Supporting wellbeing through improving interactions and understanding in self-monitoring systems

Dana Pavela¹, Vic Callaghan²

¹School of Computer Science and Electronic Engineering, University of Essex
²Anind K. Dey

Abstract:
We use computing devices at work, at home and on the go. We generate huge amount of data that is stored (either temporarily or permanent) on our machines or on remote servers. There is a lot of value in this information and many external parties already further exploit some of it. So, if others consider our information important why don't we take proper advantage of it? How can we use the information we generate to our own advantage? How can we use this information to improve our lives and support our wellbeing? And how can we create better environments that will be able to offer more personalized and engaging interfaces supporting such diversity of information? We offer here our answer to such questions by presenting the MyRoR system with its main goals of better supporting self-understanding and offer more natural interfaces for information visualizations, based on personalized and interactive stories.

1. Introduction

Wellness and wellbeing are terms used more and more these days in various contexts but what do they actually mean? A quick Internet search will bring up various definitions, more or less vague. In most instances, wellness and wellbeing are associated to being healthy and happy, even though, as discussed in [1], in reality these states include subjective perceptions meaning that an ill person can have a sense of wellbeing while a healthy person might not have it. One of the most used definitions of wellness is given by Corbin et al. in [2]: a “multidimensional state of being, describing the existence of positive health in an individual as exemplified by quality of life and a sense of well-being”. In [3] wellness is described as having 7 components: physical, social, emotional, intellectual, spiritual, occupational and environmental. Other dimensions that can be added are financial, mental and medical [4].

¹ Corresponding Author.
As described in [1], wellness can be seen as a life goal, which includes self-responsibility and a daily process of making lifestyle decisions and dealing with various aspects covered by the components described above. That is why we also believe that lifestyle management via self-monitoring solutions should try to capture more than just certain components of our daily lives. Most of the existing systems focus on physical health recording and monitoring and pay little attention to other dimensions, even though, as specified in the World Health Organization (WHO)’s Constitution health should be seen as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity”.

Smart environments offer more information about what we do and why we do, than current self-monitoring solutions take into account. We argue that by using self-monitoring technologies that are able to create a more detailed and complex picture of our lives, we will be able to address the wellbeing at a holistic level and not only by looking at various separate aspects.

There is a significant body of proof that show that lifestyle monitoring and increased self-awareness bring multiple benefits to patients as well as healthcare systems [8]. As will be discussed in Section 2, there are now multiple solutions for monitoring patients with certain conditions, as well as an increased number of applications that can be used by anybody willing to monitor certain aspects of their daily lives. Lifestyle choices play an essential role in chronic diseases onset and evolution. Self monitoring systems can help people better identify the risk factors, manage their conditions, and decide on making changes.

In this article we argue for the extension of lifestyle monitoring systems to include more varied information in order to capture multiple aspects of our lives and improve self understanding. We also discuss the challenges presented by dealing with different types of information, especially in terms of modelling and visualization. As a case study, we introduce our system approach and we discuss its design and implementation together with a user experiment.

2. Background and motivation

Lifestyle choices affect our lives in multiple ways but the most evident is their role in chronic diseases. Chronic diseases is a generic name for various health conditions that, once acquired cannot be cured but just managed. According to World Health Organization (WHO), chronic diseases are the leading cause of illness and death in the world [5] posing a huge financial and emotional burden on patients and their support networks. Some of the most common chronic diseases are coronary heart disease (CHD), cancer, renal disease, diabetes and mental health. In 2005 in UK there were more than 17.5 million people living with at least one chronic condition and it is estimated that by 2030 the incidence of chronic disease in the over 65s will more than double [6]. Many people are diagnosed with more than one chronic disease and sometimes one condition becomes a risk factor for another one. One important aspect is that chronic diseases are not only a problem of elderly, as people from various age groups are now affected, a situation mainly caused by changes in our lifestyles. Certain lifestyle-related factors, such as smoking, alcohol, physical inactivity, diet (irregular meals, salty or fatty foods) and psychosocial stress, have a huge impact on chronic diseases, which also means that they have become the main targets for preventive healthcare programs [5][7]. Prevention plays an important role both in
avoiding acquiring a disease, as well as for avoiding worsening of an existing condition. Lifestyle management support can have a huge impact as most of the patients living with chronic diseases fall into the low risk category, which means that, with the right support, they can learn how to manage their disease [6].

Various programs for inducing and supporting preventive behaviours have been implemented using media, such as printed material, TV and radio campaigns or through healthcare providers offering advice to patients, e.g., on what to eat in order to avoid cholesterol or how to avoid living a sedentary life. The advances in wearable monitoring systems allow for an increased offering in solutions that can record, store (either locally or remotely), and analyze patient data. Using such systems for outpatient monitoring benefits both healthcare systems and patients, as patients can live normal lives and avoid hospitalization. The importance of empowering both patients and medical staff with more objective information obtained through outpatient self monitoring systems is emphasized in recent reports such as [8]. The same report also documents a continuous shift in attitudes both of patients and medical staff towards using such technologies, especially as they become more unobtrusive and as their benefits (both social and economical) are better understood. A large number of the 1000 people interviewed in [8] (in UK, ages from 16+) were already using various means for self diagnosis (60%) and a significant number of people (over 60%) are interested in monitoring their own health, particularly for various parameters such as cholesterol and blood pressure.

Using wearable systems for outpatient monitoring accrues multiple benefits, for all sides involved. More information on studies using such systems (including benefits) can be found in [36], a report published by the Department of Health in UK in 2005-2006.

2.1. Lifestyle management and self-monitoring technologies

The increased availability of wearable and unobtrusive sensing devices, either based on specialized systems or on widely available mobile devices such as smart phones, has made it possible to create more sophisticated self-monitoring systems both for clinical and lifestyle scenarios. In this section we intend to take a look at some commercially available self-monitoring systems, the types of users they intend to support and describe how they usually work. Based on existing systems, we identified that they belong to two major health categories: physical and mental health.

2.1.1 Physical health

2.1.1.1. Movement (physical activity, fall detection, energy expenditure)

Systems that measure movement can have both medical and lifestyle applications. GPS and 3-axis accelerometers integrated into wristwatches, pedometers, pendants and smartphones are used both for measuring how much and how fast a person moves and for detecting falls. Some of the most popular fitness-related devices are produced by Garmin, Polar and they usually include a heart monitor that allows for keeping track of the effort level.

Products such as WristCare (from Vivago) [9] and SenseWear BMS [10] allow for creating movement activity profiles for a certain user and then detecting and signalling abnormal patterns. The WristCare also integrates skin temperature and skin
conductivity sensors and it uses a few initial days to learn what is “normal” for the user and send alarms when the values change.

For more assistive scenarios, fall detection systems such as Philips’ LifeLine [11] and Wellcore Emergency Response System [12] allow for monitoring as well as alerting in emergency situations. Usually, such solutions include various options to determine who and how to alert in emergencies. These systems mainly work only in home scenarios, as they connect through the main phone lines.

As phone applications become more and more popular and smartphones now include sensors such as GPS and accelerometer, various applications for fitness as well as assistance have started to appear (e.g., iFall for Android [13], Sports Tracker for Symbian [14], or Nike+iPod [15]).

2.1.1.2. Heart rate/blood pressure monitoring

Given that heart-related conditions top the list of chronic diseases a large selection of systems exist for recording and monitoring of such data. Data usually recorded is blood pressure, heart rate, pulse, heart rate variability and ECG. The data recording can be done at certain times or continuously, by using certain heart monitoring devices, most of them provided through hospitals or primary healthcare providers.

Examples of heart monitoring systems are: t+ blood pressure (OBS Medical) [16], Medixine’s Chronic Disease Clinic [18], HealthBuddy (from Bosch Healthcare) [17], and CardioNet solutions. For most of the existing solutions data is stored on a remote server and analyzed by nurses, doctors, clinicians, etc. Patients might be able to add certain notes, symptoms, and so on, and receive certain feedback from medical staff.

Certain sensing devices such as the Alive Heart and Activity Monitor [20] also provide finer granularity data through ECG recording and it can be connected to other recording devices through Bluetooth.

2.1.1.3. Food/calories intake/weight management

Solutions for recording food and calories intake can range from manual to fully automated. In the manual mode, the user has to record what she ate during the day and how many calories it contained.

There are now several applications that can keep track of what and when you eat by taking photos with the mobile (7).

The HealthBuddy system [17] provides a middle solution where the user is prompted to use a compatible scale that can send information to the hub through Bluetooth. The device also includes an interactive and supportive questionnaire that helps users record more information about their eating patterns.

While more automated scenarios can be imagined, where food and caloric intake can be automatically recorded through using RFIDs and web services, no such systems seem to exist yet (9).

2.1.1.4. Diabetes support

In such systems patients usually record blood glucose measurements, timestamps as well as information related to administering insulin. In most of the systems, the measurement, recording and insulin delivery is done by the patient manually. Some of these solutions are Medixine’s Chronic Disease Clinic [18], t+ diabetes from OBS
Medical [16] and HealthBuddy [17] that provide support in various ways and combine recording with visualizing and medical support.

However, new systems have recently appeared where certain or all steps of the process have been automated. For example, the MiniMed from Medtronic [21] now can use under skin sensors for automated and continuous glucose monitoring and an automated insulin pump. Less invasively, the Calisto GlucoBand [22] wristwatch can use bio-electromagnetic resonance to measure and monitor blood glucose levels.

2.1.2. Asthma and COPD (Chronic Obstructive Pulmonary Disease)

While some symptoms might be similar, asthma is more common in patients under 35 years old while COPD is mainly induced by smoking and environmental pollutants and is more common in patients over 35. As both asthma and COPD involve problems with the air flow, the main parameter monitored by systems addressing them is the peak flow information. Other parameters monitored for COPD patients are the forced expiratory volume in one second (FEV) and the blood oxygenation levels (SpO2). Usually, these parameters can be manually recorded by the patients in an electronic diary, together with certain observed symptoms. Data is stored on a server where medical staff can examine it and give feedback to the patient (e.g., t+ asthma and t+ COPD solutions from OBS Medical [16]). An interesting system is Medixine’s Health Forecasting [23] focused mainly for preventing weather related crisis, by sending alerts based on weather forecast, as there are observed correlations between certain weather conditions and an increase of asthma and COPD-related hospital admissions.

2.2. Mental health

Even though mental health is extremely important and a large number of people will suffer from a diagnosable mental condition at some point in life [37], this area remains poorly addressed by self-monitoring technological systems. Systems such as HealthBuddy [39] provide a certain support for depression patients, by using an interactive questionnaire and prompting for a periodic recording of blood pressure. Most of the self-monitoring methods for depression focus on keeping manual mood diaries.

2.2.1. Memory support

Various systems exist for helping patients with memory problems keep track of their medication. Most of the systems allow patients or their carers to pre-program alarms for times when certain pills should be taken. Some of them also store pills and include sensor that record when box has been opened, such as the Daily Alarmed PillBox from PivoTell [28]. Some systems can even communicate with a mobile phone if the pill box has not been opened at the scheduled time, such as the SIMpill [29].

Various research projects have also used camera-based systems, such as SenseCam, for supporting patients with more advanced memory problems [1].

2.2.2. Relaxation systems

Stress is part of our lives and various methods exist to address it, most of them based on various relaxation techniques. Biofeedback systems offer technological support for such processes. The systems we looked at employ various sensors and
methods. The main sensors used are for measuring GSR (skin conductivity), heart rate, heart rate variability, and EEG (electrical brain activity).

Various visualizations and interaction methods are employed to allow for controlling the measured parameters. For example, certain systems use game-based interfaces which users can control functionalities in the games through controlling their physiological parameters (e.g., Journey to Wild Divine [30] and products from SmartBrain Technologies [31]). Other systems use sounds, lights or charts for allowing users to become aware of their stress levels as well as enable their control (e.g., GSR2 Biofeedback Relaxation System [32], StressEraser [33], Resperate [34], enWave PSR [35]).

2.3. Trends

Many of the existing health monitoring system providers chose to create integrated health hub devices that allow for recording more than one parameter and even include small screens that can be used for various types of communicating with a patient. Most of the health hubs available combine two or more of the physiological parameters mentioned above. For example, the HealthBuddy [17] can integrate data received through various compatibles devices: e.g., digital scales, blood pressure monitors, digital blood glucose level readers, etc., and it has a display used for asking questions, prompting for values or tasks, giving encouragements and advices.

Similar systems are provided by Viterion Telehealthcare (Viterion 100, Viterion 200) [24] and TeleMedCare, whose TMC Home [25] collects information from various devices as well as use questionnaires to gather more information from users. Its health hub also has video capabilities to facilitate communication between the patient and the monitoring medical staff. Tunstall Lifeline provides various solutions for telecare and telehealth addressing conditions such as COPD, CHF (Chronic Heart Failure), CDM (Chronic Disease Management), diabetes and coagulation issues, by allowing it to integrate multiple sensors with their hub [26].

Another type of integrated system is sensor vests. Vivometrics and Xenetec were producing such systems but they seem to have gone away, so it’s not clear how popular such systems proved to be.

Given the pervasiveness of mobile phones, it is natural that integrated systems based on them started to appear: MobiHealth [27] provides such a system that is based on an Android phone and connects sensors that can measure multi-lead ECG and EMG, plethysmogram, pulse rate, oxygen saturation, respiration and core/skin temperature.

Most of the available solutions focus on recording and monitoring physiological parameters. The market is extremely segmented and based on proprietary devices and formats. There is however a certain drive to create interoperable solutions, such as the Continua Health Alliance [39]. In most cases user data is sent to remote servers to be stored and analyzed by nurses or clinicians.

There are very few systems that support users in understanding why something happens. Correlations between data recorded and things that might have triggered certain changes are based mostly based on recollections, subjective and prone to various memory errors. In most cases, patients can monitor certain physiological data but have no idea what context the data was collected in and what might have affected their readings.
The self-monitoring systems are mainly targeted at patients with existing health conditions and focus mainly on prevention of worsening conditions or detecting emergency situations. Systems are mainly provided by hospitals.

3. Towards an integrated lifestyle management system

3.1. Our approach

Through our work we seek to go beyond just recording certain physiological parameters and actually support people in better understanding of what happened and why it happened. In this, we do intend to build on existing sensing systems but collect additional information that will allow people to correlate physiological data with daily events. Data we produce through using various computing devices is important because it creates a picture about what we like, what we do, who we interact with and where we go.

Our vision is that the number of self-monitoring and self-understanding systems used and owned by individuals will continue to grow, driven by an increased availability of sensors and sensor-based applications as well as by the higher degree of acceptance towards digitally recording life experiences that can be observed in younger generations [38]. Though the current trend seems to be that more and more “cloud” services collect user-related information either for adapting functionalities or delivering customized information, our aim is to design and build systems that can make use of our information but also allows us to control what, where and why is stored, as well be aware of what it is used for. We use computing devices at work, at home and on-the-go. We generate huge amount of data that is stored (either temporarily or permanent) on our machines or on remote servers. There is a lot of value in this information and some of it is already further exploited by various external parties for various purposes such as improving recommendations. So, if others consider our information important why don’t we take proper advantage of it? How can we use the information we generate to our own advantage? How can we use this information to improve our lives?

We are not making the case here for a Big Brother type of society. Our vision is more about empowering end users rather than giving the power to collect and correlate our data to “cloud” entities. Our goal is to support individuals and other users in understanding the influence our daily activities over our health. For this, we set out to collect, interpret, correlate and visualize information that can make people aware of their health, where health is seen as a complex picture that includes physical, mental, emotional and social aspects.

We believe that a lifestyle management system should be able to create a holistic, if not comprehensive picture, of a user’s daily experiences. As we showed in the previous section there are currently multiple systems that address various aspects of users’ health. However, what we believe is missing, is a system that helps users better understand what the relation is between the monitored parameters and what is going on in their lives. We will discuss certain aspects of such system along 3 main information flow areas: gathering, processing and visualization.
3.2. Main scenario

Mary is 53 and she has developed a heart problem. She can still live her life normally but her doctor advised her to take it slow and pay more attention to her lifestyle. To make it easier, Mary is using the MyRoR system, which can record various activity data from her personal devices and correlate all information into a daily story view, so that she can see how certain activities performed during the day impact her physiological state, especially her heart condition. The system helps her remember what happened during the day and allows her to record her own thoughts regarding the events as well as her reactions. For example, the other evening Mary tried to figure out why she felt unusually tired. By using the MyRoR system, she could see that she had lots of meetings and skipped lunch. One meeting was especially demanding, as her colleague George kept interrupting her presentation, as usual, which annoyed her. The system not only helps her to better understand her own behavior, but also allows her to access some of the information when she talks to her doctor so together they could identify potential risk factors.

3.3. System requirements

Here are the main requirements for the system we envisioned and are currently implementing.

• Minimize the amount of sensors a user has to wear;
• Tap into available information that can describe certain aspects of user’s daily activities;
• Build upon existing monitoring systems by integrating and correlating their data
  o There are now multiple systems available addressing various aspects. It is unrealistic to think that they will go away so a better approach is to make it possible to incorporate their data. This might not always be possible, as one way to differentiate is to create proprietary formats, but it seems to be that most of these systems can export data in certain widely used formats, such as XML. Certain ongoing efforts towards interoperability between medical devices such as Continua Health Alliance [39], give us some hope that in the future integrating various monitoring devices might get easier;
• Work based on realistic scenarios, where monitoring systems cannot provide a comprehensive picture of users. It would be impossible and probably also very intrusive to try to record all our daily activities, so it is better to assume that self – monitoring systems will have to function based on incomplete information;
• Reasoning engines should not replace users and medical professionals. Even though self-diagnosis through Internet search seems to become more and more popular [8], it is not something that we aim for at least not to the extent that it replaces human interactions. Allow people to become part of the information gathering and interpretation. Such system should support users in understanding not present them with ready-made conclusions;
• Create better interfaces and interaction paradigms. This is one of the biggest challenges, as the more and diverse information we add to the system the harder it becomes to visualize it in a comprehensive way. Current systems do not posses appropriate visualization means, as they mainly focus on time-based charts or
map-based representations. So, how do we make these systems more comprehensive, interactive and engaging?

3.4. MyRoR system design

Figure 1 presents a multi-agent view of our system along the main components of the information lifecycle: information gathering, processing and presentation.

The **Data Gathering Agent** is responsible for collecting data from various input sources. Such sources can include various devices used by the user during the day (e.g., work machine, home machine, mobile phone, etc.) as well as external content servers providing user-related data, such as emails and calendar events and other information that can be used to better identify certain related factors, such as weather, financial news, etc. The data collection can be done both asynchronously and in real time, according to the intended scenario. We have so far mainly focused on the asynchronous mode, as we are more interested in providing support for user reflective behaviors. Throughout this chapter we will consider this type of information gathering.

The **Data Transformation Agent** performs various operations on input data available in differing formats and in multiple local storages, such as: data conversion (e.g., from bytes to values), data categorization, filtering, storing into a user database, including its optimization (for time and space), and Database Model management. The **Database Model** containing information about the database structure governs the storage operations. Unlike many existing lifestyle management systems described above that collect and send data to remote servers, we focus on creating a user-controlled information storage that would better address privacy concerns as well as fit the single user centric view of the current system. Ongoing work in the PAL project looks into implementing various levels of access to such storage, depending on the situation and scope.

Once data is collected into the central database it is processed by the **Information Agent** through various specialized modules. Various types of information processing take place, such as **filtering** in order to discard useless or faulty information, and
interpretation of existing information and aggregation of two or more types of data in order to create higher-level concepts, as well as correlation of two or more types of data according to certain interesting features derived through data analysis. The initial data, the newly created information and the rules for information transformation are contained in the Information Model.

As discussed before, capturing such a diverse and large amount of information allows for creating a better picture of what has happened and why but also brings in big challenges in term of presenting such information to the user. For various reasons discussed later, we have decided to use a combination of stories and advanced chart-based visualizations for conveying recorded information to the user. The Presentation Agent has the role of assembling information into a user-friendly format, according to the Story Model.

The User Interface Agent is responsible for creating various information visualizations. Since the system is envisioned as being highly interactive, the User Interface Agent and Interaction Agent need to work together in order to:

- allow the user to see and manage what is being collected;
- allow the user to query for specific information;
- allow the user to add new information as either annotations to existing data or new data altogether;
- allow the user to customize the user interface to better reflect their personality;
- take into account certain device capabilities, especially for scenarios that involve remote access to the system;

It is important to note that Figure 1 includes a larger scope than currently addressed in our implementation, as it also reflects other work currently done in the PAL project, such as incorporating privacy policies into all information-related transactions [40]. The Policy Agent is responsible for managing policies related to information usage, as well as various user preferences, and will become increasingly important once other information usages involving external parties are added to the system.

3.5. System implementation

In this section we describe the current implementation of our MyRoR system along the main information areas mentioned before.

3.5.1. Information gathering

The decisions we made regarding the information collected and sources used were governed by the requirements described in section 3.2. Some of the most important criteria were that:

- collected information can provide useful support for self-understanding and reflective behaviours;
- system can deal with both static and mobile scenarios spanning various spaces and situations;
- system should include commonly used user devices such as PCs, laptops and mobile phones;

• system should include commercially available sensing devices;
• number of sensors should be limited both because of the amount of processing they required as well as to prevent creating systems that are too obtrusive or require too much time and effort to attach.

Figure 2 shows what input sources we have now and what information we are able to collect. The system can collect information from both physical (raw data) and logical sensors (interpreted data).

Here are more details about the main sources we are using:

• Garmin ForeRunner 305 is a popular wristwatch-like device used for fitness-related monitoring. The device is capable of providing heart rate and GPS-related information, as raw as well as interpreted (e.g., distance, speed, etc.). A chest belt monitor is used to provide heart rate information. Data is collected and stored on the device in Garmin’s own file format, TCX, an XML-based format using a specific Garmin XML Schema. The files are currently stored onto the user’s machine over a USB interface. Newer versions of such devices should be able to synchronize data with a computer automatically;

• Mobile phone (Symbian-based mainly such as Nokia N97 or Samsung Omnia HD) running NORS platform [41], a mobile Java-based sensing platform that implements various sensor handlers allowing data collection of phone data as well as from attached BT-enabled sensors. The NORS platform collects data in its own file format. The file can be stored on a PC either through Bluetooth or over GPRS;

• The Alive Heart and Activity Monitor is a small wearable sensing device developed by Alive Technologies [20]. The device can measure ECG through 2 skin electrodes as well as 3 axis accelerometer data. It also provides an event button that can be pressed by the user for various purposes, such as annotating
certain interesting moments, which can make it easier for the system to find meaningful events. The data is recorded on an internal SD card. It can also be collected via Bluetooth through the NORS platform on the mobile phone and also directly recorded on a desktop (e.g., for stationary scenarios when the user is as the computer);

• A PC activity platform that provides various types of information related to user’s activity context. Currently, the platform is Windows-based mainly for the sake of experimenting, but this is not to be considered a limitation of the system. We tested multiple existing activity platforms and decided to use the ActualSpy platform, because it can record data on the local machine in text as well as HTML format, and it allows for user awareness. The platform provides URLs visited (useful to determine web as well as search activity), applications used and associated events (i.e., application started, run, and closed), user name (helpful to differentiate between multiple users), keystrokes (can be used to search for certain keywords in order to determine interest as well as counted for activity intensity), as well as screenshots (timer-based images that can be used to create a comprehensive picture of currently used applications);

• External servers are used to provide certain user activity-related information, such as emails sent and received and calendar information. We currently have modules that collect emails from POP3 and IMAP servers as well as obtain various information from a user’s Google Calendar (assuming such calendar is used by the user, of course). These modules are used differently from the other data, as they can obtain information on-demand and such information is not necessarily stored in the database but used in understanding a user’s social context as well as activities and interest. Information obtained from such servers can be filtered based on time ranges and keywords.

Figure 3 shows a platform view of the information collection process. The Data Collection Platform component comprises of various modules collecting data from multiple distributed sources, over various technologies (e.g., Bluetooth-BT, USB, IP) and storing it into distributed data storages.
The input data can be stored onto sensing devices, sensing gateways (such as phones), personal computers or remote servers. The Data Gathering Agent needs to know where the input data resides, collect it and pass it to the Data Transformation Agent for processing and storing.

In building our data collection platform we came across various issues, some of them quite expected and often encountered when building life loggers. One of the main ones is scalability. Some of the data collected, especially from ECG and accelerometer, generate a large amount of information, as they are sampled many times a second (300 for ECG and 75 for accelerometer). Hence, the following data volumes were generated over an hour-long experiment: Alive monitor – 1500KB, mobile phone/NORS – 33KB (no GPS, no attached sensors), PC platform – 20KB (no screenshots). The Alive Heart Monitor stores its data in a binary format but once the values are converted to actual values, the database size increases significantly. Because of that, we optimize the database size by creating binary file repositories for ECG and accelerometer and only store pointers to these files into the relevant databases. Hence, raw data is preserved for further processing (e.g., heart rate determination based on ECG or activity context based on accelerometer data) and database size is substantially reduced. Writing to the database is a very time-consuming operation, especially for data sampled quite frequently. Hence, we use buffered writing operations in order to improve the data storing performance.

Another important issue is the existence of various formats and synching methods used by our data sources, which requires a considerable effort when building the data gathering modules. Standardization efforts in certain areas (such as the Continua Alliance in health world - http://www.continuaalliance.org/) should improve the situation but it still remains a major issue. Battery lifetime is also important. Although the Alive Heart Monitor can record for a few days before recharging is required, the Garmin device as well as the mobile phone needs a daily recharge when GPS is recorded.

Time correlation is also an issue when using multiple devices as their clocks can differ from a few seconds to a few minutes. Also, some devices can use time zones and others cannot. For example, the Garmin can only select Western Europe, which is not enough to differentiate between London and Brussels. The Alive Monitor cannot have any time zone, which makes it hard to set when travelling. Because of such issues, special care needs to be taken in keeping them synchronized.

In our data collection experiments, we have been focusing on a single user recording data in various situations such as at home, at work, or on the go. Our preliminary findings show that:

- it is unrealistic to assume that people would wear or even remember to switch on devices all the time (e.g., Garmin requires an explicit Start/Stop action);
- the incentive of using such system depends on how eventful the day is expected to be;
- attaching wearable electronics such as a heart monitor belt is still not comfortable enough to allow for permanent data collection;
3.5.2. Information processing

The Information Model captures both raw and processed information as well as relationships between them (i.e., how processed information has been obtained). A representation of the main objects included in the model is shown in Figure 4.

![Figure 4 Main entities in the Information Model](image)

The mind map model presented in Figure 4 is used to create the semantic model and the relationships between the entities.

An important phase in the modeling process is to identify which features should be extracted from the available information. Figure 5 shows what information can be derived based on available initial data and how initial and derived information are combined to create the various types of user context. The contexts we consider are:

- **physical context**: both absolute and relative and at various granularity levels.
obtained from various types of sensors - GPS, cell information, country code, wifi-based

- **social context**: includes information about who is around or social communication
  - obtained from sensors - discovery of people through BT - or social communication from emails, calendar, chat programs

- **emotional context**: includes information about user’s emotional state
  - obtained from physiological sensors, such as ECG and heart rate monitor, and through virtual sensors, such as keyword-based filtering of registered keystrokes, email content, etc.

- **mental context**: user’s interest both as topic and as intensity
  - derived through web activity, applications used, keyword-based filtering of keystrokes, screenshots

- **activity context**: what was the user doing
  - derived from physical sensors, such as accelerometer data and GPS, as well as from applications used, calendar information

- **availability context**: if a person or a device is available
  - the availability of devices is determined through Bluetooth vicinity, battery level, signal coverage (if device is a mobile phone);
  - the availability of people can be determined through identifying people around, through checking calendar information. Furthermore, other types of context information (e.g., mental, activity) can be used for determining if a person should be interrupted or not.

- **environmental context**: includes information about the environment that can have an effect on the user, such as noise or temperature or lighting.
An appropriate balance has to be found between having too much abstraction and allowing transparency. Allowing end user access to certain unprocessed or lightly processed data can also generate abstractions that a system designer might not have considered or could not even consider due to incomplete information. For example, with all the advances in emotion recognition, it is still hard to determine with certitude what the user feels, especially when considering real world settings (as opposed to controlled research laboratory experiments), as described by Picard et al. in [42]. For example, in our initial scenario, the system can realize that Mary’s heart rate increased, her voice pitch raised and deduct that she was getting angry. However, Mary’s status could also be a reaction to an increase in room temperature or to being in a crowded environment rather than anger. Her emotional state might also be influenced by other hidden parameters, current or historical, such as previous experiences related to people present, etc. In such situations it is better to show the user through the interface that something unusual happened at a certain moment during the day (e.g., based on her heart rate and voice pitch changes) and let her deduct what exactly happened and why,
by allowing access to other collected information (e.g., who else was there, what else happened around the same time, etc.).

3.5.3. Information presentation and usage

Our exploration of interactive information systems and natural ways of presenting life experiences led us to stories as a means of relating information to humans. Stories offer a way of organizing information as collections of meaningful events brought together either by following a timeline or a certain topic or character, as described by Brooks in [44]. Through our space search we found that there has not been too much work in this specific area, as the related work either focuses on computer assisted storytelling [44] or on creating stories based on image annotations. An inspiration for creating fun and interactive environments based on collected context data is the Affective Diary project [54], where the focus was on creating better visualizations for self-monitoring systems.

In our system, we plan to explore this type of information presentation from simple to more complex structures enabled by a modeling process that takes information from the Information Model and arranges it into a story-based representation, according to the Story Model (see Figure 6).

The main elements of a story, as described in Figure 6 are:
Characters or actors: the entities that take part in the story, being them humans or other living beings. The characters have various roles and are connected by certain relationships.

Storyline: this is the plot of the story and it is formed by a sequence of meaningful events. An event can be described in terms of the context types defined above and the “meaningfulness” of an event can be determined through observing certain changes in contexts.

Setting of the story: includes important elements that create the setting of a story or of an event, such as time and place.

Theme of the story: places a certain emphasis on one or more types of contexts. For example, it focuses the story more on physical movements or on emotional changes, etc.

Point of view: it determines how the story should be told. For example, we are currently mainly considering the case when the system creates a story as a diary, where the main user (the one the data refers to) is also the main consumer. However, in the future, we would also like to look at cases where the story can be customized by its main user to be shown to other people.

The story creation is done by the Presentation Agent, working together with the Information Agent in order to determine what events are meaningful as well as use recorded context information to fill in the other elements of the story. An example of a meaningful event is given in our scenario: Mary’s meeting, her presentation and her increased heart rate. In this event, Mary is the main character with the other meeting participants being secondary characters. Through zoom-in functionalities, Mary has access to all information recorded during the meeting. She can also add her own annotations to the story (e.g., explain why she thinks she felt so stressed during the meeting). The annotations become part of the story and will be available to her when she reflects on the information in the future. This makes the story evolve in a subjective, human way, as feelings and explanations can change based on remembering things in a different way.

After considering multiple environments and libraries such as Alice, Scratch, Greenfoot, Perfuse and Piccolo, we have decided to use Scratch [46] as well as Google Visualizations [48] to develop various ways of creating and representing stories.

Scratch is a Squeak-based environment created as a way of making programming fun for kids. It has been developed by the Lifelong Kindergarten group at MIT Media Lab. Scratch provides an easy way to create rich media stories, where images, sounds and animations can easily convey the sense of change within a sequence of events. Figure 7 provides an overview of the main elements used in Scratch to create stories.

Scratch allows users to add and customize images, record voice annotations, add audio, create movements, change appearances of characters (which can be used to convey a sense of mood and activity changing), and change backgrounds (can be used to show environmental and physical changes). Time can also be conveyed in Scratch in various ways, such as using a sequence of clock images (see Figure 8) or by using an animated time line. Each character or object (called sprites) used in creating a Scratch story can be individually customized and controlled.
Scratch allows for more personalized and visually entertaining representations of daily lives while Google Visualizations allow for presenting correlated information in a more detailed way.

The visualizations are embedded into a diary-like interface built within a Wordpress environment [1]. We created a PHP script that parses the database where the data is stored and for each day that contains data it creates a post saying what type of data is available. That way, the user can easily see what days have available data, access visualizations, add new media as well as easily add annotations.
4. Case study

To better exemplify the type of system we envision and the challenges we have encountered, we are presenting here a user experiment that collected various types of user information over a few hours. In this scenario, the user is a PhD student having a board meeting and the experiment follows the user through the hours before the meeting, during the meeting and after the meeting. The table below shows what kind of data the system recorded during the experiment. The data was recorded over a few hours, during which the user kept moving from home to university, around the campus and then back home.

<table>
<thead>
<tr>
<th>Input source</th>
<th>Input data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alive monitor</td>
<td>ECG, 3 axis accelerometer, event button</td>
</tr>
<tr>
<td>Phone (with NORS)</td>
<td>Audio amplitude, Bluetooth devices around, GPS, cell ID, battery information</td>
</tr>
<tr>
<td>PC activity platform</td>
<td>Web activity, applications used, keystrokes</td>
</tr>
</tbody>
</table>

The diversity of information collected makes it quite hard to create correlated visualizations, as the current means and tools mainly offer charts and map-based representations. We have considered and used various libraries, such as Prefuse, Piccolo or PHPGraphLib. Eventually, we have decided to use the excellent collection of Javascript-based library based through Google Visualization API.

In order to create an environment that is familiar, portable and based on available and commonly-used technologies, we are using WordPress to create a blog-like interface for our system. The Wordpress interface is integrated with our MySQL backend database and we have created various PHP and Javascript programs that access, interpret and visualize collected data.
Every time the user accessed the home page of the system, a widget PHP script runs to check if new data is available in the database. If data is available for a certain day then the script creates posts that allow the user to access the data, various interpreted visualizations of the data, including the story created based on the data. In the current version of the interface individual posts are created for each source (see Figure 9). However, we are currently using this version to organize and have access to collected data as well as test various visualizations and interpretations. Future versions might have a different interface.

The problem with data that is so diverse is that it is quite hard to represent it all on the same graph. This is due to sampling differences (as data is not usually sampled at the same intervals) but also format issues, as number data fits in various ranges and string data is hard to represent. In certain cases we have managed to combine numbers and text by using annotations and labels, as in graphs a, d and e from Figure 10, which represents the number of BT devices discovered around the user as well as the name of the devices.

![Graphs a, b, c, d, e, f showing various visualizations of data](image_url)
The challenges met when combining and showing such data in a compressed and user-friendly format were the main driver for us to think of alternative means. In order to create stories we have decided to use Scratch as it gives us a lot of freedom to personalize interfaces and combine various types of media.

We have recently started using BYOB (http://byob.berkeley.edu/), which contains certain extensions to Scratch while keeping the same main interface and concepts. The main reason we are using this environment is because it allows lists of lists. Lists are collections of elements, much like arrays. You can see in Figure 11 how this feature is used.

The story is creating through running various parallel scripts that test for certain keywords and then determine the behaviours of the various sprites we have and the selection of the background. The user has a lot of freedom to decide what colours, sprites, and backgrounds to choose. In our example, the Home location is shown as a background of user’s house. The same with the university location. Driving activity is shown change of background but it can also be shown by using a car. Time is shown through various clocks but it can also be shown as a digital display or a running time bar. The meeting is shown through a sprite (Figure 11). The user has the option to
select her own representation and it can customize its colour to reflect the emotional context: in this case the user decided to choose green for energetic (during driving) and red for excited (during the PhD board). Having such freedom to map emotional states to colours removes the issues around personal interpretations of colours.

Figure 12 Two screenshots for two events: driving and having a meeting at the university.

The blog interface allows us to group various types of visualizations and media together, so that the user has access both to higher-level representations, such as stories, and to more detailed one, such as graphs, tables, maps and word clouds. Another major advantage is that users can add their own notes and thoughts, which could be reflections based on visualizations as well as other blog entries. Using the calendar as an entry point follows our thinking of creating daily stories and makes it easy to show which days have available data, as based on our experience, the data collection happens quite sparsely and it is usually motivated by the expectation that something a bit more unusual will happen during that day.

The blog can also be accessed from mobile devices (e.g., by using Wordpress apps on Android and iPod/iPhone), which makes it easy to access notes and visualizations as well as add new ones while on-the-go. More importantly, the whole environment can run within user’s own environment. We are currently using XAMPP which contains Apache server and a MySQL database and also allows external exposure for cases when user data needs to be accessed remotely.

5. Conclusions and future work

In this chapter we have focused on what we see as necessary improvements to existing lifestyle management self-monitoring systems in order to make them more informative and interactive. In the process, we’ve looked at various existing systems and we believe that what is missing in most such systems is a focus on supporting users reflect and understand why something has happened. For that, we need to not only focus on physiological and location data but also on other types of context data that can offer a better picture into what our activities and interests were at a certain point in time. However, recording such varied data also involves multiple challenges in terms of data collection, processing and visualization. We have tried to address some of these challenges through the system we presented above. When building our system we have considered existing user experiments and results with similar solutions and tried to create something that we would use.
We are also developing a user evaluation framework that will enable us to determine what kind of data as well as what type of visualizations would be more useful in supporting reflective behaviors.

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