant information. In addition, we allow only those friends to see one's shared logs who visit the location where lifelogs were generated. Thus we eliminate any chance of sharing contents of one's lifelogs that may be inappropriate or not useful for the friends. Furthermore, we also allow the viewers of the lifelogs to give their feedback to the owner in the form of comments or remarks on the shared logs.

3.5 Our lifelog sharing framework

The proposed lifelog sharing framework explains the way significant lifelogs are made visible to one's friends. This framework (see figure 3.10) assists a user to develop a sharing strategy on their respective lifelog devices [82]. We apply this framework on the lifelog device to make it proficient in valuing the owner's sharing preference for those lifelog entries produced at a place which, later on, have to be shared with the friends who arrive at the same location. The user of the lifelog device may define a sharing strategy by selecting any one of the three options to declare the scope of visibility for their lifelogs. The three options include, Explicit city, Particular street or Location independent. 'Explicit city' shared logs are visible to the friends belonging to the same city or those who visit that city in future. This scope may be useful to share sightseeing spots or social events of the city. The lifelogs shared with 'Particular street' scope are visible to only those friends who check in that street. These lifelogs may help to explore more about specific places such as restaurants, markets, stadiums or leisure places. 'Location independent' share will broadcast the lifelogs with all the friends irrespective of their locations.

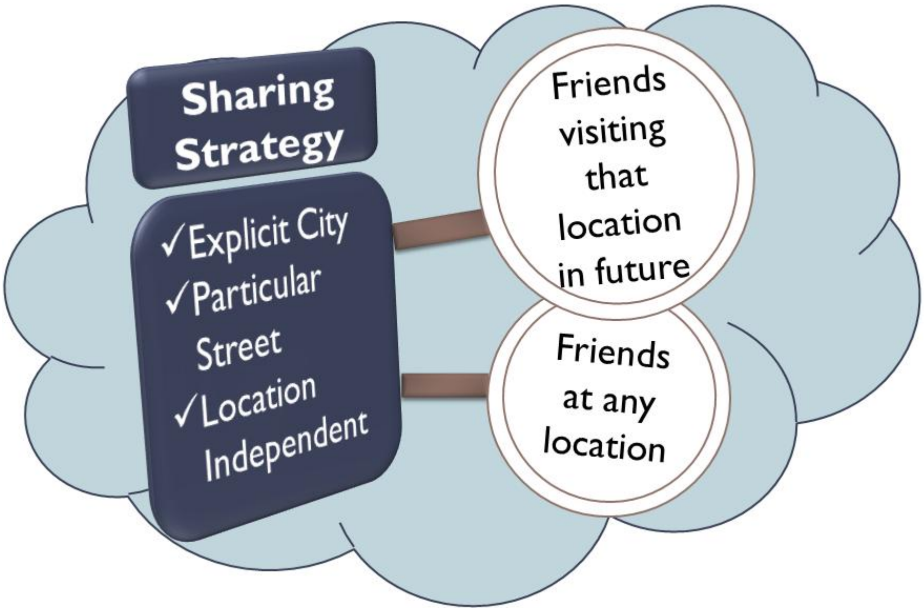

Figure 3.10: Lifelog sharing framework.

Our lifelog sharing framework attempts to shrink the number of friends who may view one's lifelogs, in addition, provide valuable information associated with the present location of friends. We further elaborate our sharing framework with two real world scenarios.

3.5.1 Suitable scenarios

3.5.1.1 Scenario 1

A person visited Tokyo city for the first time to attend an academic conference. He was delighted to see lifelogs of two friends who had been to this city in past. One of the friends shared favorite sightseeing spots and night clubs on city level, thus, the visitor enjoyed his spare time visiting few of those places. While on the way, the visitor checked in at 'Odaiba' (a sightseeing place) and found some dining logs of a Japanese sushi restaurant shared by his friend at street level. The shared logs persuaded him to go to the same restaurant and enjoy dining. The proposed system facilitated the person beyond doubt during his short stay in Tokyo.

3.5.1.2 Scenario 2

A high school student visited city library to find books related to Psychology. He found two books related with this field. The books were interesting, so he thought of sharing this experience with his friends who may visit this library in future. He selected the lifelogs generated at the library and shared them at street level. One of his class mate and friend visited city library after some time. He was confused about which book he should read at this time. While checking in the lifelog sharing application, he found shared logs of psychology books by his friend. He found this information very useful and picked the books for reading which were recommended by his friend.

There are a variety of situations where lifelogs of a person experienced at a particular place may be of assistance to the friends if shared with them.

3.6 Implementing our sharing framework

A smart phone(Nexus S) running Android operating system is programmed to work as a lifelog device. The device is worn with a 15 inch neck strap. We integrated our lifelog sharing framework with the lifelog application which runs persistently on the device. The smart phone captures an image and a 10 seconds audio clip once in every minute. Furthermore, we applied Moodstocks API to read barcodes, QR-codes and identify objects. For object recognition we need to store their templates at Moodstocks server in advance. All the captured logs are stored on the dropbox cloud [77] and their shared links are acquired for future access. Figure 3.11 shows the way lifelog device is worn with the help of a neck strap and some generated image logs by this prototype device. Our system also employs Facebook API [44] to check in particular street as well as to provide access of one's facebook friends list. Our lifelog application employs the friends list to determine friends of a user and access their shared logs.

3.6.1 Specification of sharing strategy

While the smart phone's camera and microphone snap pictures and record audio details respectively, the lifelogs are uploaded to the lifelog cloud. The current location of the user is determined when he/she checks-in via Facebook. At this time, the user may select specific lifelogs for sharing with friends and define the scope of the lifelogs visibility (see figure

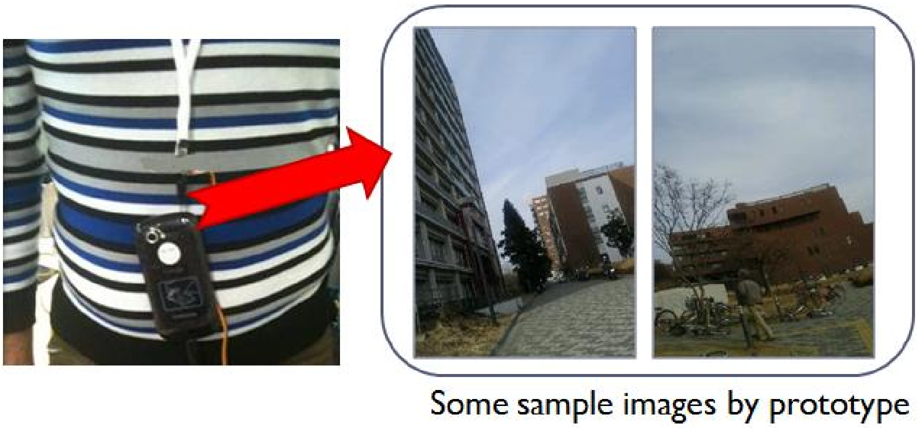

Figure 3.11: Prototype system and some captured images

3.12(a)). If the user wants to share lifelogs with only those friends who may visit the street where the user is currently present, then, he may select 'Street' share. The lifelogs can be made available to all the friends in the same city by selecting 'City' share. For sharing lifelogs with all friends regardless of their present location, the user may select 'Location Free' share (see figure 3.12(b)).

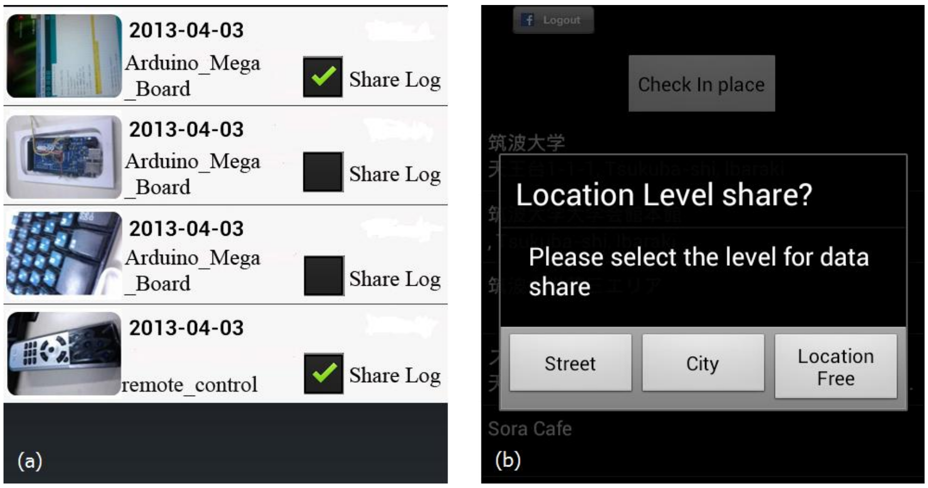

Figure 3.12: (a) Selecting lifelogs for sharing and (b)Specifying the scope of lifelogs visibility.

Finally, the shared links of the selected logs along with the sharing strategy are sent to the server. We configured this server to receive lifelog updates from loggers and entertain the requests from viewers of these lifelogs. We named it 'Live Feed' server because of its significant role in updating itself with the fresh lifelogs and their shared scope received from the owner of the lifelogs. The server is also responsible for responding the viewers with privileged logs for their current location.

3.6.2 Process of retrieving friend's shared lifelogs

The lifelogs are retrieved by a user based on their current location provided that some of his/her friends had previously been to that location. In order to retrieve shared logs, the user has to check-in and provide access of their facebook friends list to the application. When the request is send to the server for friends' shared logs, the server checks for the log entries that match with the user's current location, which means those log entries which correspond with the current city or street of the user. The server sends only the names of people to the user who had been to that location. In the next step, the user's facebook friend list is compared with the names provided by the live feed server for possible friends. If there is a match, then, the server is requested again for lifelogs of matched people, as they are the friends of the user. Figure 3.13 clarifies the process of storage and retrieval of lifelogs at a certain location. Once the permitted logs for the requesting user's current location are sorted, the server forms an .xml file with owner's name, date taken, name of the city and the dropbox link of the lifelogs to be streamed. This .xml file is sent to the requesting user and displayed on the lifelog device. The shared lifelogs consist of images with resolution of 320 x 240, audio clips of 10 seconds and the exact location where these lifelogs were produced.

3.6.3 Example 1: Retrieval of image and audio logs by friends

In figure 3.14(a) we show a situation where a person visited 'University of Tsukuba' for the first time, and used the lifelog sharing application to familiarize with the new surroundings. He recognized that four of his friends, i.e., Tom, Jack, Marry and Larry had already been there. The map in Figure 3.14(b) pinpoints the locations where the lifelogs were captured. The person viewing the shared lifelogs, finds them very useful. Figure 3.14(c) explains that the viewers of the shared lifelogs may listen to the audio clip attached to them and comment if they wish to commend or in some cases recommend something to the owner of the lifelogs.

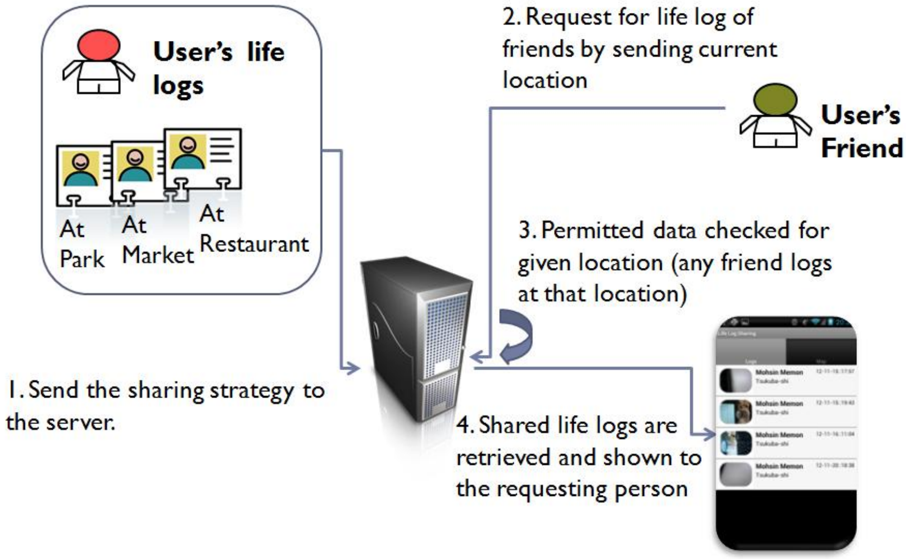

Figure 3.13: Storage and retrieval of friend's lifelogs.

3.6.4 Example 2: Retrieval of lifelogs related with objects scanned via Moodstocks API

The lifelogs consisting of objects and their context are also retrieved as an .xml file with owner's name, date taken, context of scanned object or barcode and user's perspective about the lifelogs. These lifelogs assist the viewers with the experience of objects that were previously interacted by the lifeloggers at that location. In figure 3.15(a), we show a a student who checks in the university library and receives the lifelog consisting of a picture of the book for psychology class by his friend 'Alice', prompting him to have glance at it. In another situation shown in figure 3.15(b), we talk about a person who checked-in a bakery and saw lifelog of 'blueberry bagels' captured by his friend 'Muller' who bought them earlier. Consequently, he also bought the same bagels since his friend already had a good experience of eating them.

Hence, the rich lifelogs may assist the viewers to comprehend their present location with the assistance of their friend's lifelogs. The shared logs related with the objects around the user are beneficial since they provide the friend's personal experience regarding these objects.

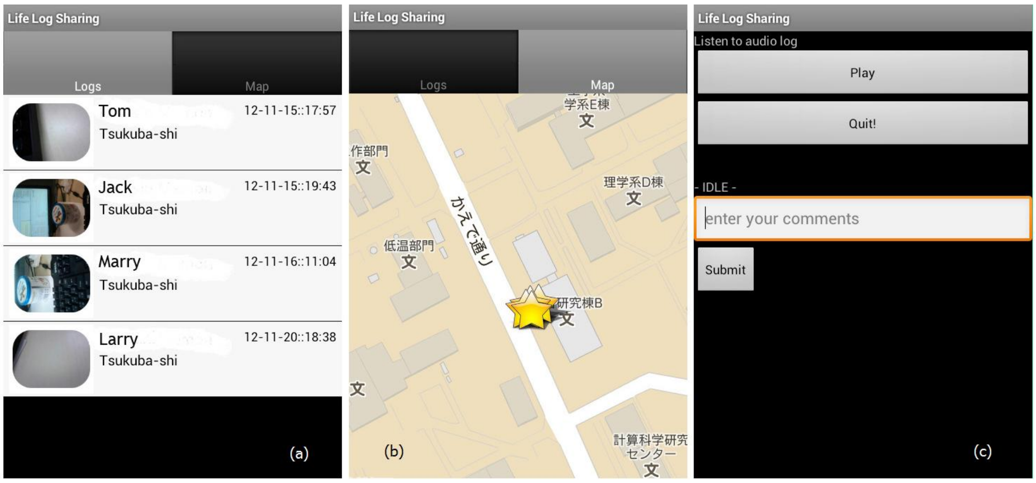

Figure 3.14: (a) Retrieval of image logs of friends, (b) Location of generated lifelogs and (c) Interface to listen audio log and submit comments.

3.7 Experiment to compare our lifelog retrieval system with Vicon Revue device

3.7.1 Purpose

The purpose of performing this experiment is to determine whether our proposed system is efficient than the Vicon Revue device [83] in retrieving the lifelogs which are helpful to the user. We analyzed the ability to retrieve the past lifelogs of matching the present circumstances of a user when using our proposed approach and comparing it with the retrieval of logs using the Vicon Revue device. The Vicon Revue is a wearable digital lifelog 3-megapixel camera which takes a photo automatically in every 30 seconds. The reason we used vicon revue for this experiment is because both, our prototype and Vicon Revue capture lifelogs in the form of pictures, however, their retrieval mechanims are different. So we had to determine which device has the best lifelogs retrieval mechanism. The logs produced by Vicon Revue are compressed and temporarily stored on the device and later on transferred to a computer for viewing and tagging. On the other hand, our prototype system sends all the data to the cloud storage for retrieval at any place and any time. While comparing these systems, we tested two hypotheses,

Hypothesis 1: The time required to retrieve relevant logs for a given situation when using the prototype device is less than that when using the Vicon Revue device.

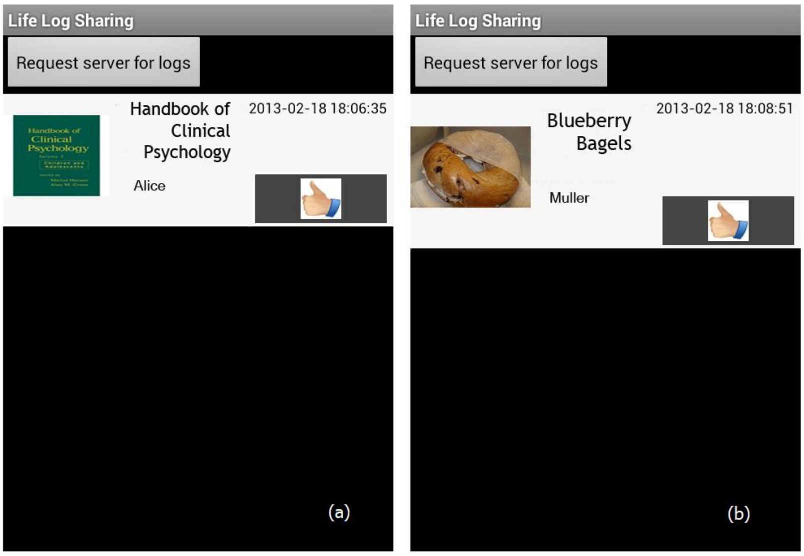

Figure 3.15: (a) Book scanned and shared by 'Alice' at library and (b) Lifelog of Bagels shared by 'Muller' at bakery.

Hypothesis 2: Retrieving past logs that are relevant to a given situation is more convenient when using the prototype device than when using the Vicon Revue device.

In order to determine the time required to retrieve relevant lifelogs for the given situation of user, we setup an experiment and asked the participants to log some events with the help of the lifelog device given to them. Later, the participants had to retrieve the logs for the given events. This experiment was based on the planned behavior and we calculated the time required by the users of each device to retrieve the relevant logs for those events.

To measure the convenience of retrieving the lifelogs, we asked all the participants at the end of the experiment to give their feedback about the overall working and the user interface of the lifelog devices that were provided to them. We prepared a total of 4 questions which the users had to answer on a five point likert scale (For question 1 and 2, 5 = Fully Satisfactory and 1 = Unsatisfactory, for question 3 and 4, 5= Fully agree and 1=disagree). The questions are,

1. How did you feel about wearing the lifelog system during the experiment?
2. How was your experience about searching the lifelogs for the events?
3. Is it easy to operate the interface for retrieving logs?
4. Is the final screen where the retrieved logs are displayed useful?

Table 3.1: Tasks performed by the participants in the morning and afternoon sessions

Session	Task
Morning (09:00am -11:00am)	Capture logs of a meeting with all the participants at a location for 10 minutes period
Afternoon (01:00pm -03:00pm)	Capture any two everyday use objects belonging to the participant

Based on the answers of the questions above, we compared the convenience of retreving appropriate logs for the given events. In the next section we will dicuss the experiment setup in more detail.

3.7.2 Experiment setup

This experiment was set up to prove the stated hypotheses by constituting a group that consists of three participants at one time. Among them, two participants were given the prototype lifelog devices while one participant was given Vicon Revue device to wear during two sessions in a single day. First session started in the morning from 09:00 am and ended at 11:00 am. Second session started in the afternoon from 01:00 pm and ended at 3:00 pm. All the participants had to capture their everyday events by using the given devices, although they were allowed to switch off the device during their private time.

During the experiment, we asked all the participants in a group to perform two tasks. One of the tasks had to be performed in the morning session and the other one required to be performed in the afternoon session. These tasks are explained in Table 3.1. During morning session, all three participants had to meet at a location for 10 minutes period in order to log the event. Similarly, during afternoon session, the participants were asked to capture any two everyday use objects which belonged to them. We asked the users of our prototype device to provide us images of these objects in advance so that we can upload them on Moodstocks server. At the end of the experiment, we asked all the participants to retrieve logs for the tasks performed in the morning and afternoon sessions.

The users of the prototype system had to make use of their present context to retrieve the logs related to the given tasks of both sessions and they were permitted to exploit the key elements to serve this purpose. On the other hand, the user wearing Vicon Revue device had to manually sift through the entire logs and search for the appropriate content related to these tasks on the computer. We measured the total number of captured logs (images) by both types of logging devices, number of relevant logs retrieved for the given tasks. We also noted down the time consumed to retrieve lifelogs of the given tasks by all the participants.

3.7.3 Participants

We recruited a total of 18 participants for this experiment and divided them in 6 groups with each group containing 3 participants. In each group, two participants were asked our prototype lifelog devices while one participant was given Vicon Revue device to wear for two sessions in one day. The participants were students (15 female 3 male) in the University of Tsukuba and belonged to various departments. Their ages were between 23 and 27 years (mean=25.6 years). All the participants were briefed for 30 minutes about the purpose of this study before asking them to start logging with their lifelog devices.

3.7.4 Results and observations

The participants of all the groups successfully completed the tasks during morning and afternoon sessions. We asked them to retrieve lifelogs for the tasks performed in both the sessions and measured the time required to fetch relevant logs for the given events. On comparing this time duration for both, our prototype device and Vicon Revue device, we found that the users of Vicon Revue device consumed more time than the users of our prototype device. In figure 3.16, we show the comparison of the mean time required by the participants of each group to retrieve relevant logs for the events of morning and afternoon sessions. The mean time consumed for retrieving logs relevant to the given events by the prototype and Vicon Revue users is 4.0 seconds and 94.0 seconds respectively. In each group, Vicon revue users always consumed more time while retrieving lifelogs for the given events than the prototype device users, which validates our hypothesis 1.

The users of the prototype device swiftly obtained the lifelogs relevant to the meeting in the morning session since their device identified the neighbor participant and fetched lifelogs of the past meeting. The users selected 'people nearby' key element to obtain the logs of meeting and these lifelogs were instantly displayed on the device. Again, for the afternoon session, the prototype device identified the objects (watch, hand cream, juice box, etc.) scanned by the users and retrieved precise logs of past interactions with these

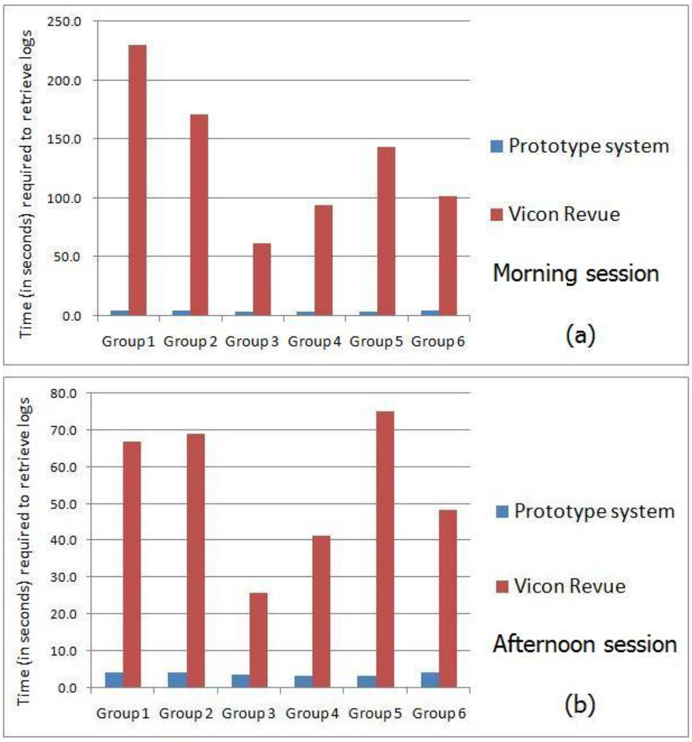

Figure 3.16: (a) Mean time required by the participants for lifelogs retrieval in morning session and (b) Mean time required by the participants for lifelogs retrieval in afternoon session.

objects. On the other hand, the Vicon Revue users first transferred all data to the computer and then viewed the logs one by one until the images of the meeting and objects appeared on the computer screen. The users of the prototype device exploited specific key elements for retrieving logs of the given events, for instance, they selected 'people nearby' key element for retrieving logs of meeting with other participants. Similarly, they chose 'object context' for retrieving logs of their daily use objects. The users took advantage of the key element selection interface (see Figure 3.8(a)) and selected only those key elements which retrieved appropriate lifelogs required by them.

We asked the users of each group to count the number of lifelogs retrieved for the given events as well as total number of logs generated by their worn device during the two sessions of the day. We show this count in Table 3.2. The Vicon revue device produced approximately twice the logs generated by our prototype device. The main reason for capturing more lifelogs is that the Vicon Revue takes a picture in every 30 seconds and it is also equipped with light and motion sensors which trigger the camera when a sensor records

Table 3.2: Total and retrieved logs by the lifelog device users

Groups	Prototype User A		Prototype User B		Vicon Revue User	
	Retrieved logs	Total logs	Retrieved logs	Total logs	Retrieved logs	Total logs
Group 1	15	458	25	411	71	936
Group 2	10	398	23	401	40	786
Group 3	10	341	10	269	51	892
Group 4	09	266	08	336	47	1376
Group 5	09	266	20	421	57	1097
Group 6	19	418	20	405	39	943

any change in the reading. That is why the count of total and relevant logs retrieved by our prototype device is less than the Vicon Revue device.

Finally, we analyzed the answers of the questions asked from the users at the end of the experiment. The users of our proposed system showed satisfaction over using the prototype lifelog device and we obtained the score of 4.1 (0.57) for question 1. In case of Vicon Revue, the users responded similarly and the score was 4.1 (0.4) for this question. In reference to question 2, the users of our system showed utmost satisfaction about the searching of lifelogs and the score was 4.4 (0.51). However, the users of the Vicon Revue were not satisfied over searching of lifelogs as reflected by the score 3.1 (0.4) for this question.

Upon asking the users for the easiness of the interface for retrieving logs in question 3, the users of Vicon Revue replied with 3.8 (0.4), where as the users of our system responded with a score of 4.5 (0.52). At the end, we asked the users about the final screen where the retrieved logs for the events were displayed. The users of our system responded with 4.9 (0.28) for question 4, on the contrary, the users of Vicon Revue device replied with 3 (0.63). These results confirm that our proposed system is more convenient for retrieving appropriate logs when compared with the Vicon Revue device, thus satisfying our hypothesis 2.

By comparing our prototype lifelog device with the Vicon Revue device, we have drawn attention to the problems of current lifelogging systems while retrieving past logs and addressed them in an efficient manner. The retrieval of lifelogs based on the key elements reduces the overall burden on the user of remembering the accurate details for retrieving the precise logs.

3.8 Experiment to determine the key elements preferred for retrieving lifelogs

3.8.1 Experiment setup

We setup an experiment to determine which key element is mostly preferred by the users to retrieve lifelogs of the past events. To serve this purpose, we asked 10 users to wear our prototype device for two sessions in one day and capture lifelogs in the form of images. The duration of each session was 90 minutes. The reason for performing the experiment in two sessions is because our prototype device requires recharging after each session. The timing of the morning session is 10:00 am to 11:30 am, while the afternoon session continued from 2:00 pm to 3:30 pm. To make our prototype device identify objects, we requested the users to provide us images of five daily use objects (cell phones, books etc.) in advance so that we can upload them on Moodstocks server. The users were asked to work similar to their usual days and log their life events for two sessions in the day.

We asked the users to retrieve lifelogs at two stages, one, at the end of afternoon session, and second, 23 days after the experiment. The users were asked to retrieve the lifelogs of any four events that occurred during the experiment sessions of that day. The users were allowed to use any single or combination of the present key elements to retrieve lifelogs for the events. We documented the total number of recorded lifelogs, the key element/s used for retrieving the lifelogs and the number of lifelogs retrieved by the users for an event.

3.8.2 Participants

We recruited 10 participants (6 male, 4 female) for this experiment and divided them in to 5 groups (2 users in each group). The participants were students in various departments of the University of Tsukuba and residents of Tsukuba city. The ages of the participants were between 21 and 34 years (mean=27.2 years). All the participants were briefed for 30 minutes about the purpose of this study and applications of the prototype lifelog device. The users of each group were asked to wear the prototype device and capture lifelogs of their daily events in two sessions of the day.

3.8.3 Results and Observations

3.8.3.1 Lifelogs retrieved on the day of experiment

Since the users were permitted to choose any past four events recorded during the two sessions and retrieve the lifelogs for these events. They exploited a variety of the key elements to perform this task. The users retrieved lifelogs for 40 events in total, out of which 23 events were from morning session and 17 events from afternoon session. Figure 3.17 shows the key elements and their combinations preferred for retrieving lifelogs on the day of the experiment. 'People Nearby' key element was used by all the participants for retrieving lifelogs of one event, thus, making it the most popular key element. This key element was used to retrieve lifelogs of 10 events which shows that the users were interested to see the retrieved lifelogs of the person with whom they interacted earlier that day. 'Object Context' was used for retrieving logs of only 2 events, whereas, 'Location' was used to retrieve logs of 8 events. The users also exploited various combinations of key elements for lifelogs retrieval. 'People Nearby' and 'Object Context' key elements were rarely used together and only one event's lifelogs were retrieved using this combination. On the other hand, 'People Nearby' and 'Location' key elements were exploited together to retrieve lifelogs of 7 events. 'Object Context' and 'Location' were used to retrieve lifelogs of 4 events only. Some users exploited all the present key elements to obtain lifelogs for 8 events. These results depict that the users showed more interest in retrieving lifelogs of events involving meetings with people and the location. Lifelogs related with objects were also retrieved by combining the other key elements.

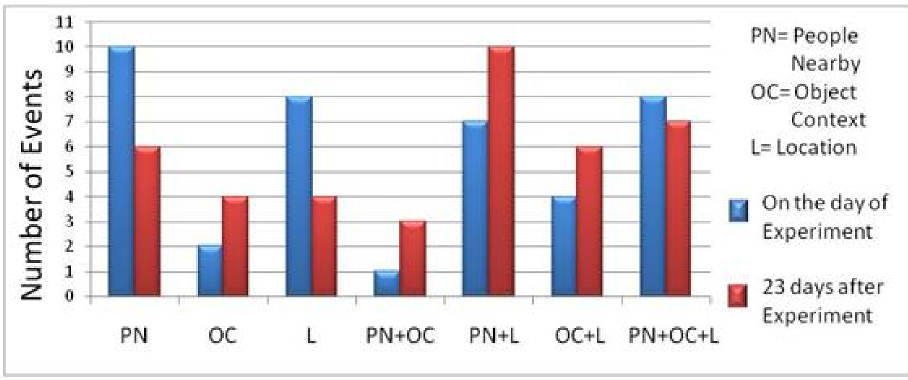

Figure 3.17: Key elements preferred for retrieving lifelogs of various events.

We asked the users of each group to count the number of lifelogs retrieved for the events. We arranged the average number of lifelogs retrieved per event based on the key elements selected by the users (see figure 3.18). The 'Location' key element retrieved more lifelogs than rest of the key elements, since the users' location did not change alot during the experiment. The average number of lifelogs retrieved using 'People Nearby', 'Object Context' and 'Location' are 11.7, 8 and 31.1 respectively.

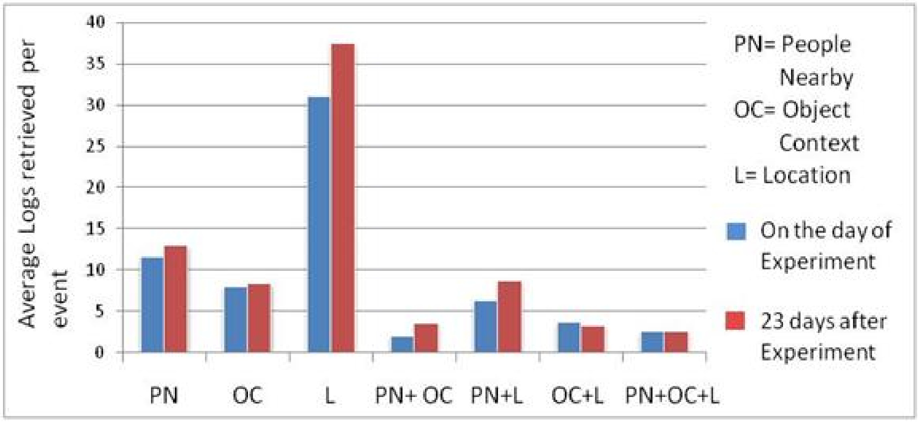

Figure 3.18: Average number of lifelogs retrieved per event based on key elements.

The selection of a single key element resulted in more lifelogs retrieved for a past event; on the other hand, selection of multiple key elements resulted in fewer lifelogs for an event. This trend can also be seen in the graph shown in figure 3.18, as the average number of lifelogs retrieved using multiple key elements are relatively less than when using single key element. But the users selecting multiple key elements obtained the most suitable logs for the present situation. Three users commented that the lifelogs retrieved using multiple key elements are very specific to their present situation.

3.8.3.2 Lifelogs retrieved 23 days after the experiment

After 23 days of the experiment, we again asked the users to retrieve lifelogs of past four events recorded during the two sessions on the prototype device. The users employed various key elements and their combinations to retrieve lifelogs of events. From a total of 40 events retrieved, 27 were old events, which mean that the users had already retrieved lifelogs of those events on the day of the experiment. In addition, 13 new events were also picked for lifelogs retrieval. From the retrieved events, 25 were logged in the morning session and 15 were logged in the evening session.

In figure 3.17, we show the comparison of the key elements selected by the users for retrieving lifelogs on the day of the experiment as well as 23 days later. In reference to retrieval after 23 days of the experiment, the users focused more on the combination of key elements than the individual key elements. Again, ‘People Nearby’ and ‘Location’ key elements were used together by all the participants and 10 lifelogs retrieved were related to meeting with people at a place. The users also employed ‘Object Context’ and ‘Location’ together to retrieve lifelogs of 6 events. The retrieval of lifelogs using all the key elements was used to retrieve lifelogs of 7 events. By comparing the key elements used on the day of the experiment and 23 days later, we found that, on the day of the experiment, users preferred retrieving lifelogs of events using single key elements. However, 23 days later, the users were more interested to retrieve lifelogs specific to their current situation by combining various key element combinations.

We also compared the average number of lifelogs retrieved using various key elements and their combinations on the day of the experiment as well as after 23 days of the experiment. The graph in figure 3.18 shows that there was no significant difference in the average number of lifelogs retrieved on the day of the experiement and 23 days after the experiment. The users’ comments after viewing the retrieved lifelogs were very positive and they were able to recall all the events correctly on both the occasions. In summary, the users preferred to retrieve lifelogs of events involving people and also employed various other key element combinations together with ‘people nearby’ key element for this purpose. All the users gave a positive feedback about retrieving lifelogs via the prototype lifelog device. Our concept of retrieving lifelogs using key elements was well appreciated by the participants and can be incorporated in commercial lifelogging devices.

3.9 Evaluating the lifelog sharing framework

3.9.1 Experiment setup

The system was evaluated with the help of 8 participants in total. We selected those participants who were friends on facebook so that they are able to view each other’s shared lifelogs. All the participants (7 male, 1 female) were aged between 20 and 30 years and belonged to the department of computer science in the University of Tsukuba. They were given a brief overview of the system and provided with the prototype device for making lifelogs as well as setting up their sharing strategy. Each participant used the device for one day and logged information at various locations in the university campus for their facebook friends to observe. In addition, they also viewed the information shared by them while checking in specific locations of the university. After the experiment, the participants were given a set of questionnaire which they could respond on a five point likert scale (1= Don't Agree 5= Fully Agree). The purpose of this questionnaire was to obtain user's viewpoint on sharing lifelogs via the proposed system. These questions are given below,

1. Did you find the system useful to share lifelogs with friends?
2. Do you believe that the comments on your lifelogs would benefit you by any means?
3. Is there any complexity while operating the system?
4. Do you feel contented to share your lifelogs with friends based on locations?

3.9.2 Results

We obtained a total of 37 logs from 8 participants with an average of 4.6 logs per person. The pie chart in figure 3.19 illustrates the sharing preference for the lifelogs produced at different locations by users wearing the device. They comprehended the feasibility of the prototype application, thus, favored 'particular street' sharing due to its limited scope. The percentage of lifelogs selected for sharing at 'particular street' level is 59%, whereas, only 38% of lifelogs were shared within the city where the lifelogs were generated. The option of sharing 'location free' was ignored by most of them due to its vast scope and only 3% of lifelogs were shared among all the friends despite of their present location. There were overall 20 comments from users on each other's lifelogs with constructive phrases, however, two users requested to place an option to re-comment on the comments made by their friends on lifelogs, likewise they used to do on a social network.

The response of users about our prototype system was quite compelling and the mean value for question no. 1 was 4.625 (0.517) with n=8, although, two users criticized the size of image logs and quality of the audio when they succeeded in retrieving friends' logs. One user mentioned that he would prefer another social network with the prototype application since he had fewer friends on facebook. There were mixed responses on the convenience of

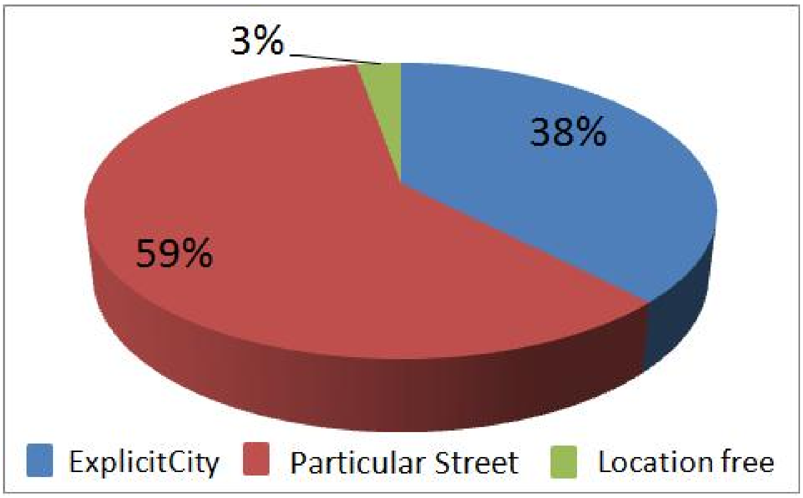

Figure 3.19: Sharing preferences for lifelogs produced at different locations by users.

comments on lifelogs with mean value of 3.25 (1.281) for question no. 2. The prototype system was not very complicated to operate, as a result, we obtained 2 (0.92) for question no. 3. Finally, the miscellaneous feelings over sharing their lifelogs with friends resulted in 3.25 (1.388) for question no. 4, may be because, a single day was not sufficient for perceiving the practicality of the prototype. Thus, we are taking into consideration to assess the system for an extended duration and observe its usefulness in varied situations.

3.10 Benefits and limitations

Our prototype lifelog device works very well in situations where a user instantly needs to recall past experiences that are similar to their present situation. The lifelogs are stored on the cloud storage so there is no issue of the storage space for keeping previous lifelogs. Since the lifelogs are automatically tagged with the key elements, therefore the users need not to worry about manual annotation. On the other hand, Vicon Revue device users have to add manual tags for easy retrieval, otherwise; retrieval of past logs becomes really messy and consumes a lot of time. The proposed system efficiently shares an individual's personal experiences with concerned friends. We do not involve the users to explicitly select the friends for sharing of lifelogs and keep them away from the hassle to decide about who should be allowed to view their lifelogs. The process of declaring the sharing strategy is simple because, with a single click the user was able to define the scope of visibility for the selected lifelogs.

Using our sharing method, the user who has shared lifelogs may not know if any of the friends have already viewed the shared lifelogs, however, the user may receive the comments on individual logs left by those friends who viewed the shared logs. Furthermore, the quality of shared image and audio recording needs to be improved as during the evaluation, few user criticized about the size of image and quality of audio.

The current prototype system needs to be charged in every 3 hours as our lifelog application keeps the camera and microphone sensors active all the time. We are working to make the lifelog application efficient in terms of battery consumption so that the user may not feel any trouble of recharging repeatedly while wearing the device for a longer period. In the next section, we elaborate significant related works to our research.

3.11 Related work

We divide our related our into two parts, retrieval of lifelogs and sharing of lifelogs.

3.11.1 Retrieval of lifelogs

The concept of reminiscence has been studied before as the remembered past [84] and "dwelling on the past and as retrospection, both purposive and spontaneous" [85]. The study by Wagenaar in [86] was concerned with the author's own memory and recalling of past events that occurred in a period of 6 years. Each event was recorded with various aspects such as, who, what, where and when, and they were also used as retrieval cues. The author attempted to recall 2400 events with the help of retrieval cues and concluded that double and triple cuing resulted in better performance. This study showed that everyday life events were much more slowly forgotten that suggested and the author was able to reproduce memories of people, of words being said, of feelings, emotions, happy times and utter despair. Our proposed system's evaluation results are similar and show that the users retrieving lifelogs were able to recall the past events. The users of our system were more interested to retrieve lifelogs related with meetings with people. On the other hand, Wagenaar claimed that 'what' as a single cue was very significant and combining 'what' with 'when' together are effective in recalling the past. The users of our system also used combinations of key elements to retrieve lifelogs of particular events and found that this approach is very efficient. They commented that the obtained lifelogs are very specific to their present situation.

At the time when wearable computers were introduced [87], a research was conducted by Rhodes et al. in which they developed a system named as "Remembrance Agent" [88]. This system worked on desktop computers and employed to provide notes that might be relevant in that context without any intervention. Several recent works are related to our research which emphasize on the need to address the issue of retrieving lifelogs on a mobile platform. Blum et al. in [53] used context recognition to predict significant moments for taking pictures and recording audio that is associated to that picture. They related interesting moments to one of the categories, that is, location, speech, posture and activities, which are detected using a rule-based system. The user is made responsible to select a pre-defined label to annotate the recorded moments. A mobile context aware system was developed in [89] that provided a web based lifelog explorer to visualize user's experiences. The presence of people at a particular place was determined by Bluetooth and WLAN services. Aizawa et al. in [54] emphasized on the conversation scenes in one's lifelog and detected human face via skin color [90] and voice, however, this approach is prone to errors in crowded places and may result in false alarm or missed detection. Our technique accurately determines the people in sight via infrared sensors and facilitates the user to instantly retrieve past meeting logs with them. Alallah et al. [91] have explored a method of marking moments to capture and recall past experiences. A single button device is used to mark moments, the researcher observing the participants captures the required data which is used later when participants are asked to recall information. In the study, several participants expressed that additional information should be captured according to the situation for easy retrieval.

ButterflyNet [63] is a mobile capture system for biologists on field trips. It combines natural input interfaces such as paper notes, digital photographs and other information. This information is captured using digital pens/notebooks, cameras, GPS devices, sensors and video recorders. The captured content is further transferred to multimedia spreadsheets for manual annotation as well as sharing among other lab mates via a single click. When a user captures information, this data is automatically linked with related context such as time, location or other metadata and helps to retrieve appropriate logs; however, this system was inconvenient to be taken to the fields for logging.

Concerning the systems for people with mild dementia, a mobile based memory support tool named as MemoryLane [92] was proposed to recall past activities and maintain these memories. The people and objects can be recognized only if they are tagged by Bluetooth devices whereas location is obtained by GPS. The users can manually change the location, add or remove persons or choose what recorded media to keep but, the process of recognition by Bluetooth in crowded places such as a bus stop or a shopping center might result in false alarm. Our approach effectively identifies individuals involved in a conversation with a person at any location. Lee et al. in [1] proposed a lifelogging system to help people suffering from episodic memory impairments (EMI) and employed Sensecam [15], voice recorder and GPS logger to provide passive logging. However, reminiscing largely depends on the expertise of the caregiver who inputs cues and reveals lifelogs to the person with EMI. Another system was proposed in [7] to trigger episodic memories of past by recognizing the context with infrared beacons that are placed in rooms; attached to persons and objects. This approach is impractical because one cannot implant infrared sensors to each and every object in real world. They retrieved past information on a head mounted display in the form of pictures and audio. Verumi et al. in [93] proposed an audio memory prosthesis named as iRemember to create a personal audio archive with contextual information. The system records conversations via microphone and annotates them with associated data such as location, email, and local weather, however, the recording is only made on user request.

A context aware system was made by Holleis et al. in [64] where they used stationary tags on objects and wearable sensors worn by presenters and visitors in an exhibition. They logged human-human and human-object interaction and examined exhibit visitors' interests based on the differences in staying time at each exhibit. Cheng et al. [94] incorporated RFID technology on mobile platform and tagged places and object with RFID tags. The users developed personal weblogs and were allowed peer to peer communication to enhance social quality of shared life experience. Mobile lifelogger [95] was proposed to index the inherently large lifelog data so that the person can efficiently retrieve the log segments that interest them the most. By converting sensory data such as accelerometer and GPS readings into activity language, they were able to apply statistical natural language processing techniques to index, recognize, segment, cluster, retrieve, and infer high-level semantic meanings of the collected lifelogs. An Android-based smartphone was programmed in [96] to collect images, audio, location and accelerometer data. With the help of multiple annotation tags, daily logs can be reviewed and segmented into meaningful events. Their model is trained, using 41 days of data, and then used to predict the remaining one day. The main drawback in their work is that, a considerable time was spent on manually annotating the information.

At the end of learning the information, alot of time was consumed to physically segment and tag the data.

3.11.2 Sharing of lifelogs

The study in [97] revealed that the users of a sharing system were willing to share more if they were provided with complex and rich privacy dimensions, thus encouraged us to propose a lifelog sharing strategy. The researchers developed “Specter” in [78] for building augmented memories with the help of various sensors, and proposed a sharing model for utilizing these memories by sharing with others while obeying the owner’s privacy preferences. They also put forward a framework for ubiquitous content sharing in [98], but, since then, there have been drastic changes in the technology that has revolutionized the accumulation and usability of personal lifelogs. The notion of cloud storage and social networking has transformed the way we perceive one’s lifelogs. The authors of [99] developed a system that can support the creation of scrapbooks that are both digital and physical in form. They developed a website where a user updates their own physical scrapbook and these scrapbook pages become visible to other family members. Restricting life experiences to family members is the major downside of this approach since one may also like to share this information with friends.

We also found studies for location sharing among users. One of them is “Locaccino”, a location sharing software developed by [100], where users were able to set privacy preferences while sharing their current location based on their customized friendlists of facebook as well as different timings on a particular day of a week. We expose our past visited locations while sharing lifelogs, thus, we mainly focused on taking advantage of one’s lifelogs. “Contextwatcher” is an application developed by [101] that allowed the users to share not only their location with friends, but also a variety of contextual information ranging from body data to pictures, local weather information, and even subjective data like moods and experiences. A cloud based mobile photo sharing application was developed by [102] which uses the users phone number as the user name. The phonebook on the mobile device was considered as a basis of the social network. The user willing to share photos has to select the preferred friends and only those contacts were able to view the shared photos. The user can also make the photos public, but even then, the contact matching was used to limit the photo sharing with contacts on the phonebook. Sharing photos with phonebook contacts using this approach is fixed, as the user is responsible to select which friends may be given the right to view photos. This method is not a very convincing for sharing lifelogs as some frieds viewing the lifelogs may find them irrelevant.

Rawassizadeh et al. proposed a sharing model in [20] for secure sharing of lifelogs with people for a limited period, but, it ended up with just a design with no real implementation. In [103], the authors focused on creating metadata automatically from personal lifelogs and constructed a virtual world. In that virtual world, physical structures, such as buildings and objects were included as a virtual representation with reference to the way the physical space was constructed but a proper sharing strategy was not defined. The authors in [104] developed a tangible platform and allowed the users to create multimedia stories and share them among other participants to engage in a reflective learning process. The participant used digital still cameras to record images for their stories and also provided voice-overs and metadata information before adding their clips to the content database. Zheng et al. tried to use location history to develop social network and offer travel recommendations. Their approach named as "GeoLife" [21], is based on the GPS traces of people and the travelers make use of these travel sequences to attain information about most popular places to visit as well as the most feasible transportation mode to travel, but, their approach is favorable to travelers and tourists only.

A broad range of concepts have been proposed in recent past to resolve the popular issue of lifelogs retrieval and sharing, however, very few of them have recommended a real time lifelog system capable of performing these task efficiently and spontaneously. We believe that our proposed system is practical and most convenient to be used as lifelog device.

3.12 Summary

Digitization of episodic memories is becoming a reality with the advancement in everyday use gadgets but, at the same time, people require an effective and robust lifelogs retrieval mechanism to obtain appropriate past logs and utilize their past experiences. The proposed reminiscence system comprises of a smart phone based lifelog device competent to realize the present situation and search for the relevant past episodes. We emphasized on the people in sight, objects interacted with and the location of lifelog device wearer, individually as well as collectively to assist in the process of reviving the past. Our vision of prospect lifelog device comprises of a self-reliant and compact system that can amass and search for the most appropriate logs complying with the present state of a person. The evaluation results have proven that our system is far more efficient than Vicon Revue device in retrieving the suitable lifelogs. We also allow a user to take advantage of noteworthy life moments by sharing them amongst friends. A user may select specific lifelogs and share them with location reservations. This approach serves to prevent precious logs from being shared with all the friends, except those who may find them informative. We succeeded to empower the users of the lifelog device to determine the visibility of their lifelogs, since they are one of the beneficiaries of shared logs. On the other hand, friends who are the recipients of shared logs feel contented when they check-in a novice location and may have a better perception of that location. The sharing of users' feedback about the objects interacted by them in their lifetime further enhances the view of the present location of friends. The evaluation results of our prototype system were quite promising with reference to sharing past happenings among friends. The technique of revealing lifelog information at the time when one's friends arrive at particular location may further open the doors of how this massive lifelog data may be utilized efficiently.

We will further investigate new key elements which can be annotated with one's lifelogs, for instance body movements and other environmental factors to accurately analyze one's present state and assist in the process of reminiscence.

Chapter 4

Conclusion

The advancement in the storage and capturing capabilities of today's digital devices has promoted the idea of pervasive logging. Pervasive logging captures a variety of information without any human intervention. This data is logged by means of pictures, audio clips, location and activity logs and commonly known as lifelogs. The lifelogs help to recall the past events occurred in one's life. However, there are a few major problems which prevent pervasive logging from becoming widely accepted among common people.

It is necessary to address these problems to make pervasive logging popular, since it has a potential to be exploited in a number application areas. At first, we must consider the privacy of people who are captured during pervasive logging if they are not willing to be a part of some one's lifelogs. Second, the lifelogs must be retrieved instantly and relevant to the current situation of a user. Finally, the user may be able to share the lifelogs with friends in such a way that the friends may take advantage of these lifelogs in their respective lives.

Our research work has presented valuable frameworks and methods to resolve the issues in the current techniques for achieving privacy, retrieving and sharing lifelogs in the course of pervasive logging. Incorporating these techniques in the future lifelogging devices will draw more people towards using a system that is able respond to their privacy concerns, retrieves the lifelogs relevant to their present situation and allows them to share the lifelogs with respective friends.

We ensured privacy in pervasive logging by proposing a *lifelog privacy framework* by which a person may easily input his or her privacy consent on the lifelog device. The privacy consent is a geo-temporal privacy policy which consists of a restricted location and time duration, where and when the user does not want to be recorded by neighboring pervasive devices. A user of the system may select the type of sensors on which restrictions are to be applied, and at the same time, allow selected friends and family members to capture while denying anonymous people. The privacy preferences set by the user are shared among neighboring devices present at a place and the lifelog sensors are suspended from logging when the user with active privacy settings is in front of another user. We designed a prototype lifelog device and implemented our privacy framework in such a way that the users may easily inscribe their privacy preferences on the device. Our approach is better than computer vision based privacy (in case of images), because it does not allow the sensors to log the person on the first hand, whereas, computer vision based technique applies privacy after capturing. The proposed system performed very well during evaluation and the users were able to hide themselves from unwanted logging of neighboring participants.

We also proposed a lifelog retrieval method by which the users may have access to those past lifelogs which are relevant to their present situation. The lifelog device is a smart phone on which this mechanism is implemented. We recorded images and audio clips as lifelogs and captured three key elements together with the lifelogs. The key elements are people nearby, object context and present location of the user. A user may exploit any one or all the key elements together to retrieve most relevant lifelogs to the present situation. This approach is very useful as the users do not have to enter any past information to retrieve lifelogs , and moreover, they are able to see their past information instantly on the device. We compared our system with Vicon Revue device and found that our proposed lifelog system is better than Vicon Revue device. Finally, our *lifelog sharing framework* recommends a method to share lifelogs with friends based on their current location. The user may share lifelogs by declaring one of the three sharing strategies which are, particular street, city and location free sharing. Again, a smart phone is configured to capture lifelogs in the form of images and audio clips. Only those lifelogs are shared with friends which are selected by the user himself and the friends may view the shared lifelogs when they visit the location where the lifelogs were generated. Sharing lifelogs based on the location may keep the friends away from viewing the lifelogs which are not useful or related to them. The system evaluation further strengthened our idea of sharing lifelogs with friends based on the location and the participants of the experiment found the shared lifelogs useful for their current location.

Our main contributions include innovative methods to perform the tasks mentioned above as follows.

1) We introduced a lifelog privacy framework which respects the privacy of people in the neighborhood of the user wearing a pervasive logging device.

2) We developed an instant lifelog retrieval mechanism which fetches past logs to help the user in the present situation and proposed a location based lifelog sharing framework that allows sharing of lifelogs to those friends of a user, who may find them useful.

Our proposed methods to achieve privacy as well as retrieve and share lifelogs are effective in overcoming the current weak areas in pervasive logging. To achieve privacy from the passerbys' lifelog device, we used fixed radius of 100 meters for restricted location selected by the user. In future, we may adjust the radius according to the selected place, for example in case of a stadium or home, the radius of restricted area could be adjusted automatically. We may also perform the experiments of comparing our prototype device with Vicon Revue device for a longer period of time.

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