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AN ENERGY EFFICIENT, MINIMALLY INTRUSIVE MULTI-SENSOR INTELLIGENT SYSTEM FOR HEALTH MONITORING OF ELDERLY PEOPLE

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Abstract- Most of the existing systems for elderly health monitoring deploy a large number of cognitive sensors including wearable sensors for physiological parameter measurement. Increasing number of sensors not only make the system power consuming and expensive but also intrusive in nature. However, there exists very limited research on power saving algorithms in such systems incorporating customer friendly features. In this paper, we report a modified health monitoring system which addresses both these issues. The central controller unit has an in-built algorithm based on two level adaptive branch prediction techniques to detect the period of inactivity of sensor nodes. Further, only one wearable heart rate sensor node is included in the system which measures the heart rate and detects abnormality. The central controller signals an alarm to the user to wear this predicting the sleeping time. This makes the system minimally intrusive and user friendly. Thus the multi-sensor network consists of motion sensor, current sensor and a wearable heart rate sensor along with a central controller unit. The prototype of the whole system has been installed in the house of elderly person and it has been observed that the time of prediction was close to the actual time for more than 90% of the days for a test period of one month. An average of 68% power saving has been achieved in the modified system.

Index terms : health monitoring, elderly people, multi-sensor system, power saving, minimally intrusive.

I. INTRODUCTION

In the world the population of the elderly people is in a steady rise, creating the need to increase the facilities for the care of the elderly. In our community, owing to changing social structure, many elderly people prefer to live alone. They do however require constant monitoring so that medical help can be provided immediately in the abnormal situation. It's true that by the help of advance technology, there is a better way for these people to resolve this problem, so that they can become independent, rather than being forced to live in an old age home. Considerable research efforts have been focused towards in-home monitoring of people [1], often using wireless personal area networks [2] and camera based infrastructure. Guillenet al. proposed a tele-homecare multimedia platform based on standard H.320 andH.323, and a standard TV set based on integrated services digital network (ISDN) and Internet protocol. The above-mentioned healthcare systems not only restrict the activity area of patients but also require that the patient or the elderly people have to enter their data which may not be a user friendly option for many elderly people [3]. Wireless local area networks have been deployed to enhance the freedom of patients [4]. In AID-N, a wearable wireless sensor node is attached to the patient's wrist. When there is an emergency issue, the node can form a 2-node ad-hoc wireless network with the first responder's portable tablet PC. The vital signs can be sensed and recorded into an electronic patient record database in the portable tablet PC and then transmitted to the medical center via CDMA based EvDO wireless technology [5]. Recently, iFIT system has been reported based on wireless wearable sensors which provide a platform for the elderly people to record and manage the assessment results and also to give personalized training [6]. But this may not be comfortable for elderly person. In [7], Talbar *et al.* proposed a WSN solution based on IEEE 802.15.4 and using multiple sensing and vision based event detection modalities to process elderly monitoring. There are some schemes which are reported as intermediate i.e. they take the help of both wearable sensor nodes and fixed sensor nodes attached to the different household objects [1]. However if the person forgets to wear the sensor nodes or move around in the house without using any equipments, then there will be no record of the activities. In some of the recently reported systems, technological assistance or monitoring of a person in the home is achieved using various types of sensors, which are centralized in structure and distributed around the house. These sensors capture the daily activities of the person and the collected data is communicated to a remote monitoring centre using conventional or wireless data transfer techniques [8]. In this system, the types of sensors used include motion sensors, inside door sensors, cabinet sensors, kitchen appliances sensors and any other sensor suitable for collecting and communicating data regarding activities ongoing in the home. Out of these, motion sensors have the advantage of monitoring the approximate location of the person even without wearable sensors or using the gadgets where fixed sensor nodes are placed. Thus the other type of sensors like the flex sensors, current sensors and flow sensors which also provide the similar behavioural information of the person related to the person mobility and location in the house may not be always required. Hence it is required to optimize the selection of the sensor nodes to reduce the redundancy which will help in minimizing cost and power. Selection of optimum number of sensors in such a wireless sensor network has been recently reported [9-15]. However, it has been observed from initial field testing results that some of the sensor nodes remain inactive for a sufficient period of time during which they may not be scanned by the central controller unit which can save power. Also, it is required to take emergency measure during the night. With this view point, we report a modified health monitoring system which addresses both these issues. Thus the major contributions of this paper may be summarized as follows:

(1) Power saving algorithm is incorporated in the central controller unit. At certain times of the day, the central controller unit will stop polling some of the sensor nodes which are expected to remain inactive. The proper time will be customer specific and hence will be decided by a prediction algorithm. owing to changing social structure, many elderly people prefer to live alone. During this time, the sensor nodes will disconnect the power supply from the sensors and the amplifiers and also put the transmitter in cyclic sleep mode.

(2) To check the health status during night, a wearable heart rate sensor in the wrist is included in the system. The timer in the controller unit sounds an alarm at the required time to remind the person for wearing this only during sleep. This makes the overall system minimally intrusive and more user-friendly.

II. SYSTEM DESCRIPTION

The overall system architecture is shown in Figure.1. It consists of the wireless sensor nodes-motion and current sensor nodes and a wearable heart rate sensor node. These nodes communicate with a central controller unit which stores data directly in USB storage. The motion sensors are placed either facing the doors or on the inner walls of important rooms like washroom, kitchen, bedroom and drawing room. They generate a pulse as soon as a movement of the person occurs within its field of view. The pulse remains on for a programmed time after which it turns off.

The current sensors are attached to important electrical appliances which are frequently used by the person like electric kettle, microwave oven, toaster, television set, radio and others. These nodes send a pulse to the central controller unit as soon as the appliances are switched on and remain active during the entire period of use. A wearable heart rate sensor node is kept in the bedroom. As soon as a person wears it and switches it on, it generates a pulse which remains on as long as it is worn. Along with that, it also generates pulses as soon as an abnormal condition occurs.

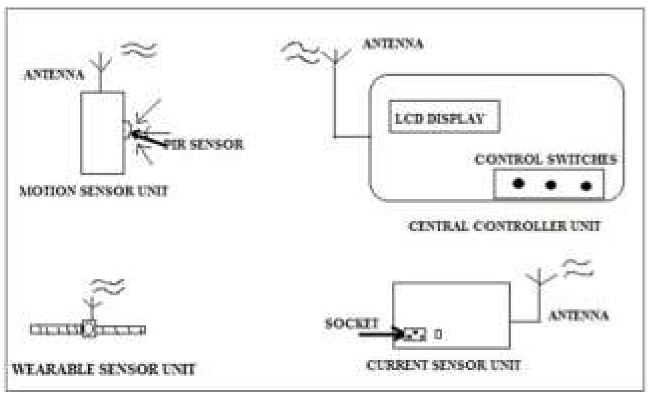

Figure1. Block diagram of the total monitoring system

a. Design and Fabrication of Motion Sensor node:

The motion sensor node has been designed using a passive infrared sensor (PIR) which detects motion by measuring changes in the infrared levels surrounded by emitting objects. The sensor has been procured from Parallax (#555-28027), similar to the report in [9]. The PIR Sensor has a range of approximately 20 feet. The motion can be detected by checking for a high signal on a single I/O pin. The signal is programmed to remain high for 5 seconds. This time is selected assuming that there will be no major changes during this time. It operates on 3.3V and consumes less than 100µA current. The output of the motion sensor is interfaced with ATMEGA8 microcontroller which is connected to a ZigBee transceiver.

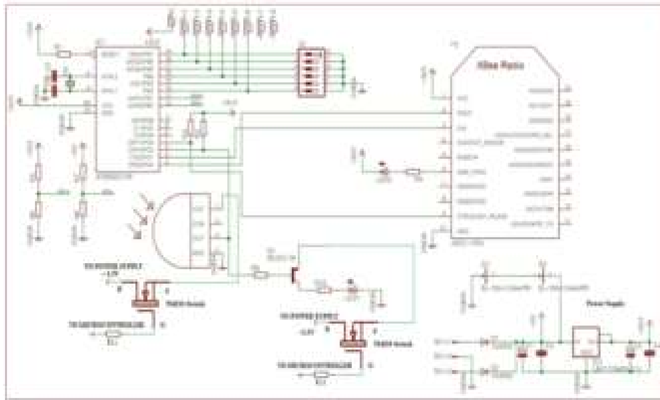

Figure 2. Schematic of Motion sensor node.

The ZigBee transceiver is normally configured in receive mode. On receiving a request from the central controller, it transmits the data. When the microcontroller senses that the central controller has stopped polling the node, the sensor and its associated circuitry is disconnected from the supply. Also, the transmitter is set to cyclic sleep mode when the central controller has stopped polling. In cyclic sleep mode, microcontroller wakes up for a few milliseconds to know whether the sleeping time has elapsed. Thus, for maximum time there will be only one chip alive, DS1307. But there is self-battery backup for DS1307. So we also configure micro-controller to cut down the power of DS1307, so that it also goes to power down mode. The circuit schematic and a picture of the installed system are shown in Figure 2 and Figure 3.

b. Design and Fabrication of Current Sensor node:

A current transformer is used for the detection of current flow in the supply line. The current transformer detects the flow of current in the phase line of the AC mains connected to an appliance and produces a voltage output. This voltage signal is then passed to a precision amplifier for amplifying to a required level. A comparator circuit generates a transition at its output when a particular appliance turns on. The generated transitions are fed to the port pins of the ATMEGA8 microcontroller, which are transmitted to the central controller. When the microcontroller senses that the central controller has stopped polling during the power saving mode, the transmitter is set to cyclic sleep mode as mentioned in Section ‘a’. The installation picture of the current sensor node is shown in Figure.4.

c. Wearable Heart Rate Sensor node:

To take care of any emergency that might occur during the night, a wearable heart rate sensor node is included in the system. It is placed in the bedroom and the central controller unit signals an alarm depending on a prediction algorithm which estimates the approximate time of the person to go to sleep. The alarm is sounded for 5 seconds every 10 minutes unless the person acknowledges it by pressing a switch on the central controller. Even after 5 such consecutive signaling, if the person does not acknowledge, the alarm stops. This makes the system user friendly and minimally intrusive since he or she does not have to wear it all the time and at the same time does not have to remind oneself. The system itself provides a reminder. The polar heart rate monitor is a sleek device which can be worn around the wrist. It has an inbuilt transmitter. A heart rate monitor interface is developed which receives the data from the device at intervals of 30 minutes. This is done to save power. The interfacing circuit works with an ATMEGA8 microcontroller and uses Bluetooth protocol for receiving the ECG data from the monitor. It then converts it into equivalent heart rate data. As soon as the interface starts receiving the data it sends pulses to the central controller using a Zigbee transceiver indicating that the heart rate sensor is on and person's health status as normal or abnormal. As long as the heart rate is within 60-75 beats per minute, it is normal, else it is recorded as abnormal situation. The polling of the node continues as per the estimated time from the prediction algorithm. The schematic of the heart rate sensor node is shown in Figure 5.

Figure 3. Picture of motion sensor node in the drawing room.

Figure 4. Current sensor node connected to a toaster in kitchen.

d. **Design and Fabrication of Central Controller Unit:**

The central controller unit has two major functions: to poll the sensor nodes and receive the data from the sensor nodes connected internally. At present, the internal communication has been established with a ZigBee transceiver in the frequency range of 2.4GHz. These modules use the IEEE 802.15.4 networking protocol for fast point-to-multipoint or peer-to-peer networking. They are designed for high-throughput applications requiring low latency and predictable communication timing. The algorithm will be discussed in Section IV. It is completely customizable and it can be configured depending on the situation. The user will have some option to configure it too by selecting the sensor ID and the location for a particular house. The picture of the unit is shown in Figure 6.

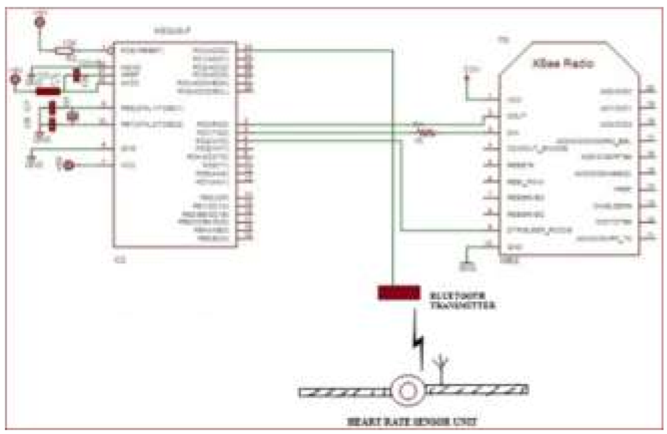

Figure 5. Schematic of wearable heart rate sensor.

Figure 6. Picture of central controller unit.

III. SOFTWARE DESIGN

a. Communication protocol:

The interface and control software has been written in Visual Basic. It allows the user to set the identification number of the sensor nodes along with the location in the house like kitchen, drawing room washroom and others as a look up table. This is customer specific and is carried out as a part of installation. The status of the sensor nodes is updated only when it changes state. The on state is recorded as 'ACTIVE' and off state as 'OFF'. This is done to enable the storage of daily activities up to six months for ten sensors. There is a built in memory to save the time of use of the sensor nodes along with their corresponding identification number, and location in a format similar to that reported in [8]. Further, a LCD display is interfaced with controller as observed in Figure 6 to ensure that the unit is working properly after installation in a customer's place. The whole unit can be interfaced with the RS-232 port to download the saved data. Once the data is downloaded, it gets erased to reuse the setup. Also the memory chip is non-volatile in nature so that if there is a power failure the data is not lost. The communication protocol is given below:

(1) The central receiver first sends data to air, which every sensor receives. Then there is some routine to check CRC (Cyclic round trip check). If it matches, then it is considered as valid data stream. After that, the particular sensor unit checks whether the address byte matches with its own. If so, then it will reply with its own address, status data, identification number data and CRC word. On the other hand central controller unit will wait for few seconds after it asks for data from a particular sensor unit and if it does not receive any data or any valid data, it will again ask for data for three consecutive times. After that it will consider that the particular sensor unit is malfunctioning or does not exist at all.

(2) There will be a five byte communication-first byte for address, second byte for the status of the sensor, third byte for identification number of sensor and fourth to fifth byte for CRC (16 Bit Cyclic Round trip Check). For the wearable heart rate sensor node, the first four bits of the second byte indicates the on or off state and the last four bits indicates the normal or abnormal condition.

b. Algorithm for prediction of inactive period:

There are certain times of the day when the person is resting for a prolonged period in the bedroom. During these times, it may be meaningful to stop polling the sensor nodes in the drawing room and the kitchen to save power is not a very frequent phenomenon and is expected to occur after a sequence of common activities. The two level adaptive branch prediction techniques [10] may be applied in this case for time prediction. The two level adaptive training scheme has two major data structures- the branch history register and the branch history pattern table The branches in our case are motion sensor and current sensor nodes in drawing room and kitchen. As the activities of the sensor node are recorded as ACTIVE or OFF, they are binary in nature. Further the long inactivity of certain sensor nodes for more than one hour. Thus the branch history register records the relevant activities of a particular day in the last 2 hours before a certain sensor node becomes inactive. When such activities are recorded for the entire learning period of 10 days a branch history pattern table is generated. To make the prediction, the earliest times of start of inactive period for the individual sensor nodes are recorded. For an unknown day, branch history register is constructed for the last 2 hours before the desired time.

The prediction for this new branch (Z_c) can be obtained as a function of the pattern history bits (S_c) already entered by equation1:

$$Z_c = \lambda (S_c) \tag{1}$$

Where, λ is the prediction decision function. If the inactive period prediction is 'YES' then this history register gets saved else the branch history register is updated by advancing the time by 15 minutes. The decision is made by a finite state machine approach**.** First, it is checked whether the contents of the history register for the unknown day matches any of the existing records in the pattern table. If so, the inactive period prediction is complete else certain important bits are checked.

c. Algorithm for signalling alarm:

To make the system minimally intrusive, a provision is incorporated to signal an alarm so that the person wears the heart rate sensor before going to sleep. As soon as the person is about to go to sleep or certain time before going to bed at night, the alarm is signaled. The prediction decision algorithm is slightly different from that required in Section b. The overall flow chart combining both the algorithms is given in Figure 7.

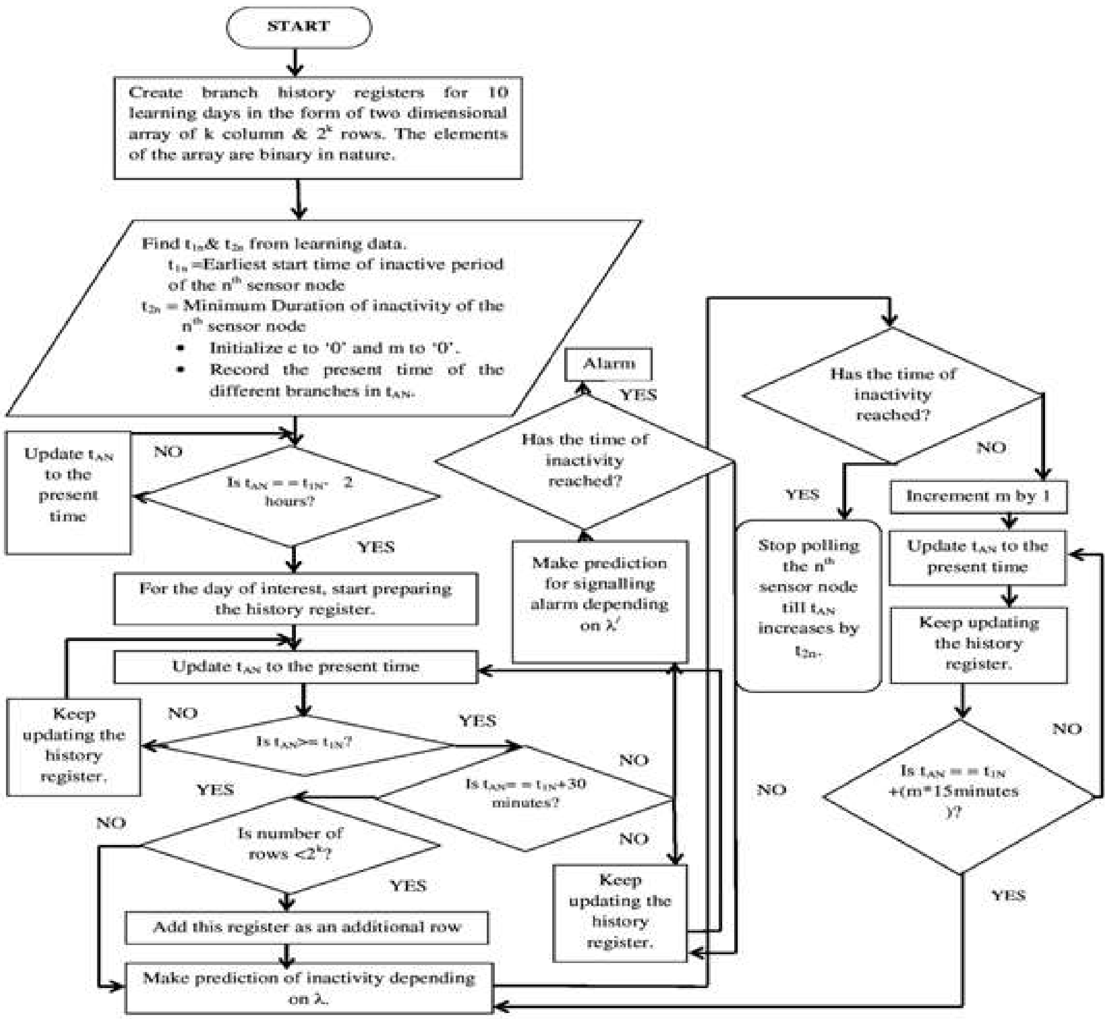

Figure 7. Flowchart of the algorithm.

IV. RESULTS OF FIELD TESTING

a. Inactivity prediction:

The whole unit has been successfully installed in the house of an elderly person in January 2013. The schematic picture of the installation with the sensor identification numbers is given in Figure 8. The target sensor nodes which can remain inactive for a prolonged period during sleep are motion sensor and current sensor nodes of kitchen and drawing room and the current sensor node of bedroom. For simplification, we have analyzed separately for the motion sensor nodes with an assumption that the inactive periods of motion and current sensor nodes approximately coincide. This also avoids false indication since sometimes; the elderly person might forget to disconnect the electrical appliances from mains. Thus in our case, two branches have been considered- B1 for sensor ID1 and B2 for sensor ID3. Now the structure of the history registers for the branches consist of the status and certain timing information of the relevant nodes for prediction of inactive period of sensor ID1.

1) Whether the sensor ID3 was ACTIVE and then OFF since it is expected that within the last 2 hours before going to sleep, an elderly person normally completes his/her dinner/lunch.
2) Whether the sensor ID1was ACTIVE and then OFF.
3) Whether the sensor ID6, i.e. the motion sensor node in the bed room was ACTIVE after the final OFF state of sensor ID1.

Thus the structure of the branch B1 history register is given in Figure 9. The content of the history register for predicting the inactivity of sensor ID3 is same as that of sensor ID1 except that for bits A and F, sensor ID1 will be replaced by sensor ID3. The history pattern tables recorded for branches B1 and B2 from 5th to 15th January 2013 before going to bed at night are shown in Table 1a & Table 1b. It is observed that for all the days, A and F are both equal to 1 for B1 and B2 which implies that this can be a major check in λ. Further E is always '1' indicating that there was an entry in the kitchen in all these days during the analysis time. The entry in the drawing room varied from one day to another. Also, there is a difference in the status of D for branches B1 and B2. For branch B1, D is '0' on some days which indicates that after entering the bedroom from the drawing room, the person went to the kitchen for some reason. This is probably due to the activity of cleaning dishes. On the whole, it is apparent that there is not much variation in the bit pattern during the learning days. This may be attributed to the fact that the major variation in the daily activity is in the number of entry recorded during the analysis period in the drawing room and kitchen but that is not recorded in the register, since it is difficult to find a pattern for inactive period prediction. There will be similar tables for B1 and B2 during the resting hours in afternoon. Based on the nature of the learning data the prediction algorithm has been formulated for sensor IDs 1 and 3 as shown in Fig.10. An additional condition has been incorporated to check whether the kitchen has been used at least once during the analysis time. If not, then an additional time of one hour is allowed to ensure that the dinner or lunch of the person is complete or will not be consumed for the day. The earliest start times for the inactive periods and the minimum duration of the inactive periods are shown in Table 2. Based on this, the inactive duration of the motion sensor nodes in kitchen and drawing room have been predicted for 16th January to 15th February 2013. For signaling an alarm for the wearable sensor node, the prediction algorithm checks whether A is equal to '1' in the current register of sensor IDs 1 and 3. Whenever A becomes equal to '1' in either of these registers, the alarm is sounded so that the reminder is given to the person just before going to sleep or sometime before this. It does not wait an extra 30 minutes for checking the status of F. This is primarily due to the fact that 30 minutes after entering the bedroom, the alarm might be a disturbance if the person goes to sleep. Applying the data of Table 2 to the algorithms depicted by Figure 7 and Figure 10, the prediction of inactive periods has been carried out.

Table 1a: Branch history pattern table for sensor ID1 during night.

F	E	D	C	B	A
1	1	1	0	0	1
1	1	0	0	0	1
1	1	0	1	1	1
1	1	0	1	1	1
1	1	1	1	1	1
1	1	0	0	0	1
1	1	1	0	0	1
1	1	1	0	0	1
1	1	0	0	0	1

Table 1b: Branch history pattern table for sensor ID3 during night.

F	E	D	C	B	A
1	1	1	0	0	1
1	1	1	0	0	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	0	0	1

1	1	1	0	0	1
1	1	1	0	0	1
1	1	1	0	0	1

The deviation of the predicted data from the actual data during night for a period of one month is shown in Figure 11. It is observed that for sensor ID1, the prediction is done after 30 minutes from the actual start of the inactive time for almost 90% of the days. This may be attributed to the extra checking time in the algorithm after entering bedroom. For around 7% of the days, the prediction is after 45 minutes from the actual start time of inactivity. This may be due to the fact on these days; the person entered the kitchen after 30 minutes. For one day, there was no entry in the drawing room for the two and half hours of analysis time and hence the prediction was delayed by that time. Similarly for sensor ID3, the prediction is done after 30 minutes from the actual start of the inactive time for around 97% of the days. This may be attributed to the extra checking time in the algorithm after entering bedroom. For around 3% of the days, the delay of prediction was by 3 hour and 30 minutes since during the normal two and half hours of analysis time, there was no entry in the kitchen and hence an additional time of one hour was spent for confirmation. For the alarm signal prediction, it has been observed that for around 60% of the days the alarm sounded within 5 seconds after entering the bedroom for sleep since on these days, the person did not go to the kitchen after entering the bedroom. For 30% of the days, the alarm sounded 30 minutes before sleep since on these days, after entering the bedroom, the person had to go to the kitchen. For 7% of the days, the alarm sounded one hour before sleep since on these days, the person went to the kitchen 30 minutes after entering the bedroom. For one day, the alarm sounded 1 hour after going to bed since on this day, to sleep earlier the person went to sleep earlier. Thus we observe that the prediction algorithm works quite effectively within a certain margin.

Table 2: Earliest start time and duration of inactive periods

Motion sensor nodes	t_{1n}(hrs)	t_{2n}(hrs)
ID 1	t_{11}= 12:39:21	t_{21}=3
	t_{12}=22:18:03	t_{22}=9.5
ID 3	t_{13}=13:58:08	t_{23}=2
	t_{14}=23:46:54	t_{24}=8

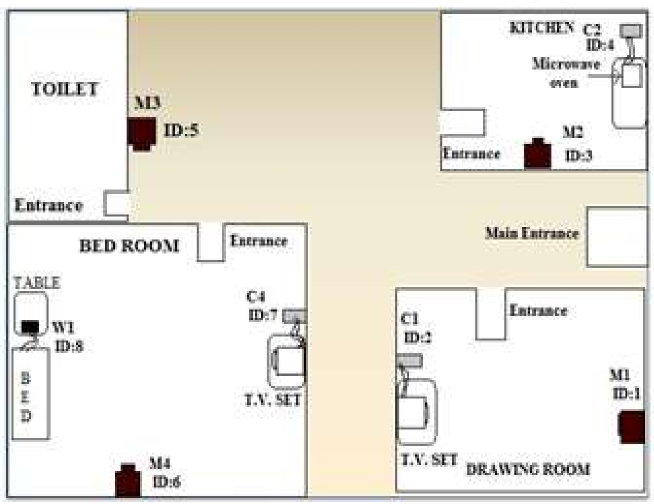

Figure 8: Installation of the various sensor nodes in the house.

F	E	D	C	B	A

A = 1 if ACTIVE state of sensor ID6 occurs after the last OFF state of sensor ID1.
B=1 if sensor ID1 is finally OFF after ACTIVE.
C= 0 if sensor ID1 is never ACTIVE.
D= 1 if sensor ID3 is finally OFF after ACTIVE.
E= 0 if sensor ID3 is never ACTIVE.
F=1 if after 30 minutes from the last ACTIVE state of sensor ID6, the status of sensor ID1 is always OFF

Figure 9: Structure of branch history register for sensor ID1.

b. Estimation of power saving:

The power consumption when all the nodes are polled is around 940 mW. The current consumptions of the current sensor nodes are significantly more than that of the motion sensor nodes since they are connected to the electrical appliances which consume high power. The power consumption of a sensor node (ID_n) is calculated based on the duration for which they are ACTIVE (t_n). The total power consumption (P_t) is given by equation 2:

$$P_t = \frac{\sum_{n=1}^{8} ID_n t_n}{24} \tag{2}$$

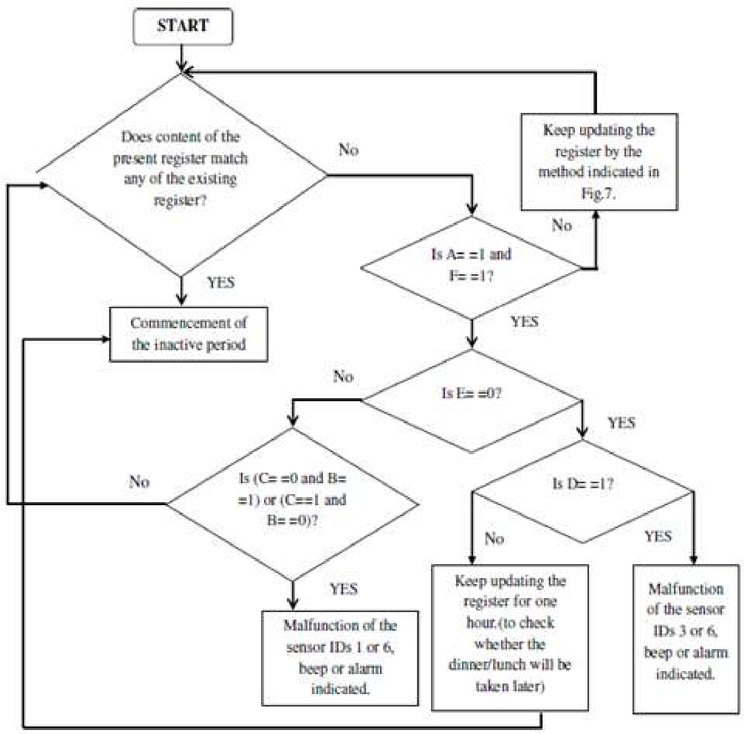

Figure 10a : Prediction algorithm for sensor ID1.

The average duration in a day when the central receiver does not poll any of the four sensor nodes in the kitchen and drawing room and the current sensor in bedroom is around 10 hours. The power consumption distribution for the period of one month is shown in Figure 12. It is observed that the average power consumption for this period decreases to 300mW which is a reduction by 68% and hence is very significant.

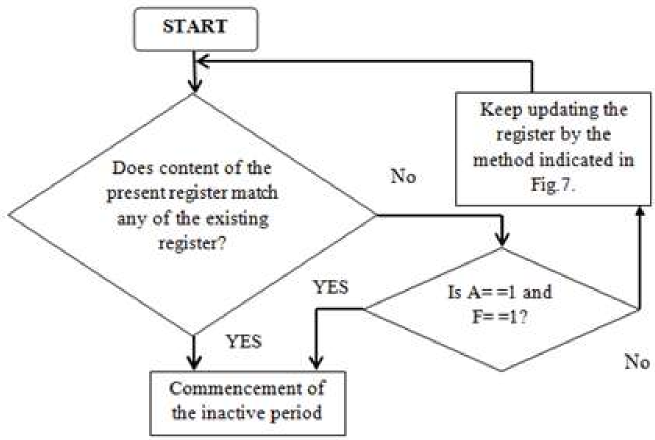

Figure10b: Prediction algorithm for sensor ID3.

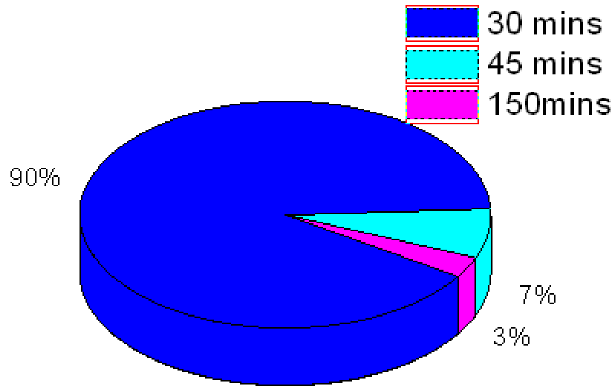

Figure 11a:Distribution of deviation of predicted data from actual data for one month (sensor ID 1)

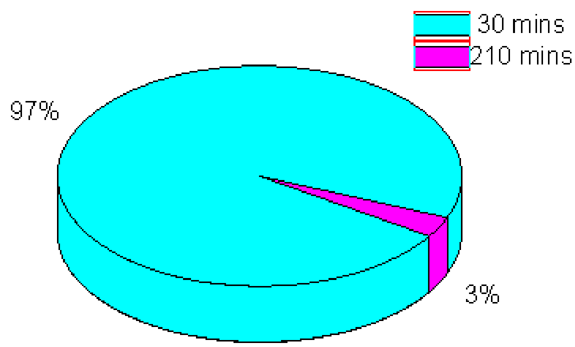

Figure 11b: Distribution of deviation of predicted data from actual data for one month (sensor ID 3)

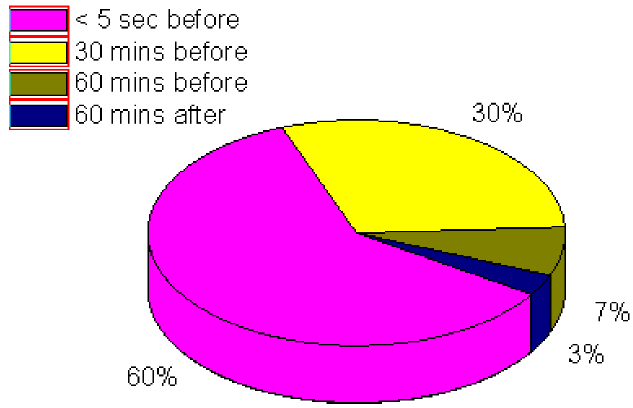

Figure 11c: Distribution of timing of signaling alarm with respect to sleeping time.

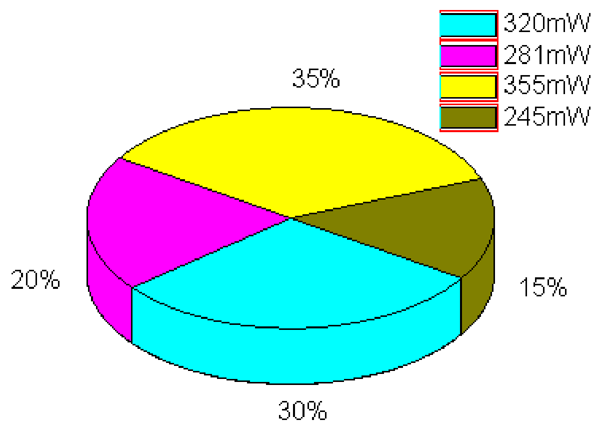

Figure 12: Distribution of power consumption.

V. CONCLUSIONS

In this paper, a low power and minimally intrusive multi sensor network has been developed for health monitoring of elderly people. The system consists of current sensor node, motion sensor node and wearable heart rate sensor node. The sensor nodes along with the central controller have been installed in the house of an elderly person and it has been observed that these three types of sensors can predict the activities of the person faithfully. To save the power consumption of the unit, inactivity periods have been estimated using an algorithm during which the inactive sensor nodes are not polled by the central controller. The algorithm is based on two level adaptive branch prediction methods and has been found to work satisfactorily for more than 90% of the days within a time margin of detection. An average of 68% power saving is achieved by the incorporated algorithm which adds to the commercial potential of the optimized system.

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