Leveraging Smart Monitoring and Home Security Technology for Assisted Living Support

A Vision for the Future

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Abstract— **In recent years there has been a rapidly increasing intensity of work going into investigating various methods of facilitating assisted living for the benefit of the elderly and those with difficulties in mobility. The paper describes one such effort which distinguishes itself from the rest by considering and describing a system with true commercial potential and thus significant social impact. Promising efforts in investigating and identifying the requirements for a system of smart monitoring and adaptive lifestyle pattern detection and analysis are described. An initial proposal for a system relying on remote monitoring using persistent communications technology and a centralized data gathering, analysis and decision making is presented and a prototype developed in facilitating initial investigations is described. Finally the vision for further developments in the near future is discussed.** (*Abstract*)

Keywords—assisted living; pattern recognition; remote sensors; communications protocols; simulation; rule-based inference (key words)

I. INTRODUCTION

Advancements in technology has significantly changed the way we think and act. Banking, travel, science, education and health are some of the areas that have seen huge improvements as a result of recent innovations in technology. This is especially true in the case of the health services. Leveraging modern computing power, communications technology and advancements in software developments for the benefit of those who suffer disabilities and health problems and are in need of regular supervision and personal caring has become essential for providing the best support in the context of affordable, enhanced and caring social services. This support is aimed at providing two main benefits: enhancing independent living of the individuals affected and making significant savings in the cost of support to individuals provided by the social services and the local authorities.

It is undeniable that humans naturally prefer independent living but with advancing age or disabilities this becomes risky when living alone. Elderly or people with disabilities often end up living in sheltered housing where nursing and care facilities are available at a price. Many products are available in the market to enrich the lives of people with disabilities and elderly to enjoy the freedom of independent living but unfortunately these systems do not always reduce the risk of injuries or mishaps; as many as 30%-40% of community dwelling older people fall each year and this is the most serious and frequent accident in the home and accounts for 50% of hospital admissions in the over 65 age group. According to the World Bank the 2011 population of United Kingdom was over 62 million [1]. The number of people aged sixty and over in United Kingdom is projected to increase from 12 million (20% of the population in 2001) to 18.6 million in 2031 (estimated 30% of population) [2]. This is likely to impose increasing pressure on the resources of the social services and the local authorities to provide efficient and cost effective carer services for a significant percentage of the needy of the population especially during the current and the predicted future bleak economic climate in which the voices calling for more stringent austerity measures are likely to become louder.

It is in this climate that universities as well as commercial companies, often in collaboration, have turned to technology and are looking to devising systems that will help empower the aged and the disabled by enhancing their levels of independence and at the same time help reduce the cost of providing care services to individuals. The rapidly increasing pervasiveness of computer systems and communications devices readily lends itself to the fulfilment of this vision. It is therefore natural that any future systems devised will heavily rely on the successful marriage of these two core technologies.

For a successful and productive system that is likely to make any impact in social context it makes sense for university computer departments to work in collaboration with the industry. This has two benefits: the university department provides research expertise and expertise in different specialist areas such as advanced software engineering, project management, wireless and mobile communications protocols, embedded systems, interface design and physical computing; the industry in turn provides expertise in communications hardware, hardware system design and development, testing and project management.

It is in this setting that we at the Department of Computing got together with a local high-tech commercial security systems company Securecom Ltd. based in Rochdale, UK. Securecom design and develop specialist remote monitoring

systems for the security industry and work closely with local authorities to provide secure housing for the large number of local authority tenants. The collaborative work is on the initial definition of the requirements for and the subsequent development of a scalable assisted living support system based on the extensive experiences of Securecom on remote monitoring and the application of this to software based adaptive lifestyle pattern recognition technology. The requirements have resulted in a number of challenges for us to face and find solutions for. We elaborate on these challenges later on.

II. REMOTE 'SMART' MONITORING FOR ASSISTED-LIVING

Fig 1 depicts the general setup for remote home monitoring system designed to provide assisted-living support. Sensors placed in a property are used to track the various aspects of the monitored persons' daily activities. The sensor data are gathered by the transmitter installed in the property that is responsible for sending the sensor data to a central station via a permanent Internet connection available in the same property. This transmitter also functions as a security alarm panel protecting the occupants from hazards like intrusion or fire.
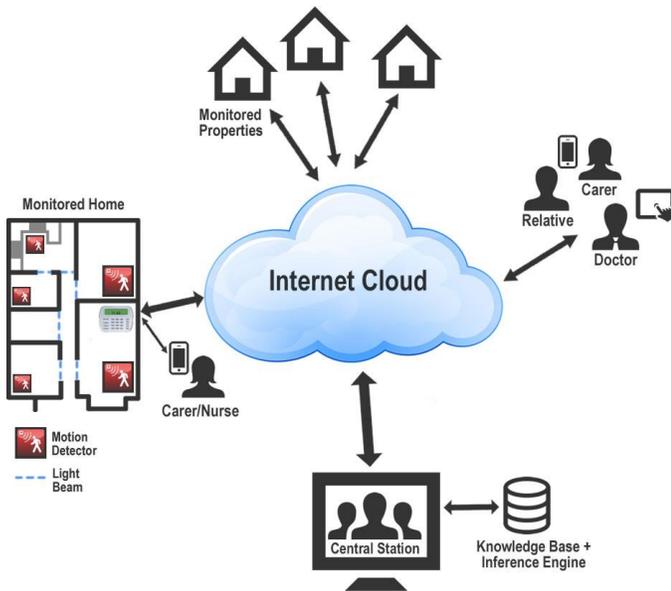

Fig. 1. Outline of remote 'smart' monitoring system

The central station constantly monitors and evaluates the incoming sensor and security alarm data and stores the information in a customer database while at the same time analysing the sensor data in order to detect any anomalies in persons' daily activities and life-style patterns; on detection of such anomalies the central station can alert the nominated person(s). The system is highly scalable and is designed to handle monitoring many properties.

The information gathered can be presented in many different forms that can represent a 'picture' of a person's life-style and highlight any significant anomalies or deviations from the 'norm'. It can also identify any gradual subtle changes in behavioural patterns that may be indicative of possible onset of illness, e.g. loss of weight (if measured), increasing visits to toilet, increasing instability in movements, etc. This information can then be made available to interested relatives, carers and doctors via their mobile equipment such as mobile phones and tablet computers.

III. RELATED WORK

Research in assisted living has been an area of rapidly increasing interest involving both the academics and the health industry for some time now under various names such as Ambient Assisted Living (AAL), Tele-Health Systems, Smart Home Environments, E-Health Services, etc. and covers a very wide area generally involving assistance to enhance the quality of life of elderly and the disabled. The common theme is based on the acknowledgement of the power of modern computing and communications technologies that can drive and facilitate these systems and schemes. The published number of research is too numerous to include here. However, we can classify the work done under some general groups that distinguish their contributions:

- Sensor networks and activity detection devices: The research work in this group describe sensor networks, sensor devices, use of Internet for sensor data transmissions, wireless sensors and devices that can be remotely controlled for robotic assistance [3, 4, 5].

- Pattern recognition and analysis: Behavioural pattern recognition is an area that is attracting much attention. Advancements in ways of analysing patterns of daily activities are central to assisted living support [6, 7].

- Complete monitoring systems: These are systems that include sensor networks, communications methods and pattern recognition algorithms and form total systems for wide range of assisted living support [8-11].

Most of the work carried out has been theoretical and experimental with several systems proposed and frameworks developed. However, to our knowledge, there has not been any significant system developed and demonstrated at a commercial level and scale. Therefore we claim in this paper that what sets our work apart from most of the others is that our work has primarily been driven by the desire to realise the results of our research in commercial settings.

IV. THE CHALLENGES

Our research work was prompted by a need for a new comprehensive and tightly integrated technology within security industry involving 'intelligent' remote monitoring for assisted living support. The challenges faced are multifaceted:

- Collection of multitude of data using a wide range of remote sensors.

- Transmission of sensor data to a remote central station

- Storage, analysis and visual presentation of the collected sensor data.

- Determination and prediction of state-of-health using 'intelligent' inference engine.

We investigated each of the above challenges through preliminary test cases which involved software prototyping and

simulations of sensor data collection, transmission and analysis. Below we consider our initial responses to each of the above challenges.

A. Collection of multitude of data using a wide range of remote sensors

In order to be able to provide support for assisted living regular collection of data on location is a necessity. The challenge in this case is to determine what sensor data to gather, what the optimal placements of the sensors are and how frequently the sensor data should be gathered. In order to be able to investigate this challenge a unique software simulator was designed and developed. This simulator served three purposes: a) to investigate sensor requirements and placements, b) to assist in the development of new transmission protocols and c) to serve as a test data generator for the analysis software based at a central monitoring station. With this simulator the investigators can define the floor plan of a property, select from a range of sensors, place the sensors, capture and animate the movements of person(s) being monitored and generate the corresponding sensor data. The generated data are captured and used as off-line test data for the analysis software.

B. Transmission of sensor data to a remote central station

The challenges here are a) the economy of the format of sensor data packets, i.e. the minimum content required that can be efficiently (in terms of frequency, priority and size) transmitted and stored and b) the storage of data by a local data-logger and transmitter. The sensor data is sent wirelessly across the property to the data logging device which will transmit blocks of sensor data to the central monitoring station at suitable intervals. The transmission method is persistent and will rely on the transmitter's ability to use any one of the progressively lower quality transmission routes: Internet using TCP/IP connection, GPRS, telephone line using DTMF signalling and SMS text messaging.

C. Storage, analysis and visual presentation of the collected sensor data

The sensor data received at the remote central station will be stored in the most suitable and efficient manner which should enhance the accuracy and speed up the analysis phase. The central station should be able to receive and store sensor data from many remote locations often at the same time. The main challenges here are a) formatting of sensor data which may be stored in compressed form, b) the real-time analysis of sensor data and c) the presentation of the results of the analysis. The digital receivers at central stations will be capable of communicating with many remote digital transmitters using proprietary protocol, which will be independent of the chosen transmission route. This protocol will rely on high-level handshaking and error detection/correction methods for maximum reliability. The biggest challenge is the analysis phase. The project proposed and investigated the use of 'Adaptive Life-style Pattern Recognition and Analysis' (ALsPRA) process as the linchpin of the project and the system being investigated. The life-style pattern of a person being monitored is developed over a period of time and is central to the detection of any significant or trending deviations from a baseline, i.e. the most recent 'norm'. As the sensor data accumulated can be very large the analysis establishes a progressive or most recent baseline at regular intervals. Any decisions rely on the baseline and the most recent data received thus making near real-time analysis attainable. The analysis relies on an 'intelligent' inference engine which is described in a later section. The next challenge is the presentation of monitored data on-demand and on detection of an exception. It is envisaged that such data may be useful for monitoring by different interested parties: nominated relative(s), carer(s), personal doctor and monitoring station staff who will have direct access to nominated contact(s). Such information can also be made available on hand-held remote devices such as mobile telephones and electronic tablets.

D. Determination and prediction of state-of-health using 'intelligent' inference engine

This part of the investigation looks into the future. It is expected that ALsPRA method will have the potential for short-term predictive capability. This is most appropriate in the case of health and behavioural monitoring. Any deviation from norm over certain period of time may be indicative of impending health problem(s) which if treated on time may save lives or improve quality of life. Such predictions may also be used to help plan financial and material requirements by the local authorities and by those who will be called upon to care for the ailing person(s) well in advance. The ALsPRA method is being developed with this aspect in mind.

V. SIMULATING ASSISTED-LIVING

In order to be able to study the requirements for sensor selection and placements as well as the requirements for the essential communications parameters such as higher level protocols, data formats and frequency of transmissions we designed and implemented a simulator with two-dimensional graphical interface. Fig. 2 shows the main screen of the simulator. Using the colour-coded design objects floor plan of a property can be interactively defined. This allows the placement of the walls and the internal doors guided by the grids. Different rooms are identified and furniture such as the chairs and the beds are also positioned. Next various sensors are placed in selected locations within the property. For example, there are sensors for detecting entry and exit through the doors using light beams or pressure pads at doorways; there are sensors that can sense pressure placed in beds, in chairs and on toilet seats. Each sensor is designated a unique identity number which is used to identify the type of the sensor. The person who is assisted is identified as a colour-coded solid circle and can move within available spaces along the grids simulating day-to-day activities of occupants of the property. As the person enters and exits rooms, climbs into and out of the bed and occupies and vacates the toilet seat relevant sensor data are generated and displayed at bottom right of the screen.

The simulated movements of the person being monitored can be manually captured as a series of scenarios in a library of activity scenarios. Various sequences of activities can then be constructed from this library and played back at selectable speeds. This method can be used to generate a large series of sensor data in a relatively short period of time reflecting a person's life-style al be it in a much accelerated manner thus simulating a time period that represents a much longer time in

reality. Fig. 3 shows the screen used to capture and play back the scenarios.
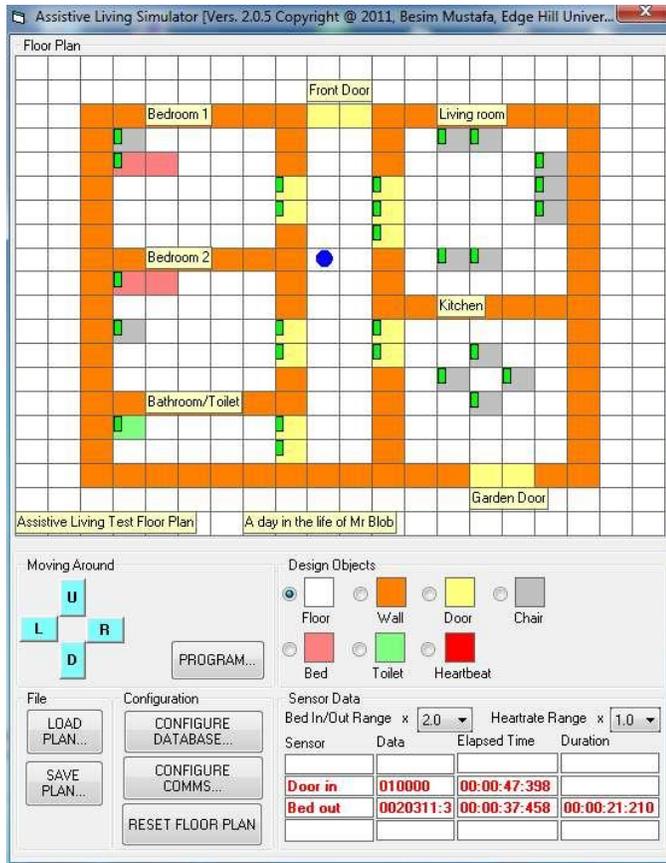

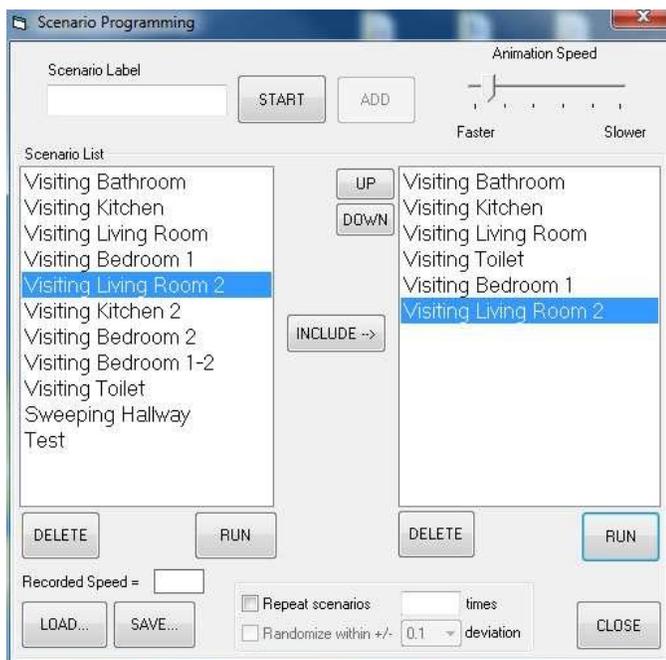Fig. 2.   Main simulator window

Fig. 3.   Life-style scenario capture and playback screen

The simulator enables investigation of the various aspects of sensor data generation. These are

- Definition of sensor data formats

- Specification of sensor data transmission protocol (size of data packets, frequency of transmissions, handshaking, etc.)

- Determination of optimum frequency of sensor data generation

The simulator can also be used to generate test data for life-style pattern recognition and analysis engine without having to physically install sensors in a property or in a laboratory environment thus enabling parallel and independent development of the monitoring and communications systems on the one hand and the analysis software on the other.

A. Definition of sensor data formats

Each sensor data gathered will be formatted in such a way that it conveys all the essential information to the analysis software in the most economical manner as potentially large number of sensor data can be generated in a relatively short period of time. We investigated properties of sensor data and the following represent some of the essential components of sensor data

- Sensor id: used to identify individual sensors.

- Time stamp(s): can be multiple time stamps, e.g. bed-in time and bed-out time or toilet-in time and toilet-out time.

- Priority indicator: determines the urgency of sensor data, e.g. fall detected or raised blood pressure, etc.

The sensor id and time-stamps are needed in order to be able to track the matching activities of the individual sensors. For example, a sensor can be responsible for detecting the person going to bed and the same sensor detecting the person coming out of the bed. These sensor data can be used to determine three important pieces of information: the fact that the person went to bed (presumably for sleeping), the time the person spent in bed, the fact that the person came out of the bed (presumably woken up from sleep). From these several inferences can be made: if the person sleeps; if the person sleeps long enough; if the person is able to come out of bed. Still further inferences can be made from this information such as the person is or is not sleeping, or the person is or is not sleeping well or the person is unable or unwilling to come out of bed which in turn can be further connected to the ambient temperature of the bedroom or to the count of visits to the kitchen and the toilet; it may be that an elderly person is unable to come out of bed due to lack of heating in the bedroom or it may be that the person is possibly too weak to climb out of the bed and walk. The sensor data can be used to determine the frequency of activities such as how often a person visits the toilet or the kitchen that can be used to infer any potential health problems (i.e. not eating well or regularly or changing toilet habit indicated).

The sensor data priority is required to determine if the sensor data needs to be immediately transmitted to the central

monitoring station or that it can be delayed in order to minimise communications traffic when several sensor data can be collectively transmitted at pre-determined intervals as a block. For example, if an elderly or a disabled person has fallen the data sent by the accelerometer sensor needs to be urgently transmitted so that help can be provided for the fallen person as fast as possible; the vibrations detected in a child's cot by a sensor due to an epileptic episode needs to be acted upon as soon as possible. On the other hand sensor data on going to bed and coming out of bed do not need to be sent immediately but can be stored for later transmission. The priority is implied by the type of sensor as identified by its id or channel number and is facilitated by a look-up table maintained for this purpose.

B. Specification of sensor data transmission protocol

One of the aims of this investigation has been about identifying any new supporting features that are needed to be designed into Securecom's new breed of advanced commercial digital transmitters in order to provide efficient support for the assisted living system we are proposing. These advanced transmitters are designed specifically for remote monitoring of properties for security purposes. As a result of our collaborative work we have been able to identify and specify an extension to the existing protocol used for providing assisted living support at an early stage of product development. We describe the digital transmitter further later on.

The transmission protocol the digital transmitter uses is based on the standard used by the security industry. In order to be more flexible Securecom decided to define and use an extended proprietary version which is not publicly made available. Due to non-disclosure agreement we are unable to reveal this information in detail. However, it suffices to say that the basic elements include a means of identifying the property, the identification of the alarm trigger condition(s) and the device status. Depending on the mode of transmission each data transmitted may require acknowledgement along the same path of connection, e.g. acknowledgement packets on Internet connection (TCP/IP) or audio frequency signalling on land-line and mobile audio (GSM) connections.

C. Determination of optimum frequency of sensor data generation

Monitoring persons' life styles in terms of their daily activities will require handling of a potentially relatively large number of sensor data and the number generated in a single day can be in hundreds in the case of an active person. The sensor data generated can provide three types of information: 1) frequency of activities, 2) times of activities and 3) durations of activities. These can be used to make inferences such as that an activity is taking place (e.g. moving, sleeping, eating, going to toilet, etc.), that an activity is taking place at expected or during normal times (e.g. having breakfast in the morning, taking the pill in the morning, going to toilet at night, etc.) and that an activity is taking as long as expected or normal (e.g. sleeping around six hours, spending no more than ten minutes in the toilet, staying in kitchen for at least half an hour, etc.). The words expected and normal are used in relative sense and can be interpreted differently for different people; what is

expected and what is normal will be established on a per person basis after a period of monitoring.

The challenge here is the determination of the number of activities to monitor and how often to monitor. It is quite possible that not all activities will be necessary to monitor and monitoring only the targeted activities that reflect a person's particular nature of disability or age will be meaningful. Nevertheless monitoring of the daily activities of thousands of individuals can put a large demand on the communications devices and networks. The system we have been using has been designed primarily to remotely monitor properties for security but is also able to function as an assisted living support system by leveraging its remote monitoring capability and different persistent modes of communications. This is facilitated by the following new features in the design of the new digital transmitter:

- New communications interface using TCP/IP

- Extension of the communications protocol

- Changes in the firmware

- Changes in the central monitoring station software

Each of the above features is briefly considered further below.

1) Communications interface using TCP/IP: The availability of permanent Internet connection makes it possible to send sensor data and receive acknowledgements with relative ease and at any time of the day which are necessary requirements for assisted-living support.

2) Communications protocol: The current protocol is designed to handle security alarm conditions. It will need modification and possibly extensions in order to deal with the additional sensor data using the same framework as the existing one as it will still need to handle the normal property security related alarms as well.

3) Firmware: In order to be able to implement the features in 1 and 2 above the digital transmitter's firmware will need extensions too; it will need to handle the new protocol over TCP/IP and at the same time be able to buffer the non-urgent sensor data prior to trasmission at some pre-determined intervals and on demand.

4) Central monitoring station software: The sensor data are sent to the central station software. This software will need to process the security alarm data as well as the sensor data. The sensor data will also be further analysed in order to develop lifestyle patterns for the monitored individuals based on their daily activities. It will then be responsible for presenting the processed information in suitable visual formats.

VI. SENSORS, SENSORS AND BIOMETRICS

The proposed system relies on activity sensors in order to be able to gather information on persons' life styles. The sensors are used to obtain three types of information: that an event has taken place, frequency with which it takes place and whenever relevant the duration between the matching events

(e.g. in and out, on and off, etc.). For example, we need to know if a person goes to bed, i.e. goes to sleep, and when the person leaves the bed, i.e. wakes up, and how long the person spends in bed, presumably sleeping; a fall detection sensor needs to detect the event and this can be used to determine how often it takes place over time but the duration of the event is not necessarily relevant in this case. Therefore it is important that the correct sensor technology is used and that the sensors are optimally positioned and configured.

The system proposed can be configured to use any number of sensors although this will be restricted in reality to a few relevant and strategically placed sensors. The sensors used can be off-the-shelf and relatively inexpensive devices. However, for practical reasons we propose to use sensors with wireless capabilities. For this reason the digital transmitter we use is able to handle wireless sensors as we are adopting a system that already accepts wireless detection devices for security alarms, e.g. fire, intrusion, etc. Table I lists types of typical sensors that can be used in order to help establish persons' life style patterns over time. The table includes information on types of data the sensors can provide and whether the frequency and durations of data are relevant or not.

The sensor triggers will be detected by the digital transmitter using the standard wireless communications protocol. This is likely to be similar to or same as the ZigBee communications protocol offering low power requirements, good range, low price and low susceptibility to interference [15]. Fig 4 shows the relative position of ZigBee standard against similar wireless standards in terms of power consumption, complexity and cost with respect to their data rates; although ZigBee has the lowest data rate (20 to 250 Kbps) this is nevertheless more than adequate for short bursts of sensor data transmissions. It is decided to use the lower frequency band of 868 MHz for sensor transmissions. This band offers better penetration characteristics through brick walls as most of the older properties tend to be brick built inside. This frequency band is restricted to a single channel necessitating the transmission of sensor id numbers; each sensor is given a unique id number for this purpose. The id will then be transmitted to the local digital transmitter/data logger. The low priority events will be logged by the transmitter in its buffer in 5-byte blocks of information: 7- bit sensor id, 1-bit sequence number and 4-byte time stamp. This format will allow a maximum of 128 sensors; the sequence bit will be used

to identify two-state matching events from the same sensor (e.g. in and out, on and off, etc.) and time stamp will be used to indicate the time of occurrence of the event. If the event is of high priority then this will be immediately transmitted to the central monitoring station in the same format as above without being buffered first. The buffer size will be determined by the frequency with which the buffered data will be transmitted and can be configurable depending on the circumstances of the monitored subject.

Although the sensors in Table I are capable of providing data from which current and to a certain extent future state of health can be indirectly inferred they are nevertheless not able to directly provide biometric data that can be further relied upon for real-time supportive evidence of state of health. For example blood-pressure sensor data can be used in conjunction with the data from accelerometer sensor in order to reasonably conclude that a fainting episode is a strong possibility and together with the spatial and the temporal information gathered over time the subject's future state of health can be projected; data from pulse rate sensor, data from blood-pressure sensor, data from accelerometer sensor and a microphone can be combined to infer a possible onset of a stroke demanding immediate attention and more aggressive follow-up monitoring. One of the uses of biometric information is that it can be used to authenticate the monitored subjects through 'liveness' detection [12, 13].

By taking full advantage of biometric data capture, both authentication and medical data can be captured and correlated within a system in a secure environment [14]. Table II shows some of the most popular biometric devices and their potential data capture types that are applicable within assisted technology systems. Some of these biometric devices could in turn be combined with the common sensors listed in Table I. For example pressure pads could be combined to gather gait biometric data and temperature sensors combining with fingerprint/vein scans to detect fevers and associated illnesses; use of the 'magic carpet' is another convenient and unobtrusive method of obtaining biometric data such as steady deterioration or change in walking habits or changes and improvements in a person's gait [17]. Within the assisted living concept using devices that are robust and accepted by the public is most appropriate, thus fingerprint, retina/iris, facial recognition devices would be the most popular and the most trusted [12].

TABLE I.   ATTRIBUTES OF SOME COMMON SENSORS.

| Sensor	Priority	Placement	Information	Duration	Frequency
Motion detector	Low	Rooms, other spaces in property	Motion, paths of movements	Not relevant	Not relevant
Pressure pad	Low	Doorways, beds, chairs, toilet seats	In and out of rooms, on and off chairs and toilet seats, in and out of beds	May be relevant	May be relevant
Light beam	Low	Doorways (may require two to detect direction)	In and out of rooms or property	May be relevant	May be relevant
Accelerometer	High	Worn on person	Orientation, degree of instability in movements	Not relevant	Relevant
Thermometer	Low	Rooms, outside the property	Temperature (above or below threshold)	Not relevant	May be relevant
Panic button	High	Worn on person, next to bed	Alarm	Not relevant	May be relevant
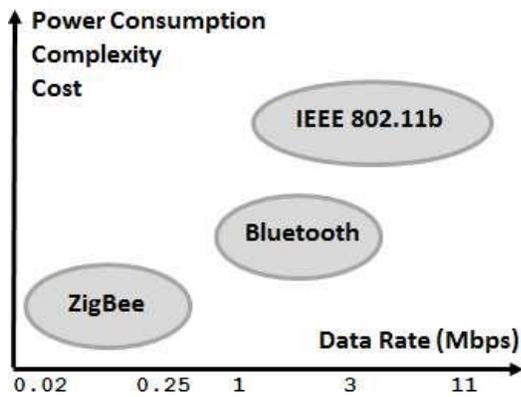
Fig. 4. Short-range wireless standards [15].

TABLE II. SOME COMMON BIOMETRIC DEVICES

Biometric Device	Health Indicators
Retina	Eye related implants: cataracts, diabetic retinopathy, retinal atrophy, etc.
Fingerprint	Temperature, pulse, blood pressure, etc.
EEG	Brain functioning illness: epilepsy, dementia, etc.
Facial Recognition	Thermal imagery, fever, etc.
Gait	Mobility, fitness, etc.

As with all system implementations involving persons and health data the security concern is always present, and biometric devices are no exception. There are a number of biometric security concerns that must be addressed, especially if the systems are going to contain data about vulnerable users such as those our system is designed for the benefit of. We are closely allaying with the research work of one of the authors of this paper on the definition of a security related framework on biometrics which we believe our work can benefit from. There are various security related issues that need tackling; use of encryption is particularly useful in resolving few of these issues.

We envisage primarily two ways of collecting biometric data: 1) automatically using wearable biometric devices and sensors, 2) by a visiting nurse or a carer using mobile devices. The former requires that the monitored person is semi-permanently connected to biometric devices such as blood pressure and pulse rate monitors; the latter is carried out by a nurse or a carer during regular visits who manually enters the data in the mobile device they carry which then gets transmitted to the local digital transmitter at the end of the visit. The former can be cumbersome, less convenient and may not be accepted but data is instantly available and less prone to erroneous values. The latter is more practical and convenient but data is not instantly available and may be erroneously recorded. Which method is adopted is likely to be dependent on the circumstances and the resources available.

VII. DIGITAL TRANSMITTER AND DATA LOGGER

The digital transmitter we have been working with belongs to a new range of transmitters designed by Securecom specifically for remote monitoring of properties for security

purposes. At its heart is the processing power based on a 32-bit power-efficient ARM Cortex-M4 core technology. These microcontrollers are popular high-performance choice in low-power constrained and cost-sensitive signal processing devices offering Ethernet connectivity.

The digital transmitter is designed to be located at the property to be monitored. It is actually integrated into the alarm panel and is responsible for transmitting alarm data whenever an alarm condition such as intrusion, fire or panic button is triggered. Each property is identified by a site code which is also transmitted to a central monitoring station capable of monitoring hundreds of properties fitted with the same transmitter. Fig 5 shows the general components of the digital transmitter. The alarm sensors communicate with the transmitter using a wireless protocol on 868 MHz band using a single channel and employs a contention based protocol where if a sensor needs to send data it establishes a connection with the transmitter and all other sensors are prevented from transmitting their data while this connection is present. The transmitter acknowledges all sensor data. Once the current connection is removed, the transmitter polls all other sensors for data. When no more sensor data is available both the transmitter and the sensors go into sleep mode. This method affords low duty cycle for the sensors thus minimising their power requirement.
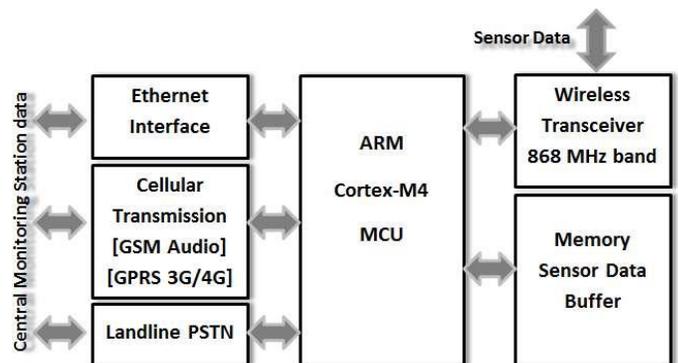

Fig. 5. Digital transmitter block diagram

The alarm data is normally transmitted to the central monitoring station immediately using a proprietary format conveying enough information for the central station to act upon in consultation with the user data stored in a customer database. The transmission uses a persistent mode of establishing connection depending on how it is configured. This mode has a sequence of priorities for establishing the transmission path and in order of preference these are: TCP/IP connection via Ethernet interface, GPRS connection via 3G/4G mobile data services, GSM audio with DTMF signalling and finally SMS. In all but the SMS method acknowledgments are possible.

The digital transmitter is capable of supporting enhanced system integrity and reliability using three main methods: 1) embedded MCU watchdog mechanism, 2) application level error detection and correction, and 3) periodic or on demand test signalling. The watchdog method is a standard mechanism for resetting MCU whenever it fails to respond to independent

watchdog commands. This method attempts to mitigate mainly obscure embedded software related problems. Test signalling can be done at two levels: central station sends test data to remote digital transmitter and expects an acknowledgement; the digital transmitter sends each remote sensor test data and expects acknowledgements. This can either be done regularly, say once a day or it can be done at times when sensor activity is deemed to be lower than expected.

Working in collaboration with Securecom we have experimented with leveraging the existing remote monitoring and communications capabilities of their digital transmitter in order to facilitate our requirements for assisted-living support. We have managed to use the data from our simulations in order to be able to identify additional requirements that can be integrated with the current design of the transmitter in its final stages of development. The following new provisions have been identified for this reason:

- Changes to the proprietary protocol to make allowance for the assisted-living mode of operation

- Changes to transmitter firmware to handle assisted-living protocol requirements

- Changes to transmitter firmware to implement sensor data buffering/logging and periodic transmission of this data

The assisted-living data is intended to use the TCP/IP connection only as this will mean permanent connection to the network and that all data sent to central station can be readily acknowledged. It is expected that Securecom will implement the above changes that needs to be done in conjunction with the development of the sensor data analysis and inference engine software described in the next section.

VIII.   LIFE-STYLE PATTERN RECOGNITION AND ANALYSIS

Large number of sensor data sent to central station needs to be stored, transformed, analysed and if necessary acted upon in order to effectively provide support for assisted-living mode of operation. As the total number of data received from many individual transmitters can be large the central station has to be a server capable of handling this traffic often concurrently.

The central station software is responsible for various activities that are required to support remote "smart" monitoring and responding on demand to the information it receives. This software is therefore required to offer a range of services; we identified the following essential services:

- Data capture

- Data storage

- Data transformation

- Data analysis

- Identification of exceptions

- Data presentation

The whole purpose of this setup is to provide assistance to persons who are too frail or who are experiencing difficulty with their daily mobility but nevertheless who wish to live their

lives, often alone, as independently as possible, i.e. with as little active intervention, medical or otherwise, or burden and interdependence on others (e.g. family, carers, etc.) as possible. However, there is still a need to keep an eye on such people to make sure they are adequately protected and that help is at hand on demand and on time if and when needed. It is therefore necessary that we are able to monitor their daily activities as unobtrusively as possible always respecting their privacy and pride (we do not envisage the use of remote cameras). One way of doing this is by collecting daily activity data from a range of remote sensors that we can use to develop evidence based and informed view or representation of their normal way of life while at the same time looking for any significant deviations from this, by inference or otherwise, that develops either in real-time or gradually over a period of time. We therefore opted for a rule based inference and decision making method of accumulating knowledge and analysing day-to-day living patterns of persons generated over a period of time. Fig 6 shows an outline of this method.
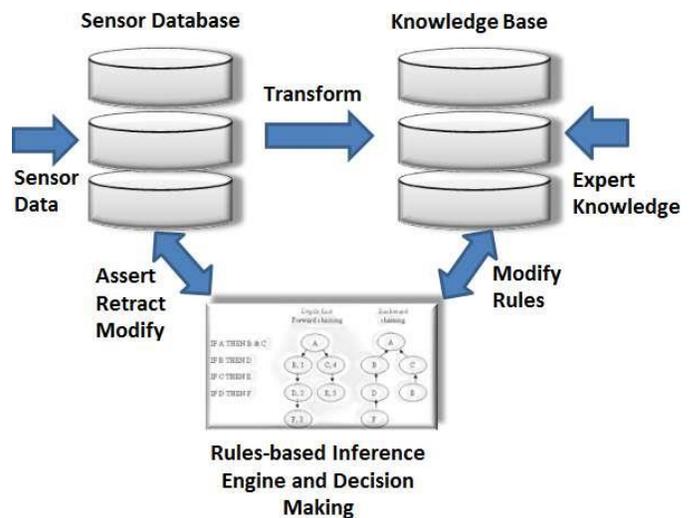

Fig. 6.   Adaptive Life-style Pattern Recognition and Analysis System

Sensor data are collected in the sensor database in a format that is more compact and amenable to efficient processing than the raw data received. The knowledge base contains sets of rules that are used to facilitate pattern recognition and determination of exception conditions and whether any action should be taken. Initially the basic rules are provided by the domain experts. However some of the sensor data gathered can be transformed into additional sets of rules thus enabling the knowledge base to adapt to the changing living conditions over time. The inference and decision making engine is fed from both the knowledge base and the sensor database. The results of the process of inferring can be fed back to the knowledge base in order to facilitate evolution of existing and adaptation of new rules over time. Similarly a path from the inference engine to the sensor database can be used to assert, retract or modify sensor data. For example, initially, during the learning period, a monitored aspect could be based on the assertion of the rule "for person X it is normal if he goes to bed and comes out of bed within 24 hours". As time passes this rule will adapt to reflect more precisely the reality and may gradually evolve into the new rule "for person X it is normal if he spends

between 5 and 8 hours in bed within 24 hours"; a similar rule for person Y may be based on a different set of personal facts. Therefore the knowledge base will accumulate expertise on life-styles of each of the monitored individuals by adaptively generating sets of rules that closely reflect their way of life.

As always the reality is not as simple as we would like it to be and there are several practical considerations we need to take into account when making inferences if our system is to be workable in practice. We look at three such areas:

- Multiple occupancy

- Accuracy of inferences

- Security of information

A. *Multiple occupancy*

The proposed system is optimised to work with single occupants in properties. This however presents a dilemma whenever there is more than a single person in the property. For example, an elderly occupant may be visited by relatives or by a carer; the occupant may have a dog for a company. We can identify and authenticate the monitored person or alternatively we can regard the visitors and pets as part of the monitored persons' way of life and hence also part of their life-style pattern. We opted for the latter for two reasons: 1) simpler, cheaper and easier to implement, 2) unusual visits and pet behaviours can also be indicative of exception conditions worth investigating.

B. *Accuracy of inferences*

In order to enhance the accuracy of decision making the inferences can be based on contextualised sets of actions that take into consideration temporal and spatial indicators. For example, the action of rapidly lowering into a chair needs to be distinguished from falling down. If this takes place in the bathroom or in the hall (as sensed by the motion detectors) this may be construed as a valid fall; if in the living room or bedroom and is followed by pressure sensors triggering then this may indicate actions of sitting in a chair or lying on a bed as opposed to falling down.

We are aware of the potential drawbacks of the proposed rules based inference engine [16]. However we have chosen it as it is relatively easy to implement and is well understood. The mechanisms for mitigating these drawbacks are available and are also well understood. We must emphasise that the system we are proposing is neither meant to be precise nor be able to offer detailed diagnosis of health problems. It will merely help identify and facilitate attracting attention to any unexplained deviations from normal daily activities be they significant or gradual but persistent.

C. *Security of information*

Security of information has two dimensions: 1) snooping and 2) falsifying. Security is particularly important when biometric data is being gathered. Both of these security concerns can be significantly minimised by encrypting both the sensor data received from the sensors and the data the digital transmitter sends to the central station.

IX. PROTOTYPING AND RESULTS

In order to test our ideas we resolved to implement a proof-of-concept prototype system. The sensor data was provided by both manual means and from the output of the assisted living simulation scenarios as explained before. We used the manual means in order to inject test cases that simulated abnormal data that deliberately and significantly deviated from norms; we used the simulator output to provide rapid succession of sensor data in order to speedily establish life-style norms. A TCP/IP connection was used in order to establish secure communications between the simulator and the simulated central station monitoring software. In the prototype system we did not implement an adaptive rules-based knowledge base; instead we used relatively simple algorithmic means of processing the sensor data. A web-based graphical user interface was also implemented to communicate with the user and to present sensor data; MySQL was used to create access and manage the sensor knowledge database.

Fig. 7 shows two views of the prototype user interface. The foreground view represents the logging screen for central station personnel as well as for the carers and the family members of the persons being monitored; the background view displays the colour-coded graphical representation of sensor data gathered from the daily activities of a person being monitored; normal data (green), data needing close watch (yellow) and data that needs to be acted upon urgently (red). The daily activity information is made available on daily, weekly and monthly bases in various graphical formats designed to enhance visual impact in the identification of possible exception conditions. This information will also be accessible via mobile devices that will present information in formats relevant and suitable to the type of users, e.g. doctor, carer or family member. The positive results from the prototype have been encouraging enough for us to carry on with our work; we are now seeking collaboration with our colleagues from the Faculty of Health.
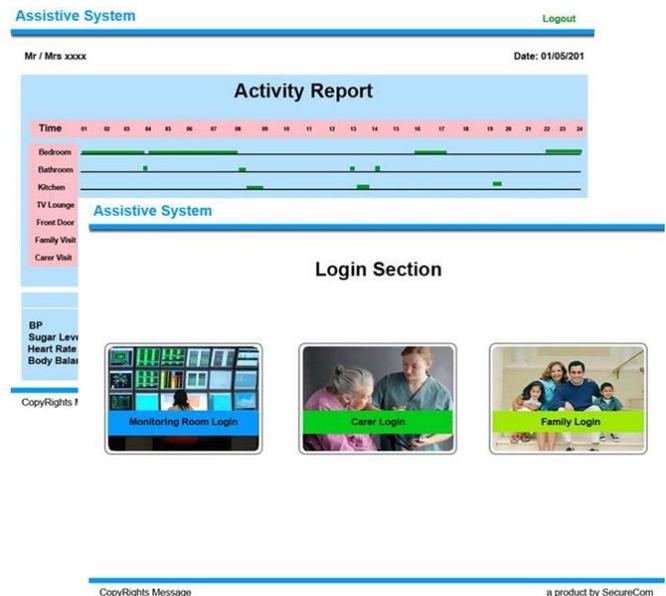

Fig. 7. Central station assisted living support interface

An important reason for developing the prototype was for Securecom to use it as a proof-of-concept to a large housing authority as a potential customer base with a vested interest in the technology. This demonstration was successful and suitably impressed the senior staff of this authority to such an extent that they expressed keen interest in further development work investigating predictive technology where the state of health of persons can be predicted into the future. This is seen to be desirable for facilitating efficient planning and funding of public services such as health care for elderly and disabled; at times of sweeping government cuts in spending on public services this technology is suddenly a welcome prospect.

The full implementation of the monitoring software will be integrated with Securecom's existing central station system normally used to handle monitored alarm incidents. Once this implementation is stable the next stage will be to install sensor devices in some selected properties in order to further evaluate and fine tune it over a period of time before commercially rolling it out. For a larger scale validation we intend to seek the assistance of housing authorities responsible for large numbers of care homes.

X. LOOKING INTO THE FUTURE

We continue working on the remotely monitored assisted living system described in this paper in collaboration with Securecom Ltd. and expect it to become a commercially viable product in the near future. There is still some work to complete especially in the development of efficient algorithms for life-style pattern recognition and algorithms for inference engine and decision-making that can monitor the daily activities and accurately assess significant deviations from what is regarded as norms as well as detect subtle trends of changes that can point to any future health related problems needing attention sooner than later. One other area we expect to concentrate on in the future is the ability to accurately predict any future health related problems of the monitored subjects. Firstly, local authorities can use the information of this kind in order to better plan and target for future support and funding requirements. Secondly, a more timely medical intervention may be administered potentially enhancing quality of life and life expectancy.

XI. CONCLUSIONS

In this paper we considered a wide spectrum of assisted living issues and technologies. We described our initial and promising investigations into the potential of leveraging smart remote monitoring using a range of sensors and home security technology using ubiquitous communications methods for the benefit of elderly and disabled who wish to maintain their independence and dignity as long as possible often living alone. We then went on further and proposed a scalable system that can recognise daily activities as life-style patterns for establishing norms over time and uses rule-based adaptive knowledge base method in order to detect any alarming deviations from these norms. Working with a commercial partner we aim to help realise the proposed system as a commercial concern thus fulfilling our purpose to support the aging populations. There are many productive and promising research activities in this area and we are hoping that our work will also be able to make a modest contribution.

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