APPLICATION SPECIFIC ENERGY PERFORMANCE ENHANCEMENT IN WIRELESS BODY AREA NETWORKS

(KABLOSUZ GÖVDE ALAN AĞLARINDA ENERJİ BAŞARIMININ
UYGULAMAYA ÖZEL İYİLEŞTİRİLMESİ)

by
Özgün PINARER, B.S

Thesis

Submitted in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE
in
COMPUTER ENGINEERING
in the
INSTITUTE OF SCIENCE AND ENGINEERING
of
GALATASARAY UNIVERSITY

May 2012

APPLICATION SPECIFIC ENERGY PERFORMANCE ENHANCEMENT IN WIRELESS BODY AREA NETWORKS

(KABLOSUZ GÖVDE ALAN AĞLARINDA ENERJİ BAŞARIMININ
UYGULAMAYA ÖZEL İYİLEŞTİRİLMESİ)

by

Özgün PINARER, B.S.

Thesis

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

MASTER OF SCIENCE

Date of Submission	: May 25, 2012
Date of Defense Examination	: June 25, 2012

Supervisor : Assist. Prof. B. Atay ÖZGÖVDE
Committee Members: Assist. Prof. Gülfem IŞIKLAR ALPTEKİN
Assist. Prof. Çağrı TOLGA

ACKNOWLEDGEMENT

Foremost, I would like to express my sincere thanks to my advisor Asst. Prof. Dr. B. Atay ÖZGÖVDE for the continuous support of my master study and research, for his patience, motivation, enthusiasm, and immense knowledge.

My warm thanks are due to Asst. Prof. Dr. Burak ARSLAN who directed me in biomedical studies.

I wish to express my warm and sincere thanks to Asst. Prof. Dr. Laurent MOUNIER, who introduced me to Verimag Lab in Grenoble, France. His kind support and guidance have been of great value in this study, as well as essentially teaching me everything I know about the simulation I used in France.

My sincere thanks also go to Prof. Dr. Florence MARANINCHI and Asst. Prof. Dr. Catherine PARENT-VIGOUROUX, for offering me work opportunity in their groups.

I would like to thank to my family and my friends for their encouragement and support.

This thesis is supported by the SAN-TEZ program of Turkish Ministry of Science, Industry and Technology under the grant number 00845.STZ.2011-1.

Özgün PINARER
May, 2012

TABLE OF CONTENTS

LIST OF SYMBOLS

AAL : Ambient Assisted Living
ADC : Analog to Digital Converter
BAN : Body Area Network
BPM : Beat Per Minute
BT : Bluetooth
CPU : Central Processing Unit
DMA : Direct Memory Access
ECG : Electrocardiography
EEG : Electroencephalography
EMG : Electromyography
HRV : Heart Rate Variability
IEEE : Institute of Electrical and Electronics Engineers
MAC : Medium Access Control
NesC : Network Embedded Systems C
PDA : Personal Digital Assistant
RF : Radio Frequency
SD : Secure Digital
WBAN : Wireless Body Area Network
WPAN : Wireless Personal Area Network
WSN : Wireless Sensor Networks

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Remote health monitoring in general, mobile health applications in particular are becoming increasingly popular, especially in developed countries, in parallel with the increasing hospital care costs and aging population. In such applications the objective is to collect relevant information with a set up that will least affects the user’s everyday life, processing of the data and the determination of the necessary alarm states with minimum error. Communication issues relevant to the scenarios are mostly studied under the Wireless Sensor Networks, Body Area Networks and Personal Area Networks domains. The hardware and low profile firmware to be used in these kinds of applications are still in the research stage and only a few commercial implementations can be come across.

When the requirements of the remote health monitoring applications are considered, it is observed that they have to be performed by wearable/ attachable, small sized devices having wireless communication features. In this respect, Wireless Sensor Networks (WSN) as a technology comes up as a natural candidate for the realization of the remote health monitoring applications. For the cases studied, the network nodes are equipped with limited battery energy; therefore, they have to be recharged for the continuous operation. Changing and/or recharging of the wearable sensor units are a troublesome process, especially for the elderly that have to be avoided as much as possible. Therefore, increasing the energy efficiency of the nodes is necessary for increasing their functional lifetime which, in turn, means less frequent energy based maintenance operations. This fact is of critical importance as it directly affects the usability and acceptance of the monitoring system proposed as a whole.

In this study, to increase the energy efficiency of the wearable sensor nodes, a novel approach based on application specific data processing and communication scheduling is employed. In order to exploit the application based information, applications must be analyzed and custom algorithms have to be design. To demonstrate the concepts proposed, two mobile health monitoring scenarios with different internal characteristics are chosen, namely the heart rate monitoring and the pedometer. Embedded algorithms specific to the applications are developed and the energy gain figures are reported. Specific to the pedometer case, dynamic sleep scheduling with parameters modeling the application is implemented. Experiments with both real and synthetic data are carried out. It has been shown that the algorithm parameters affect the monitoring performance and the energy performance differently and that operating regions where high quality monitoring achieved with less energy consumption indeed exists.

RESUME

En générale, la surveillance de la santé à distance, en particulaire les applications de santé mobile sont devenus un sujet d'actualité de jour en jour. Ces sujets sont très populaires spécialement dans les pays développés avec l'augmentation des coûts des soins hospitaliers et avec le vieillissement concept de population. Dans ce genre d'applications, l'objectif est la collecte d'informations pertinentes avec un ensemble jusqu'à ce que sera au moins affecter la vie quotidienne de la personne, le traitement des données et la détermination des états d'alarme nécessaires avec une erreur minimum. La partie communication de ces applications sont étudié dans le cadre de «réseaux des capteurs sans fils », « les réseaux a la conquête du corps humain ». Les types de matérielles utilisé sur des capteurs, les firmwares qui consommes moins d’énergie sont des titres des sujets travaillés par les scientistes. Par contre seulement quelqu’un de ces capteurs sont devenu un produit dans le marché.

Lorsque les exigences des applications de télésurveillance de santé sont considérés, on observe qu'ils doivent être effectués par portable / attaché, de petits appareils de taille ayant des caractéristiques de communication sans fil. À cet égard, les réseaux de capteurs sans fil (WSN) comme une technologie qui se présente comme un candidat naturel pour la réalisation des applications de télésurveillance de santé. Pour les cas étudiés, les nœuds du réseau sont équipés d'énergie de la batterie limitée, par conséquent, ils doivent être rechargés pour le fonctionnement en continu. Modification et / ou la recharge des unités de détection portables est un processus pénible, surtout pour les personnes âgées, qui doivent être évitées autant que possible. Par conséquent, accroître l'efficacité énergétique des nœuds est nécessaire pour augmenter leur durée de vie fonctionnelle qui, à son tour, signifie moins de fréquentes opérations de maintenance de l'énergie à base de. Ce fait est d'une importance essentielle, car elle influe directement sur la facilité d'utilisation et l'acceptation du système de suivi proposé dans son ensemble.

Dans cette étude, afin d'accroître l'efficacité énergétique des nœuds portables, une nouvelle approche basée sur des analyse des data des applications spécifiques et l'ordonnancement de communication est implémentés. Afin d'exploiter l'application basée sur des informations venant des capteurs, les datas doivent être analysées et des algorithmes écrit par chaque application spécifiquement doivent concevoir.

Pour démontrer les concepts proposés, deux scénarios mobiles de surveillance de la santé avec différentes caractéristiques internes sont choisis, à savoir la surveillance du rythme cardiaque et le pédomètre. Algorithmes embarqués spécifiques aux applications sont développées et les chiffres de gain d'énergie sont signalés. Spécifique à l'affaire pédomètre, l'ordonnancement dynamique avec le sommeil des paramètres de modélisation de l'application est mise en œuvre. Des expériences avec des données réelles et de synthèse sont réalisées. Il a été montré que les paramètres de l'algorithme ont un effet visible sur la surveillance du rendement et la performance énergétique différente et que des régions d'exploitation où le contrôle de hautes qualités obtenues avec moins de consommation d'énergie en effet existent.

ÖZET

Günümüzde popülaritesi artan araştırma konularının başında uzaktan sağlık izleme ve mobil sağlık uygulamaları gelmektedir. Gelişmekte olan ülkelerdeki halkın yaş ortalamasının artması ve hastane masraflarındaki artış uzaktan sağlık izleme uygulamalarına olan ihtiyacı açık bir şekilde gözler önüne sermektedir. Bu tür uygulamalardaki amaç insanın gündelik hareketlerini kısıtlamadan vücuduna takılan giyilebilir donanım olan algılayıcılardan veri toplamak ve bu toplanan fizyolojik sinyallerden bazı çıkarımlarda bulunmaktır. Uygulamaların haberleşme kısımları “Kablosuz Algılayıcı Ağlar”, “Gövde Alan Ağları” veya “Özel Alan Ağları” başlıkları altında çalışılmaktadır. Bu uygulamalarda kullanılan donanımlar düşük enerji tüketimi sağlayan yazılımlarla birleştirilmiş ve araştırma aşamasındadır ve ticari ürün olarak sayıca azdır.

Uzaktan sağlık izleme uygulamalarının gereksinimleri dikkate alındığında, bu tür uygulamalarda kullanılan algılayıcıların giyilebilir ya da vücuda takılabilir halde olmaları gerekmektedir. Bu cihazlar yerel merkez ile kablosuz haberleşme teknolojisi ile veri iletimi yapmaktadır ve Kablosuz Algılayıcı Ağlar teknolojisi bu tür uygulamalar için gereken altyapı desteğini sağlamaktadır. Üzerinde çalışılan bu sistemlerde kullanılan algılayıcıların sınırlı pil enerjileri bulunmakta ve düzenli olarak şarj edilmeleri gerekmektedir. Sağlık izleme uygulamalarında algılayıcıların ve isterlerin türüne göre şarj etme işlemi özellikle de yaşlılar söz konusu olduğunda sıkıntılı olmaktadır. Enerji takviyesi işlemlerinin daha seyrek tetiklenmesi, bu tip sistemlerin kullanışlılığını ve son kullanıcı tarafından kabulünü oldukça olumlu olarak etkilemektedir. Bu bağlamda enerji veriminin arttırılması, buna bağlı olarak algılayıcı ömrünün uzatılması önem kazanmaktadır.

Bu çalışmada giyilebilir algılayıcı üzerinde enerji veriminin arttırılması amaçlanmakta ve bunu başaran yeni bir yaklaşım ortaya konmaktadır. Çalışma kapsamında uygulamaya özel gömülü veri işleme ve çizelgeleme haberleşme metodları kullanılmıştır. Önerilen yöntemlerin işlerliğini gerçek deneyler ile gösterebilmek için birbirinden farklı karakterde iki mobil sağlık uygulaması seçilmiştir: nabız ölçümü ve adımsayar. Bu kapsamda uygulamaya özel gömülü hesaplama yöntemleri ve algoritmalar geliştirilmiş, enerji kazancı ve verimi analiz edilmiş, grafikler olarak raporlanmıştır. İkinci uygulama olan adımsayara özel olarak dinamik uyku çizelgelemesi gerçeklenmiş ve gerek gerçek, gerek yapay veriler üzerinde testler koşulmuştur. Test sonuçları incelendiğinde kullanılan algoritma parametrelerinin uygulama performansı, algılayıcı ömrü ve buna bağlı olarak enerji verimini farklı olarak etkilediği gözlemlenmiştir. Düşük enerji tüketimi olan çalışma bölgesi içinde yüksek uygulama başarımına olanak sağlayan kısımlar ortaya çıkarılmıştır.

1. INTRODUCTION

The progress in electronic technology which transformed the giant computers into a small smart phone hold in a packet also changed the way of communication and protocols. The structure and the architecture of the network systems are changed in deeply also. In first, wired communication was in use because it was fast, secure and stable but then with the improvement in the wireless technology, there is no need to have cables. So that this day, everyone with a smart phone can access any information whatever he wants and does not matter where he is. With the wireless technology it simplifies the usage of these devices. In every restaurant, cafeteria, probably it exists an access point to get wireless connection.

Furthermore, with the wireless technology, and the advanced in the micro-processors, it is possible to produce small components for the lightweight sensor. Thus the usage of these components and the number of applications related with them increased due to this progress in wireless technology[1, 2]. As the wireless technology lets these sensor devices to communicate either each other or with specific device, it makes possible to build a network with sensor devices that can communicate in a wireless way. This opens new research area named Wireless Sensor Networks(WSN) and brings a distinct increase of number of application with using new sort of sensor devices which can do sampling, computing and communicating. In these networks, there is usually one special node which gathers sampled data from every node in the architecture called sink.

As it is mentioned before that the components of the sensor device are getting smaller and lightweight, the number of applications and usage area of WSN are increased. In WSN, the network consists of sensor devices that are named nodes which communicate with each other by wireless technology. By using smaller components, sensor nodes dimensions’ are also getting smaller day by day.

The characteristics properties and the behavior of the nodes in wireless sensor networks are different, regarding that it is impossible using same communication protocols as in the wired network applications. So that new protocols are generated for WSN applications. New protocols means new type of communication and data transfer between nodes in the wireless network.

As it is indicated before, the structure of WSN consists on sensor nodes deployed on the area. The duty of these nodes is quite simple. They sample according to the firmware installed on them and the hardware feature of the sensor device. The sampling frequency is set at the begining while preparing environment. After sampled data, sensor sends this data to the sink. In addition to be able to send the sampled data to the sink sensor node, each sensor node which has microcontroller on them, can analyze the sampled data by the embedded algorithm running it.

In default structure of WSN, depending on the architecture of the network, all nodes should send their sampled data to the sink. In these applications, duty of the sink sensor is to gather all data from all nodes. According to the capacity and the communication range of nodes, in some cases, nodes cannot send their data to sink because of the high distance between itself and the sink node. For these types of cases, other architecture of network can be implemented such as multi hop systems or cluster systems. So that one node which cannot send its data to the sink, it sends its packet to another node nearby in order to send it to the node with its own packet.

Through the fast progress in wireless technology, radio technology and semi-conductor technology, sort of WSN applications and type of sensor devices increased. These sensors can be used not only outdoor but also indoor, in our house. In this high variety of the sensors, it exists also various light-weight sensors, wearable sensors[3, 4]. Furthermore new sensors have more properties such as improvement in data capturing, data storage (capacity). With all these properties of WSN, different sort of applications can be implemented in different domain. It is possible to use WSN applications in acquisition system of fire risk[5], in military monitoring[6], in health care[7], in agriculture monitoring[8].

In parallel, this amelioration in technology can be seen in mobile phones also. Mobile phone companies work on smart phones that have high capacity and connectivity. With new generation smart phones, users are all time connected to internet especially to the social sites for sharing personal information in their page. When compared with previous generation of handsets, these devices have relatively high computational capabilities with increased memory sizes and faster microprocessors. Moreover, these devices can build a wireless connection with other wireless devices like other smart phones, personal computers, etc. Thus, it is possible to build architecture with wireless sensor nodes with smart phones.

As the smart phones in market have a high computation power through its microprocessor running on it, it can interact with other devices around it. This interaction gives to these phones pervasive computation property. User can check his mail, connect to web sites, do Skype calls, listen music online etc. In other words, pervasive or ubiquitous computing is post-desktop model of human-computer interaction. With the smart phones and its high communication advantage, users can access to information everywhere and whenever they want. That’s why in global the goal of researchers who work on pervasive computing is try to create smart products that communicate unobtrusively.

The important point in pervasive computing and the reason why it is popular is the intersection between wireless sensor nodes and the smart phones, in fact the connection and data transfer between these devices. As the sensor devices are small factor, these devices can be used indoor also. For gathering information coming from sensor nodes, special sink nodes can be put indoor which makes this area ‘Smart Home’. In smart home technology, house is equipped with several sensor devices and a local center as a sink. This sink node collects all data sampled from sensors, either with the web, it can send data to the global center in order to process or it may analyze itself by using its own microcontroller on it. According to the result of the analyze, smart home system can generate alarms if it is necessary. Thief alarm system, turning on the light when someone comes inside or turning off when there is no one in the room, air conditioning systems are few examples of smart home systems. In some thief alarm systems, when the system generates alarm, it calls police and the owner of the house.

In smart home systems, by equipping the house with sensor devices gives chance to monitor inside. These types of systems can able to monitor human activities and takes decisions like alarm generation. In these applications, the component that generates alarm is the sink which is the node that gathers all data coming from the sensor nodes all around the house. For the alarm generation, an embedded algorithm runs on the microcontroller. This embedded computation on the sampled data gives new vision to the ambient intelligence. Ambient intelligence consists on analyzing data and taking decision according to the results of the analyze.

As it is mentioned before, due to the progress and improvement in technology, variety of sensors increased and related to that, number of applications increased in parallel. Depending to the type of the sensor, implementation of the firmwares is suitable for programmers. This high variety of sensors makes classifications in WSN. It exists sensors for measure temperature, pressure etc. On the other hand there exist sensors that samples human’s physiological signals generating from the body. The applications that work on these types of signals belong to Body Area Network.

1.1. Body Area Networks

In BAN, main goal is to collect signals that human body generates like heart or muscles. In this case, sensor devices are a little bit different from usual sensors of WSN applications. Sensors that are in use in BAN applications are small factor and wearable. For measuring heart activities, sensor should be worn. For that reason, these types of sensors must be designed flexible and suitable for human body. It should not prevent the user from doing his daily activities. Sensor devices that are used in this work are wearable and designed for especially BAN applications.

In developed countries because of the high average age and the high hospital costs, monitoring patients indoor is popular. With these biomedical sensors, it makes possible to monitor patient’s health state from a distance. As it is indicated in the previous part of the document, wireless technology nowadays makes possible to take sampled data and send through internet real time. With the aid of smart home systems, patient’s data can be sent to a global center that can be reachable by the patient, doctor, caregivers and health personal. If we generalize it, not only for the patients but for everyone who wants to control his health state can use this kind of system.

Applications related with the Activity Daily Living consist on biomedical wearable sensors which let user to monitor his heart/muscle activities or to monitor motion pattern. When we gather wearable sensors, global center to collect all data and share with permitted people and the connection between them, it comes out e-health and in this context, there is also mobile healthcare monitoring. In these applications improvement in mobile phones and their capabilities are used because using a power device in architecture gives several opportunities such as powerful signal processing, storage of data and several analysis techniques. It also gives an impression for generating new methods, new techniques that cannot be done before[9, 10].

The reason why BAN is popular for researchers is the rapid growth in physiological sensors, low power integrated circuits and wireless communication. With all these progress has enabled a new generation of wireless sensor networks named BAN. BAN applications are used to monitor traffic, crops, infrastructure and health. In this case monitoring activities should be inexpensive and continuous with real-time updates of medical records via Internet according to the structure of the system.

With advanced BAN applications health personal can monitor patient’s health state while the patient is not in the hospital so BAN apps allows the mobile monitoring of patients and this can free up hospital beds, with the monitoring carried out in the home of the patient[11].

In BAN, powerful intelligent physiological sensors which are wearable and comfortable for human can be used for computer assisted rehabilitation or early detection of medical conditions. The implanted worn sensors in the human body can collect various physiological changes while monitoring the patient's health status no matter their location. The information coming from these sensors are transmitted wirelessly to an external processing unit in order to analyze.

As in all applications, in Ban also there are some challenges. First of all in smart home systems or in BAN applications, communication range of the sensor devices is very important. These devices make connections wireless so that the distance between two points affects the stability of the system. Due to that reason, using smart phone as a local center that collects data, minimize the distance between. So that in health monitoring applications mobile device is chosen for gathering data coming from wearable sensor devices on the human body.

The second important and for this study, the major point is the limited power. These wireless sensor devices contain battery. But as this battery is limited, sensor nodes should be charged periodically. A sensor device consumes energy during sampling, sending sampled data and if there is, computing data before sending. Just the distance between sensor and the external unit that is called sink is very important in term of energy consumption. The importance of the energy and the lifetime of the sensor will be explained in the next section of the document.

1.2. Challenges and Importance of Energy Efficiency

In the WSN research domain, capabilities and the hardware features of the sensor devices determine the limits of what can be achieved at the application level. An important constraint in this context is the limited power in the battery unit. Increasing energy efficiency has been a central research theme for WSNs and several studies aimed at minimizing the energy consumption in order to increase the lifetime of the sensor nodes[7, 12-16].

As it is mentioned in the previous section, a simple sensor has three main properties: sampling data, data computation (analyze sampled data before sending to the local center) and wireless communication (sending sampled data or the result of the computational analyze to the neighbor or directly to the sink). In these three main duties of sensor node wireless communication uses more than 60% of the energy budget of the sensor[17]. This ratio shows that communication and sending data is the most expensive process for a sensor. This high energy cost decreases the lifetime of the sensor node. In order to prevent from consuming high level energy consumption, instead of sending all sampled data, other capabilities of sensor device like computation on its microprocessor.

In order to consume less energy, user wants to analyze the sampled data on the sensor by using computation property of the sensor device unless an external processing unit is needed to do more complex analysis techniques, because it is clear that more sampling means more data generation and more data needs more processing but as it is said before because of the limited energy, it is very difficult and sometimes impossible to do all these process on the sensor[18, 19].

In this study, we focus on energy consumption of the wireless sensor nodes. These sensors have limited energy and needed to be charged periodically. In a case where these sensors are used by elderly, charging process is not simple as charging mobile phone in daily life. When we think about a sensor device that monitors heart activities, it is not so simple to remove the device for the charging process and then wear again. On the other hand, according to the type of the application or the user need, it is possible to modify the firmware on the sensor to minimize the wireless data transfer. For example with the default configuration of ECG application, sampling frequency is 500Hz which means just in one second, sensor device samples heart activity 500 times and it sends 500 packets to the local center every second. Depending on the user demand, maybe the application running on the external center unit, all of 500 packets are not needed. In these cases, microcontroller of the sensor device and its computation power can be used and it can analyze the sampled data and according to the result of the embedded algorithm, it may send fewer packets. In fact, biomedical sensors operate at incredibly low power usage, running for years on small batteries and harvesting energy[20]. Depending on the battery, in parallel, lifetime of the sensor node increases when it consumes less energy.

BAN sensor devices are used for measuring physiological of human body and have the ability to diagnose critical events such as heart attacks or heart failure. According to the user’s need, application and the sampling frequency can be modified which result with different sensor lifetime. As our case study is the e-health and health monitoring, wearable sensors are also in our field of interest because wearable systems for continuous health monitoring are a key technology in helping the transition to more proactive and affordable healthcare. They help maintain an optimal health status. These kinds of applications and systems can even alert medical personnel when life-threatening changes occur[21].

In wireless body area network physiological sensors, generally low power integrated circuits are used, especially in wearable sensors. In the application where wearable sensors are used, the main idea is to allow inexpensive and continuous health monitoring with real time updates of medical data via internet. These systems are called wireless body area network. In these systems, wearable sensors are used for computer assisted rehabilitation, early detection of medical conditions, collecting various physiological changes in order to monitor health status.

In daily life, using these systems and applications is not always suitable. There are some challenges that the researches faced. It is clear that these systems make people’s life easy. For example patients who use wearable sensors can walk easily covering cell phone network instead of staying in hospital. But there are some problems that should be solved. We can list problems in three main points. First of all as explained before, because of the limited energy, lifetime of the sensors is a restriction for the user and should be increased by using several methods that will be held in this study. Secondly, slow computation prevent user to do complex data analysis techniques in an embedded way depending on the features of the microcontroller on the sensor device. The third problem is the low amount of memory capacity. In this list energy consumption is our major problem that most of people work on like us. As there is limited energy on the sensor, these sensors should be recharged regularly by the user themselves. In general charging sensors may frustrate the users who are elderly because depending on the application removing and wearing again the sensor is not so easy, for example for monitoring muscle or heart activity, as it is indicated before, there are biomedical pads connected to the body with wired to the board; so instead of force them to charge every day, it is highly necessary that the lifetime of the sensor is much longer.

1.3. Application Aware Energy Efficiency in BAN

In all WSNs, radio-communication components consume a large proportion of the energy budget. Each byte transmitted by the radio consumes as much power as 8000 instructions on the processor and this clearly prove the high energy consumption by the communication [10]. That’s why the main goal in this work is to try to reduce the amount of energy consumed by transmission. As communication is very expensive in terms of power and more power is used to communicate than to compute, instead of transmitting all the sampled data, computation property of the sensor can be used. It is said that the communication needs energy, power used by a transmitter is a function of a distance and the number of bits transmitted.

In this study, we try to generate embedded algorithms that can be run on the sensor device in order to decrease the energy consumption. These algorithms analyze the sampled data by using computation property and the memory capacity of the microcontroller and the other hardware features of the wireless sensor node. After analyzing data by using on board processing techniques, the result or the summary of sampled data can be sent to the local center instead of sending all.

In addition to embedded processing techniques, duty cycle which means sleep schedule can be used in these BAN applications. In this case, depending on the application and the signal, for a specific duration CPU or/and communication module (RF or BT) can be turned off. For decrease the communication range, in some applications mobile phone is used as a sink in the architecture. Gain of energy depends on the application so that for every application, other techniques can be used. In order to gain more energy, we added sleep schedule for CPU and radio component of the sensor. Furthermore performance of algorithm can be varied according to the gain of energy. This can be observed in performance evaluation section of this study.

1.4. Contribution of the Thesis

According to the challenges on BAN, the most important point of these applications is the energy efficiency. In this study, we focused on energy consumptions of BAN applications and try to implement some methods in order to increase the lifetime of these sensor devices by keeping the signal quality.

In the applications that we worked on, we used wearable sensor devices which are small and lightweight. These sensors have their battery which means limited power and a microcontroller with high capability on it. The goal is to try to find a way of increasing lifetime of the sensor and reducing energy consumption. In order to realize this aim, we worked on embedded programming and in the applications, with on board processing; sensor device analyzes sampled data on its microcontroller with embedded algorithm written by us. Thus, sensor device will not send all sampled data but just the summary or the result of this pre-process which is took place on the microprocessor of the sensor node.

In addition to that, duty cycle is used in chosen application. During the execution, sensor device can pass to sleep period with a definitive duration. With this sleep schedule, depending on the algorithm and the settings, communication module or/and central processing unit pass to sleep mode with given time duration. After passing to sleep mode, according to the parameters and sleep mode, sensor can continue sampling if CPU is on. Moreover when CPU is also turned off, sensor will consume very less energy that will be explained in this study. Related with the sensor and its configuration parameters, sleep duration can be dynamic during the execution of the application. At last, by using these two methods: on board processing and sleep schedule, sensor node consumes less energy than running mode with its default configuration.

In this context, we generated embedded algorithms for each application differently. For ECG, heart rate is calculated on board, for accelerometer signal, dynamic duty sleep schedule is implemented on the sensor device. With these specific applications, for every wearable and rechargeable sensor, depending on the signal, special embedded algorithm can be used in order to increase the lifetime of these nodes. In this study we interested also e-health applications and the connection between the patient and the health personal. Also in these architectures, we used a smart phone with Android operating system as a local center which is related with mobile health (m-health).

2. LITERATURE REVIEW

The research show that day by day mobile devices and telemedicine become more and more popular[11]. There are some reasons for this popularity. First of all, the powerful signal processing and analysis techniques are developed that can be useful on sensor. Recent advances in sensor and computer technology have led to the development of various light-weight sensor devices with embedded processor and ratios that can be woven by the patient[1]. Such system enable on body and mobile healthcare monitoring. Wireless sensing units are proposed for monitoring the behavior and health of civil structures based on advanced embedded system technologies that are commercially available[2].

In this domain, the most important point is the energy consumption and the lifetime of the sensor. As it is indicated in the introduction part, wireless sensor device has three main modules: Data acquisition system, computational core, and wireless communication channel. In data acquisition part, sensor samples data with or without a definitive frequency. The measured data is sent to computational core which means if there is an algorithm running on the sensor. In this case, computational property of the sensor is used and CPU is running. The result of the analysis techniques (on board processing), resumed and preprocessed data is ready to be put in the packet to send to the sink. Wireless communication channel is responsible for transmitting the data to the local center.

As the energy consumption and efficiency is the most significant point and the most important metrics in BAN, it is highly necessary to determine energy consumption for each component of the sensor. Main goal is to increase the lifetime of the battery because sensors need to consume as little power as possible since power supply is very limited. In fact for all type of sensors energy is used for: Running the sensor, Processing the information, Data communication. In home health care applications that use wearable devices have strict power constraints due to the small size of the battery in the device. The radio-communication components consume a large proportion of the available energy[17]. That’s why we try to reduce the amount of energy consumed by transmission.

There are some propositions in order to solve the high energy consumption. First method that can be seen in literature review is the data compression. That means in fact two means. Sensor stocks and compresses all measured data and sends in one time instead of sending them separately. The other choice is the compression of each sending packet. In reality compression means there is a compression algorithm running on CPU which means more computational power but less transmission bytes. There exist two sort of compression: lossless compression which is in use in medical imaging applications and this method guarantees the integrity of the data without distortion and uses Huffman coding, lossy compression in which data contains some reasonable distortion but this method can archive higher compression rate[2, 22-25].

Another way for the gain of energy is to modernize the algorithm of Lazy packet scheduling. Important points in lazy transmission are the number of packets in the buffer, and the way of calculate the transmission time based on the amount of backlog[11].

Another proposition is to send data over shorter distance to an on-body processing device rather than external base station around us, after processing, low bit rate signal or alarm can be sent to the external station[3]. In this proposition a closer center can be our mobile phone because nowadays, the uses of smart phones are very increased and they can be acted as a local center[26]. A concrete example for this case is to analyze heart rate variability (HRV) from ECG can be implemented using discrete wavelet transform. Memory requirement is low. It can be implemented on low power processor. But same thing is not suitable for EEG.

Dividing the sensors into different types is one of the ways in order to reduce power usage and using clusters of sensors and rotating them to equalize power usage. To determine cluster heads is a way for reducing energy because only small fraction of the nodes make expensive long distance transmits to external base station[4].

Also it is possible to reconstruct the same signal measured by the sensor with less data. This is called modeling. It means sensor doesn’t send all the sampled data but just the significant ones. Therefore the local center by using modeling techniques can build the same signal with less sampled but significant and characteristic samples[27].

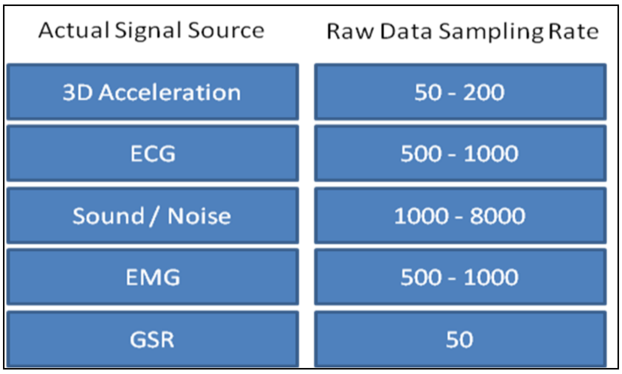
Among these techniques, the most popular technique is using the computational property of the microcontroller on the sensor device. Before sending all the sampled data, some on board processing algorithms are running on the CPU use these sampled data and the result of the preprocess is sent to the local center. With this method, all sampled data is in use and some part of analysis on the data is done on the sensor side before sending. In this case, there is less number of packets sent from sensor, so that amount of energy consumed decreases.

3. PROBLEM DEFINITION

In this section the problems of BAN will be explained. The main problem of BAN is the energy restrictions. On every wireless sensor, there is a limited battery located. When the battery energy is finished, the sensor turns off. In some cases, the sensors should be recharge but in some cases like WSN in large scale, the sensor dies and the routing is changing [28-31].

In BAN, there are several applications that can be use. Some of them are given below in table 3-1 with their raw data sampling rate in default mode. Increase of frequency means more sampling rate which comes out more data.

Table 3-1 – Biomedical signals and sample frequency (Hz)



Actual Signal Source	Raw Data Sampling Rate
3D Acceleration	50 - 200
ECG	500 - 1000
Sound / Noise	1000 - 8000
EMG	500 - 1000
GSR	50

In our study, our main goal is to increase the lifetime of sensor by keeping the signal quality. The general methods for doing this enhancement are given in the introduction part. In our work, we use advanced computation property of the microcontroller situated on the sensor. Before sending the sampled data to the local center, it is possible to do some preprocess on this sample and send just the necessary information to the center.

In generally, BAN applications are very useful for elderly. These sensors are designed as wearable devices, so it is easy to hold it on our body and it doesn’t prevent from doing our daily activities. But as these devices have limited energy, regularly they should be recharged by the users and sometimes this action scares elderly because according to the type of the sensor and the application, it is not always easy to remove and then wear it like ECG applications. That’s why in this study we try to find ways how to increase lifetime so that there will be less necessary to do recharge process.

4. SYSTEM MODEL

In this section, the device used in experiments, the environment and the architecture of the constructed system are presented.

4.1. Architecture of System

4.1.1. Components of the System

In BAN applications, there are at least two main parts of the system. The first and the main component of the system is the sensor device. According to the application, the additional external devices can be attached or added to the system for sampling these signals.

The other and the complementary part of the system is the local center component of the architecture. As in the BAN applications, devices that are used are designed as wearable sensors, the connection between sensor device and the data receiver/collector is in a wireless way.

4.1.2. Communication Protocol in Use

In BAN, currently the wireless technology is in use. In this case, the connection between the sensor device and the local center can be established by IEEE standard 802.15.4 or Bluetooth connection. The features and goals of either radio technology are sufficiently differentiated to lead to a choice based on application needs and available resources according to the coarse matrix in Table 4.1.2-1 below:

Table 4.1-1 - 802.15.4 and Bluetooth Comparison

Metric	802.15.4	Bluetooth
Power Consumption	BETTER	WORSE
Agility/Connection Speed	BETTER	WORSE
Out-of-box compatibility with mass-market devices	NO	YES
Prebuilt Application	NO	YES
Number of nodes	GOOD	POOR
Range	OK	OK
Mesh Implementations	YES	NO
Ability to customize	YES	NO
FCC Modular Certification	YES	YES
Data Rate	WORSE	BETTER

IEEE 802.15.4 is a specification of a very low-power wireless personal area network (WPAN) protocol. It specifies the physical layer (air interface-layer 1) and the accompanying MAC protocol layers. 802.15.4 is a CSMA/CA MAC based system with a total of 27 channels specified in the frequency bands of 2.4 GHz, 902-928 MHz, and 868.3 MHz. Three different over-the-air data rates can be allocated: 16 data channels with a data rate of 250 kb/s, 10 channels with a data rate of 40 kb/s and 1 channel with a data rate of 20 kb/s. Such a network can choose one of the 27 channels depending on availability, congestion state and the data rate of each channel. It is optimised for short range (typically 30-50 meters), low data throughput with a 30 ms network join time and supports flexible topologies, i.e. star or peer-to-peer topologies. It also supports a very large numbers of nodes. A single 802.15.4 network can accommodate up to 216 devices, which are assigned during the association procedure. It is designed to achieve good energy efficiency both in the physical and MAC layers. The duty cycle of communications in an 802.15.4 network is around 1 percent, resulting in very low average power consumption for static and dynamic environments. However, it is also up to higher protocol layers to observe the low duty cycle. Most power saving mechanisms in 802.15.4 is based on beacon-enabled mode. The simplicity, low-cost,

low-power features of 802.15.4 are intended to enable broad deployment of wireless networks which are able to run for years on standard batteries, for a typical monitoring application.

Bluetooth (IEEE 802.15.1) is a low-cost, low-power, robust, short-range wireless communication protocol which was initially founded by Ericsson in 1994 to replace traditional mobile phone and computer cables with wireless links. It operates in the license free 2.4 GHz ISM (industrial, scientific, medical) band with a short range (power-class-dependent: 1 metre, 10 metres, 100 metres) based on low-cost transceiver microchips in each device. With the introduction of the (EDR) Enhanced Data Rate feature devices can communicate with each other at up to 3Mbps. The Bluetooth special interest group (SIG) was founded in 1998 by companies such as Ericsson, Nokia and Intel and the core system consists of an RF transceiver, baseband, and protocol stack. Bluetooth radios are designed for busy environments with many users. Up to eight Bluetooth devices can communicate together in a network called a piconet. The piconet is a point to multipoint network consisting of one master and up to seven slave devices. Multiple piconets can coexist and join together to form scatter nets. Bluetooth uses 79 1MHz channels to transmit data. Interference between other ISM band devices (802.11 and 802.15.4 devices) and other Bluetooth piconets is minimised using frequency hopping spread spectrum (FHSS), where the carrier is rapidly switched (hops) among the 79 available channels. The frequency hopping sequence is controlled by the master within the piconet. Other Bluetooth interference reduction techniques include adaptive power control, Channel Quality Driven Data Rate (CQDDR) and Adaptive Frequency Hopping (AFH).

4.2. Equipment in Use

4.2.1. Hardware Features of Device

In this subsection, the environment used in this work is presented. During this study, for BAN applications ‘*SHIMMER*’ (Sensing Health with Intelligence, Modularity, Mobility and Experimental Reusability) wearable sensor hardware is used which with its small form factor developed specifically for e-health applications[32, 33]. Table 4.2.1-1 shows the hardware specifications of the shimmer sensors and Figure 4.2.1-1 depicts the physical appearance Shimmer stands for “Sensing Health with Intelligence, Modularity, Mobility and Experimental Reusability”.

Table 4.2.1-1 - Shimmer Hardware Features

Technical Specification	Value
Microprocessor	MSP430F1611
Sensing Modes	ECG, Accelerometer, gyroscope, EMG, GSR
Analog/Digital Conversion	8 Channels, 12 Bits
Analog Expansion	Exists
Modes of Communication	Bluetooth/802.15.4
SD card support	Exists
Memory size	10Kbyte RAM, 48Kbyte Flash
Battery	280 mA
Dimensions	53mm x 32mm x 15mm
Weight (including battery)	20

Figure 4.2.1-1 - Shimmer device with ECG board

Main advantage of Shimmer device is its small factor, designed as a wearable sensor incorporates wireless ECG, EMG, GSR, Accelerometer, Gyro sensors. Shimmer sensors are small wireless sensor platform, it can record and transmit physiological and kinematic data in real-time. With this hardware EMG, ECG, GSR, acceleration, gyroscope data can be measured. The block diagram of the shimmer nodes is given in figure 4.2.1-2.

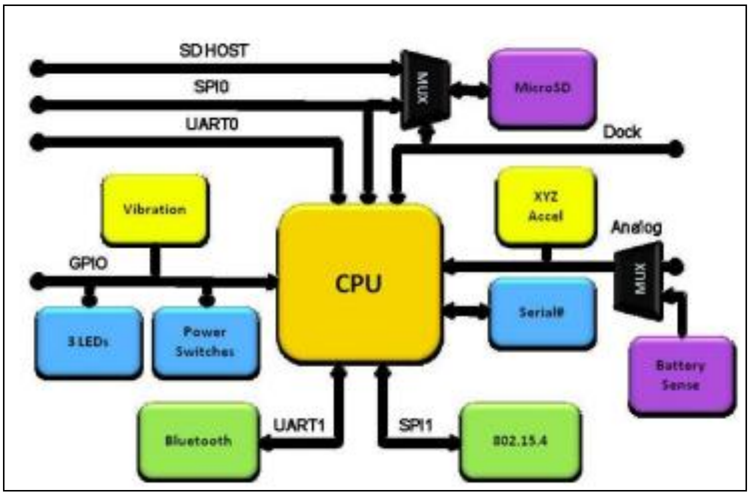


Figure 4.2.1-2- Shimmer Block Diagram

Shimmer sensor uses MSP430F1611 microcontroller[34]. For the applications, ECG, EMG, GSR boards should be connected to the shimmer in order to use it but for the accelerometer signal, it exists in default accelerometer component on the device. In figure 4.2.1-3, the internal components of the device are given with the two sides of the sensor.

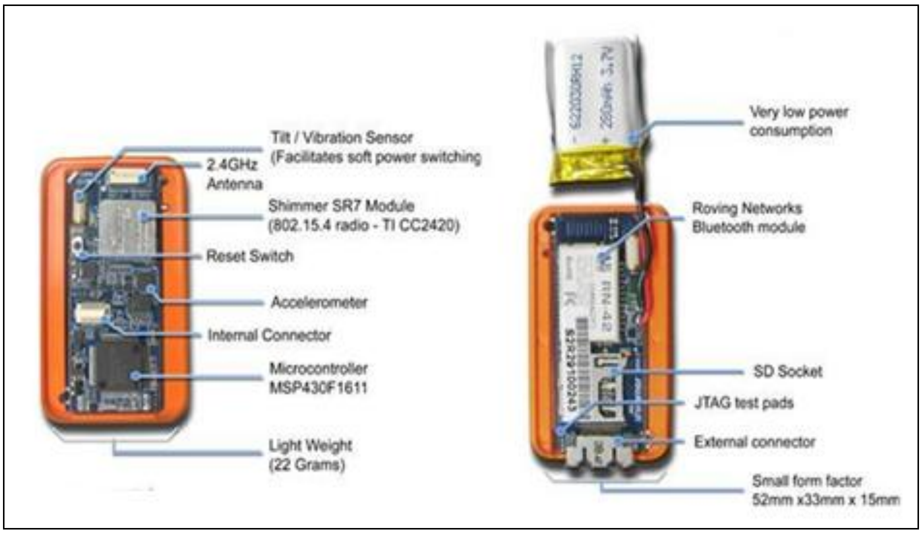


Figure 4.2.1-3 - Shimmer internal components

The SHIMMER baseboard contains a MicroSD card socket to incorporate extra memory resources, with capacities up to 2Gbytes. This prevents losing data where wireless connection is lost during streaming so that existing of SD card ensures no loss of data while mobile, during network outages or while changing batteries[35-37].

4.2.2. Software Properties and Platform Descriptions

The software part of the platform consists on TinyOS[38]. TinyOS is the special operating system runs on Shimmer nodes. TinyOS is a free and open source component-based operating system and platform targeting wireless sensor networks. TinyOS is an embedded operating system written in the nesC programming language as a set of cooperating tasks and processes. TinyOS applications are written in nesC, a dialect of the C language optimized for the memory limits of sensor networks. Its supplementary tools are mainly in the form of Java and shell script front-ends. Associated libraries and tools, such as the NesC compiler and Atmel AVR binutils toolchains, are mostly written in C. TinyOS programs are built out of software components, some of which present hardware abstractions[39]. Components are connected to each other using interfaces. TinyOS provides interfaces and components for common abstractions such as packet communication, routing, sensing, actuation and storage.

5. ENERGY AND APPLICATION AWARE APPROACH

5.1. Characterization of BAN Applications

Body area networks (BAN), wireless body area network (WBAN) or body sensor network (BSN) are terms used to describe the application of wearable computing devices. This will enable wireless communication between several miniaturized body sensor units and a single body central unit as a local center worn at the human body. The development of WBAN technology started around 1995 by considering wireless personal area network (WPAN) technologies for communications on, near and around the human body. Later around 2001, this application of WPAN has been named as body area network (BAN) to represent the communications on, in and near the body only[40, 41].

Low power integrated circuits and wireless communication has enabled a new generation of wireless sensor networks. These wireless sensor networks are used to monitor traffic, crops, infrastructure and health [9, 42, 43]. The body area network field is an interdisciplinary area which could allow inexpensive and continuous health monitoring with real-time updates of medical records via Internet. A number of intelligent physiological sensors can be integrated into a wearable wireless body area network, which can be used for computer assisted rehabilitation or early detection of medical conditions. This area relies on the feasibility of implanting very small bio-sensors inside the human body that are comfortable and that don't impair normal activities. The implanted sensors in the human body will collect various physiological changes in order to monitor the patient's health status no matter their location. The information will be transmitted wirelessly to an external processing unit. This device will instantly transmit all information in real time to the doctors throughout the world. If an emergency is detected, the physicians will immediately inform the patient through the computer system by sending appropriate messages or alarms. Currently the level of information provided and energy resources capable of powering the sensors are limiting [19, 44, 45].

Initial applications of BANs are expected to appear primarily in the healthcare domain, especially for continuous monitoring and logging vital parameters of patients suffering from chronic diseases such as diabetes, asthma and heart attacks.

A typical BAN or BSN requires vital sign monitoring sensors, motion detectors (through accelerometers) to help identify the location of the monitored individual and some form of communication, to transmit vital sign and motion readings to medical practitioners or care givers. A typical body area network kit will consist of sensors, a processor, a transceiver and a battery. Physiological sensors, such as ECG and SpO2 sensors, have been developed. Other sensors such as a blood pressure sensor, EEG sensor and a PDA for BSN interface are under development.

5.2. Heart Rate Monitoring Application

5.2.1. ECG Signal

Electrocardiograph is a transthoracic (across the thorax or chest) interpretation of the electrical activity of the heart over a period of time, as detected by electrodes attached to the outer surface of the skin and recorded by a device external to the body. An electrocardiogram (ECG) is a test that records the electrical activity of the heart[46, 47]. ECG is used to measure the rate and regularity of heartbeats, as well as the size and position of the chambers, the presence of any damage to the heart, and the effects of drugs or devices used to regulate the heart (such as a pacemaker).

A typical ECG tracing of the cardiac cycle (heartbeat) consists of a P wave, a QRS complex, a T wave, and a U wave which is normally visible in 50 to 75% of ECGs. Sample ECG signal is given in figure 5.2.1-1. The baseline voltage of the electrocardiogram is known as the isoelectric line. Typically the isoelectric line is measured as the portion of the tracing following the T wave and preceding the next P wave [40, 48-50].

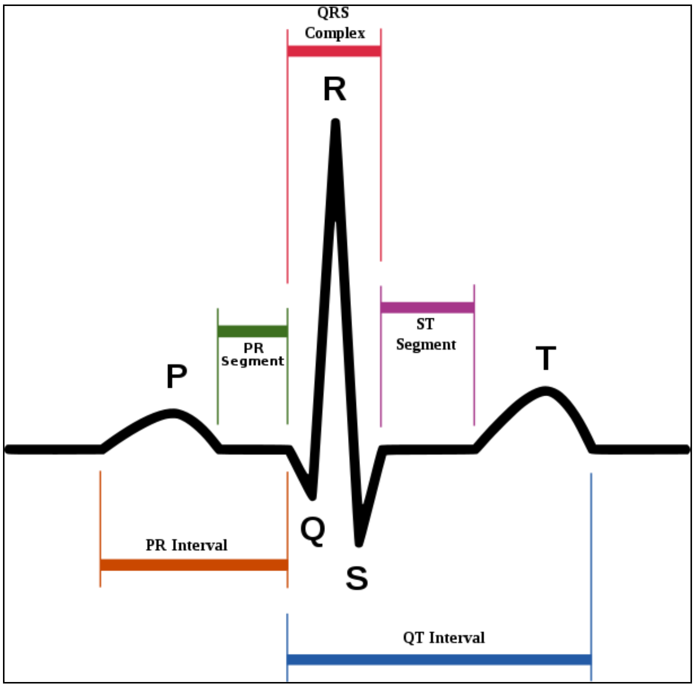


Figure 5.2.1-1 - Schematic representation of normal ECG

5.2.2. BPM Derivation

Beat per minute (BPM) or heart rate is the number of heartbeats per unit of time, typically expressed as beats per minute (bpm). Heart rate can vary as the body's need to absorb oxygen and excrete carbon dioxide changes, such as during exercise or sleep. The measurement of heart rate is used by medical professionals to assist in the diagnosis and tracking of medical conditions. It is also used by individuals, such as athletes, who are interested in monitoring their heart rate to gain maximum efficiency from their training. The R wave to R wave interval (RR interval) is the inverse of the heart rate[51, 52].

5.2.3. On Board Processing For BPM Calculation

In this work, with Shimmer sensor devices, ECG signal is measured and then by using on board processing and the high computation property of microcontroller, BPM value is calculated and is sent to local center[53].

In figure 5.2.3-1, shimmer device and its ECG board is shown. ECG board has four connection pins. The connections of these pins are established by the leads according to the right side of the same figure. This type of connection is called Einthoven’s triangle. Einthoven’s triangle is an equilateral triangle whose vertices lie at the left and right shoulders and the pubic region and whose center corresponds to the vector sum of all electric activity occurring in the heart at any given moment, allowing for the determination of the electrical axis. Einthoven's triangle is approximated by the triangle formed by the axes of the bipolar electrocardiographic (ECG) limb leads I, II, and III. The center of the triangle offers a reference point for the unipolar ECG leads.

RL: ground

Figure 5.2.3-1 - Shimmer ECG board connection

The flow chart of this process is given in Figure 5.2.3-2. ECG firmware starts with the device and environment preparation and then the connection is established. After this pre-process, sensor starts sampling ECG signal. By on board processing BPM value is calculated and then the result of this calculation is sent to the local center by Bluetooth.

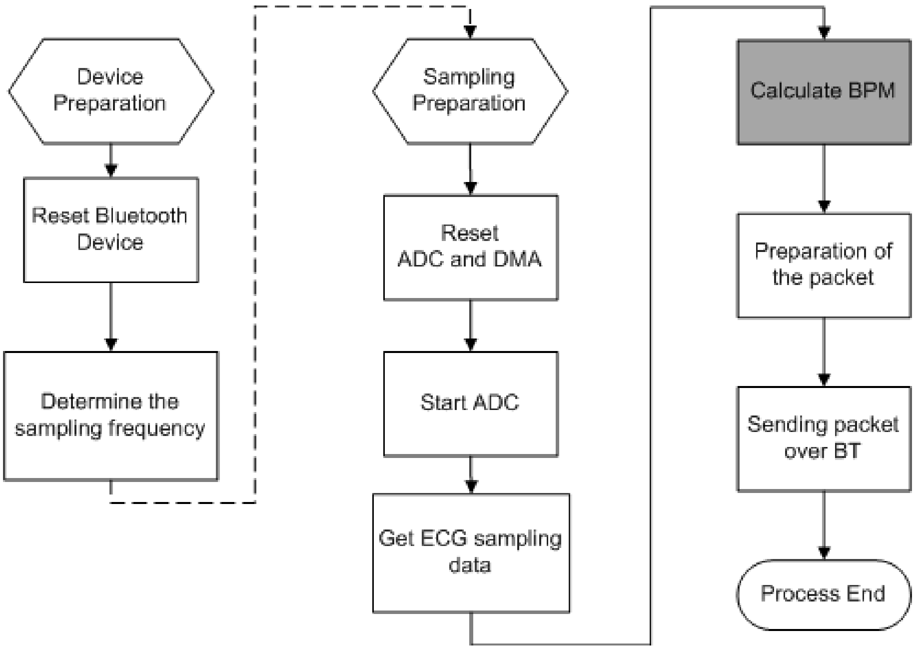


Figure 5.2.3-2 - ECG firmware flow chart

In the calculation of BPM value, we use R peak of the ECG signal and the time difference between two R peaks. The flow chart of the process for finding R peaks and then the calculation of BPM value is given in Figure 5.2.3-3.

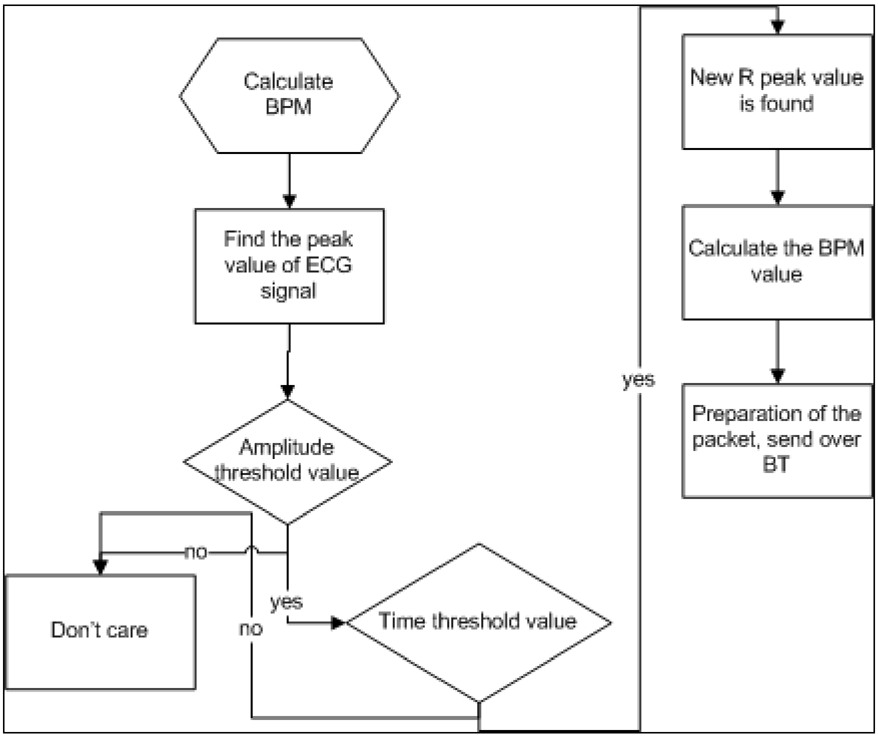


Figure 5.2.3-3 - Flow Chart of Calculation of BPM value

In the ECG signal, we use amplitude threshold to find the R peak value. The ECG signal with 2 R peaks is given in Figure 5.2.3-4. For the calculation, time values of R peaks are important. In this figure below:

x axe represents time in seconds

y axe represents the value coming from ADC in sensor device

R1: First QRS peak

t1: time value of R1

R2: Second QRS peak

t2: time value of R2

BPM = 60 / (t2 - t1)

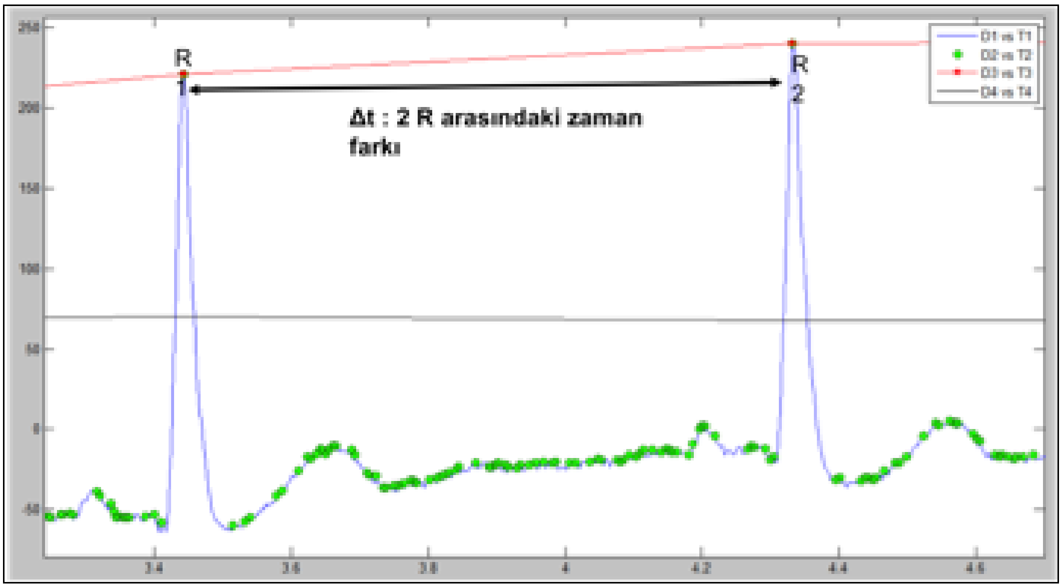


Figure 5.2.3-4 - Finding R peak of ECG signal

With the on board BPM calculation, instead of sending 500 packets in one second, sensor device sends just the BPM value in each second approximately so that by decreasing the number of sent packets, we obtain a great gain of energy. While current usage of CPU increases from 0.5 to 1 mA, current usage of Bluetooth module decreases from 20mA to 2mA and the lifetime of the sensor becomes 3.8 days which means 6 times longer lifetime. These values are given in Table 5.2.3-1. It is clear that instead of using Bluetooth module, using computation property of microcontroller will be a good choice for energy gain.

Table 5.2.3-1 - Result of ECG Monitoring application

Result Values	**Central Calc.**	**Embedded Cal.**
MCU Av. Cur	0.5 mA	1mA
Bluetooth Av. Cur	20 mA	2mA
Analog/Dig. Conv.	~0.01mA	~0.01mA
Monitoring period	0.5 days	3.8 days

5.3. Pedometer Application

In this section, another application used with Shimmer Sensor Device will be presented. The name of the application in this case is the “Pedometer”. In general a pedometer is a device, usually portable and electronic or electromechanical, that counts each step a person takes by detecting the motion of the person's hips or legs.

Pedometer devices are used originally by sports and physical fitness enthusiasts, pedometers are now becoming popular as an everyday exercise measurer and motivator. Pedometers can be a motivation tool for people wanting to increase their physical activity. Various websites exist to allow people to track their progress; however, many will also find entering their daily step count and a heart rate onto a calendar to be motivational as well. Pedometers have been shown in clinical studies to increase physical activity, and reduce blood pressure levels.

5.3.1. Accelerometer Based Pedometer

The technology for a pedometer includes a mechanical sensor and software to count steps. Early forms used a mechanical switch to detect steps together with a simple counter. If one shakes these devices, one hears a lead ball sliding back and forth, or a pendulum striking stops as it swings. Today advanced step counters rely on 1-, 2- or 3-axis detection of acceleration. In our application, we used 3 axis accelerometer of our Shimmer sensor[54]. Figure 5.3.1-1 shows the functional block diagram of

MMA7260Q accelerometer component. Pedometers which are based on accelerometer are called “Piezoelectric” because these pedometers use a piezoelectric strain gauge which bends to accurately record each step taken. These pedometers have no moving parts, therefore any clicking sound. Accelerometers can be worn on the waist, on the wrist, in a pocket or hang from a lanyard around the neck (depending on the model). This sophisticated technology is user-friendly and offers greater motivation and goal setting tools for every walker. They are accurate and reliable. There’s no doubt pedometers based on accelerometer signal will replace the traditional pendulum pedometer in the near future.

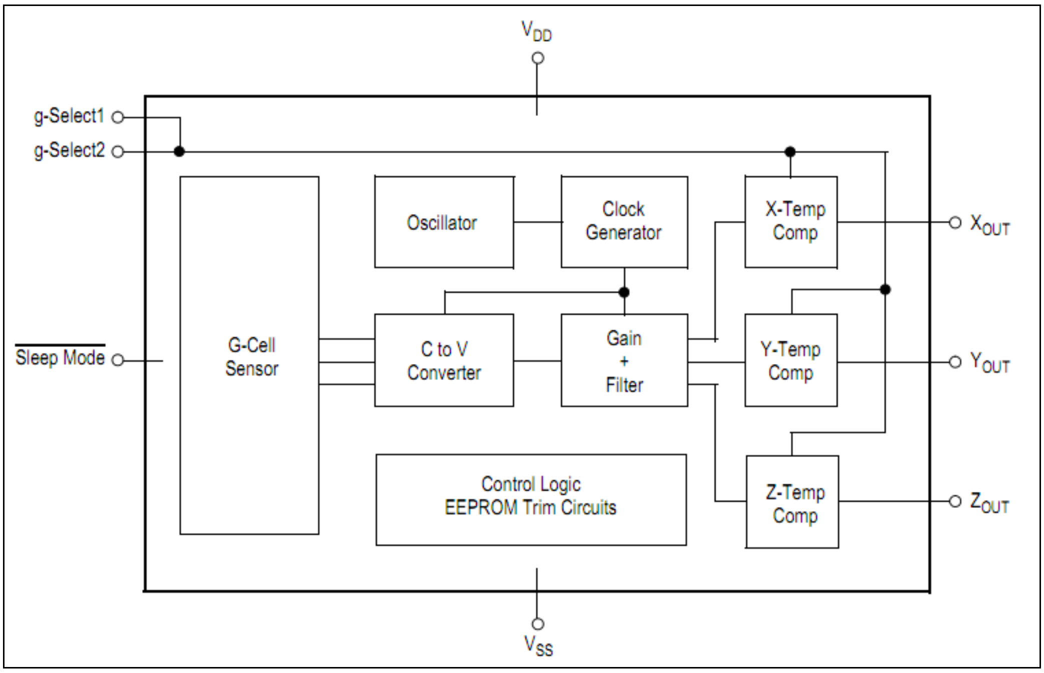


Figure 5.3.1-1 - Simplified Accelerometer Functional Block Diagram

5.3.2. On Board Processing For Step Count

In this application, the accelerometer firmware is used with the sampling frequency 200Hz. As our goal is to analyze the measured data instead of sending all measures, sending packet frequency will be less than sampling frequency. In order to detect the steps, first of all we should gather measured values coming from 3 axis accelerometer. We take sum of squares of 3 axis measured data. For us, finding the peak points are useful to detect if it is a real step or not. To know that a point is a peak, we should compare it with the pervious and the next measured values. If the compared data is bigger than these samples, it means that it is a peak and it is a potential step for our application. For eliminating the false step detections and to be sure that the peak value is relevant, the peak value should pass the threshold value. The determination of the threshold value is related with the ADC device settings. So if the measured value is higher than its neighbors and the threshold value, this peak point is relevant for a step in term of amplitude.

Another important point is the time domain. Between two steps, there should be a meaningful time difference. The time difference is put in order to prevent the false step detections. To be able to measure the time difference between two steps, the previous step must be saved temporary. In our on board algorithm, the time difference cannot be less than 0.35 second. So the comparison between the time values of detected possible steps is necessary. Figure 5.3.2-1 given in below shows the thresholds used to detect the steps. X axe represents time in seconds and y axe represents value of ADC coming from ADC.

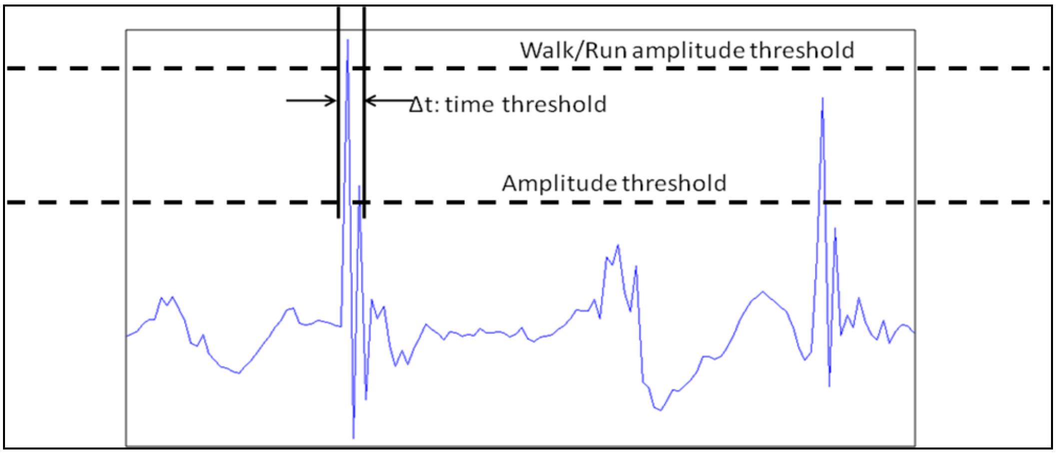


Figure 5.3.2-1- Detecting Step

Furthermore the Shimmer device in our application is attached to person’s ankle. With the accelerometer signal, it is possible to detect each step done by foot left or right although the signal coming from the ankle which holds the shimmer sensor device is stronger and more characteristic. Simple accelerometer signal coming from shimmer is given in Figure 5.3.2-1.

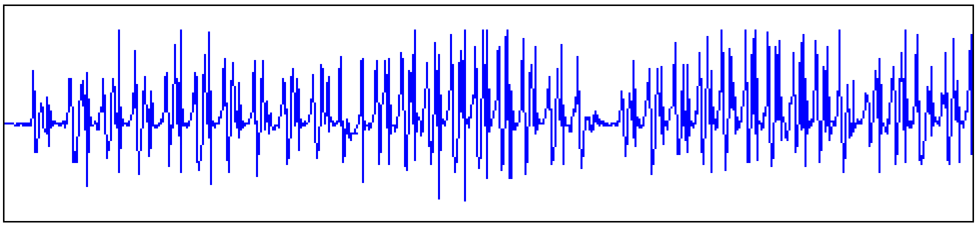


Figure 5.3.2-2 - Simple Accelerometer Signal

After detecting peaks and comparison time difference, we can detect the steps as in Figure 5.3.2-2.

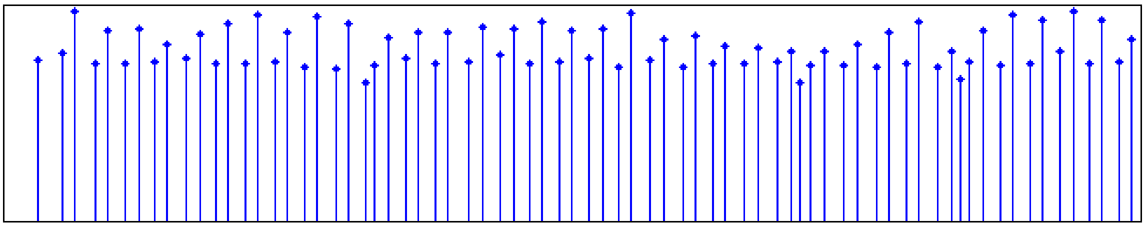


Figure 5.3.2-3 - Detected Steps

In our case, we do this process on board and instead of sending all sampled measures to the local center; we detect the steps with our embedded computation. Figure 5.3.2-3 shows the flow chart of our on board algorithm.

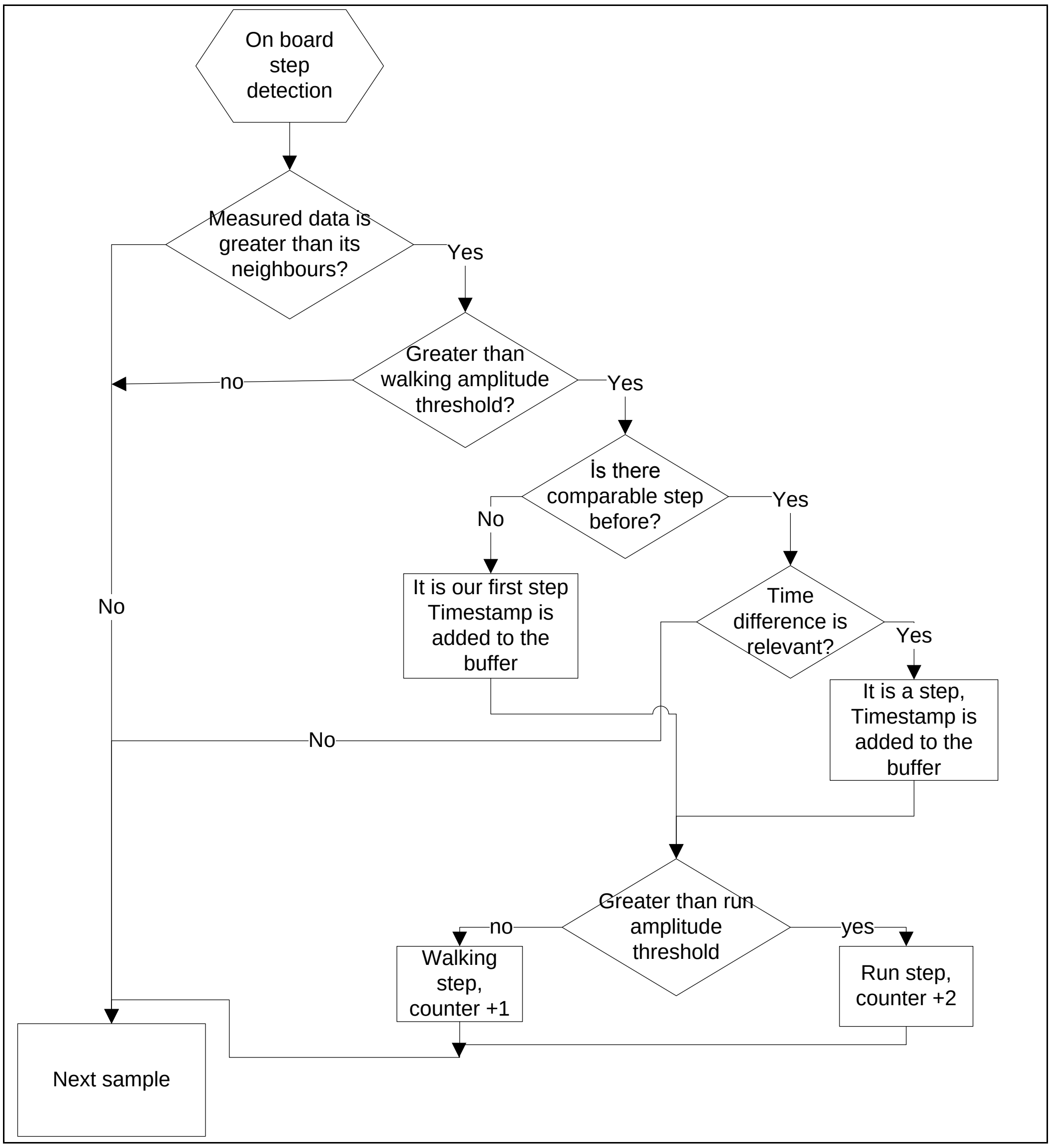


Figure 5.3.2-4 - Step Detection Flow chart

5.3.3. Dynamic Sleep Schedule Based Operation

Until now, communication frequency is related with the step detections. When the step is detected, it sends a signal to the local center to say that step is detected; step counter may run either on sensor or the local side.

When analyzing the graphs and the steps considering the step times, it is clear that it is possible to make the sensor sleep while waiting the next step. In this case, in order to set the sleep duration properly, it is highly necessary to know the step frequency. So that determination of the sleep duration is calculated by using the step frequency. Step frequency can be calculated by analyzing the previous detected steps. The question is: “how many steps are necessary to calculate the step frequency?”. This depends on the precision required. In our case, the calculation of step frequency is done by considering last 5 steps. In fact, only the time difference of these 5 steps can give us the step frequency. At the same time, doing a small storage of the recent steps gives us a chance to make better comparisons during step detection. Instead of comparing with only the last step, with using this buffer, we are able to compare the possible step by existing several steps.

It is normal that while monitoring steps of a person, the walking speed won’t be the same all the time. There will be transition between different sort of movements like walking, running or stop walking. In these cases, the frequency will change and the frequency must be recalculated in order to determine the sleep duration if it is possible. So, for each detected step, it is necessary to control if there is a deviation of frequency of steps or not. If the step frequency is changed according to the comparison, than for the sleep cannot be occurred, before setting the sleep duration, we need to store steps for samples to calculate the new step frequency and then the sleep duration time can be calculated by using new steps and new step interval times. The estimation of the next step is given in Figure 5.3.3-1.

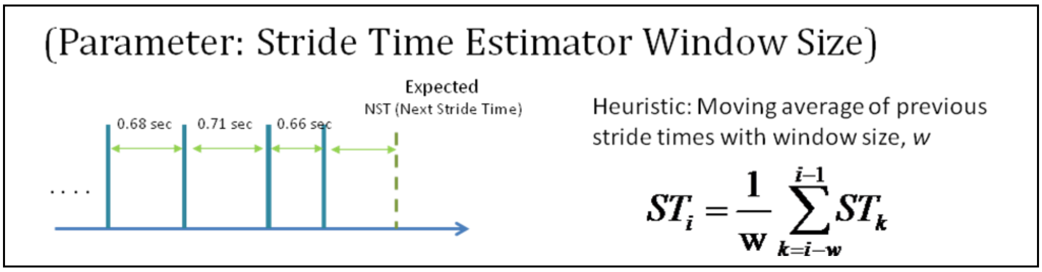


Figure 5.3.3-1 - Estimation of next stride time

As it is indicated in the previous sections, before passing the sensor to the sleep mode, the period of movement or gait regime should be calculated firstly. So there are some parameters in order to realize this sleep process. With the parameters that will be explained, the sleep or awake state or sleep duration can be chosen according to these parameters.

- Averaging Windowing Size

In order to determine the sleep duration, first of all, the step frequency should be known. Having an averaging windowing size as a buffer with a determined size can help to calculate the frequency. It is up to the user to set the windowing size. In our experiments averaging windowing size can be given by manual or set a desired size by using the configuration file where all the parameters of the system are located. The importance of the averaging window size is the start point of sleep period because, for passing the sensor node to the sleep mode, the averaging window should be filled with step times so that the average of time difference of each steps can be calculated which means the frequency of step. In our experiments we use the buffer size as 5 steps but can be modified by using the configuration file.

In the case where the step frequency changes, it is necessary to recalculate the new frequency by using new steps so, the buffer will be clear and refill it with new steps. The decision of this action will be explained in this section.

- Alpha, Instantaneous Duty Cycle

Parameter “alpha” is a coefficient to determine the sleep duration. After the calculation of the frequency, the step frequency is multiplied by this coefficient in order to set the sleep duration. The relation between α and the sleep duration is given in the equation (5.3.3.1)

$$\boxed{T_{sleep,i} = \alpha \, . ST_i}$$

Equation 5.3.3-1 - relation between alpha and sleep duration

In equation 5.3.3-1, $T_{sleep,i}$ represents the sleep duration just after the ith step and ST_i means the ith stride time. The coefficient alpha can vary between 0 and 1. When alpha is equal to 0, sleep duration becomes zero which means that sleep mode is off and the sensor continues sampling. On the other hand, when the value of alpha becomes 1, this means that the sleep duration is exactly equal to step frequency. The sleep duration and the estimated stride time is given in Figure 5.3.3-2.

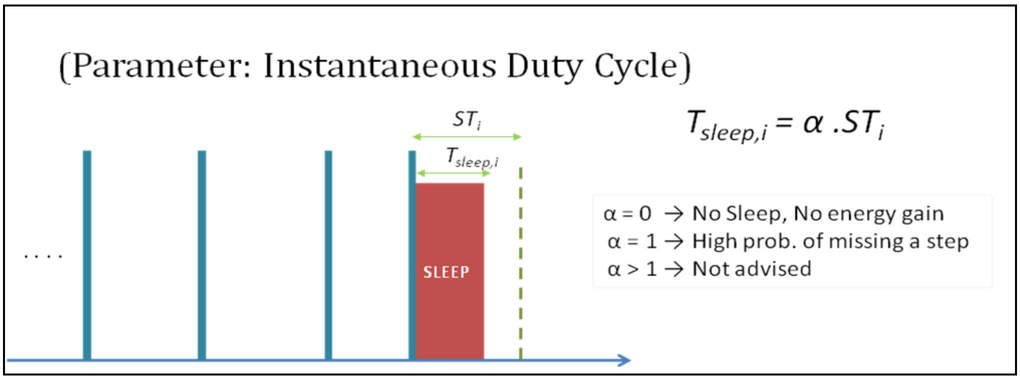


Figure 5.3.3-2 - Instantaneous Duty Cycle

- Stride Time Deviation Tolerance, β

Parameter 'deviation' is used while taking decision whether the step detected belongs to the movement stored in the buffer or not. This decision is related with the ratio of the instantaneous time difference of stride time and the step frequency calculated by using averaging window. In fact deviation is a percentage of acceptances of a new step. The formula for the deviation is given in the equation 5.3.3-2. Setting a time deviation tolerance in fact creates an interval for us. It uses the average of stride times (step period) and then it takes the difference between this value and the new stride time which is detected lastly and it calculates the percentage of deviation as indicated in the formula below.

$$\boxed{\frac{\left|ST_{i,Actual} - ST_i\right|}{ST_i} \le \beta}$$

Equation 5.3.3-2 - Time Deviation Tolerence

If the time difference over the last stride time is less than the tolerance value, it means that the detected step belongs to same manner of movement. Otherwise, it is considered by another movement. In this case, the sleep duration cannot be calculated because the stride times that are located in the averaging window represent past movement. For the sleep duration, these stride times cannot be used so, it is highly necessary to make the buffer empty and stoke new strides in order to recalculate the sleep duration. While filling the window, the sleep mode is off. When the averaging window gets full and new step frequency can be calculated then the sleep mode can pass active.

6. PERFORMANCE EVALUATION

In this section, the experiments related with the applications explained in the previous section and its results are presented. Also the sensor device used in these experiments is presented. Experiments show us some restrictions related due to the device we use. Actually with the shimmer sensor device, we use Bluetooth technology for the wireless communication protocol. Shimmer device has two main modes: command mode and data mode. In command mode, the configurations and the parameters are set according to the selected firmware and selected communication protocol. Once all configurations are done, the device does not return to command mode again[55]. After the command mode, it passes to data mode where it starts sampling and sending/registering on SD card.

In application where we use sleep duty cycle, device in real time changes the sleep duration which means a process should occur in command mode. As the reason indicated, we didn't find a solution for this. That's why we needed another tool to realize, to simulate our experiments. On the other hand, using a tool may create some cases that cannot occur in the experiments. We used synthetic data generator in order to analyze these cases.

6.1. Synthetic Data Generator

As in the previous part, we explained the reason why we need another tool for the experiments. For the solution, we created our own data generator. In our experiments, first thing to do is the determination of the step and then time difference of steps, so that in our tool, we can generate step times as we want with, giving some parameters to the simulator.

For generating step times, we made a configuration file in which we put the parameters for the simulation. First of all, we give the number of steps we want to have at the end of the generator. Also we can have a chance to decide to separate these steps in small intervals with giving the average of stride time and its random interval.

Table 6.1-1 - Configuration of stride time

First step	**Last step**	**Average stride time**	**Interval (±)**
1	100	0.7	0.1
101	150	0.6	0.05
151	200	0.5	0.1
201	300	0.4	0.1

In Table 6.1-1 above, sample configuration parameters are given. First column shows the beginning of the interval, second column is the end of this interval. Third column shows the stride time generated randomly by the simulator with using the interval given in the fourth column.

From the table, we understand that there are at total 300 steps finally. From first to the 100^{th} steps, stride time will be generated from the interval [0.6; 0.8], from 101th to 150^{th} steps, stride time will be generated between values [0.55; 0.65]. The last row indicates that from 201^{th} to 300^{th} steps, stride time will be chosen between the values [0.3; 0.5].

For an experiment more scientific, only one data set is not sufficient, for this reason, with the same parameters, more experiments should be done in order to get more concrete result. In this case, we gave another parameter “a number of cycles”. This means the number of times the simulator will use the configuration file and the number of dataset will be created.

6.2. Data Analyzer

After generating stride times, it is necessary to analyze them. By using synthetic data generator tool, we don’t need step detection algorithm because the simulator gave us steps. With the stride time, we can use the duty sleep schedule algorithm. The process is the same as just after detecting the step. Parameters averaging windowing size, alpha and stride time deviation are available in this case also. In order to analyze the effect of these parameters, in the configuration file, alpha and deviation parameters are given. For each value of alpha and stride time deviation, the dataset is reanalyzed. In our experiments, we made an interval for the parameter alpha, $\alpha \in \{0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1\}$ and for the stride time deviation $\beta \in \{0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9\}$. Data analyzer runs the same algorithm by using each parameter and the number of cycles reported in the previous section. Number of running the algorithm is ***N * card(α) * card(β)***.

6.3. Experiment Data Sets

We have 2 real data sets:

- Data set 1: 30 sec walking & running
- Data set 2: 20 sec walking, 10 sec downstairs, 50 sec walking again

We have 2 synthetic data sets:

- Data set 1: 440 steps with gradually increasing speed
- Data set 2: 100 steps with constant speed

6.3.1. Real Data Set - 1

First real data set is a combination of walk run and with the duration 90 seconds. Figure 6.3.1-1 shows the 90second data set. Between 39 and 44 seconds, it’s the running period of the experiment. For this experiment, parameters are given below:

- w = 5 (Stride Interval Estimator Window Size)
- α = 0.1 – 0.2 – 0.3 – 0.4 - 0.5 – 0.6 – 0.7 – 0.8 – 0.9 – 1
- ß = 10 – 20 – 30 – 40 - 50 – 60 - 70 – 80 – 90 (percentage)

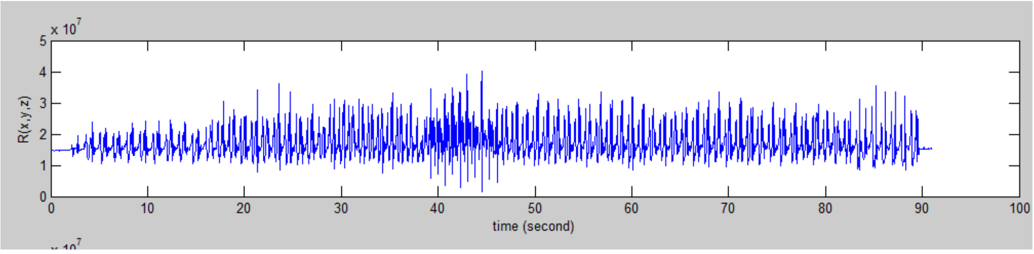


Figure 6.3.1-1 - Walking-Running Accelerometer Signal

In Figure 6.3.1-2 gives the summary of the experiment with the real data set. First row is the pure signal without any pre-processing. Normally, in order to get clearer signal, we do double windowing on the sampled data before detecting steps for getting clear and meaningful signal.

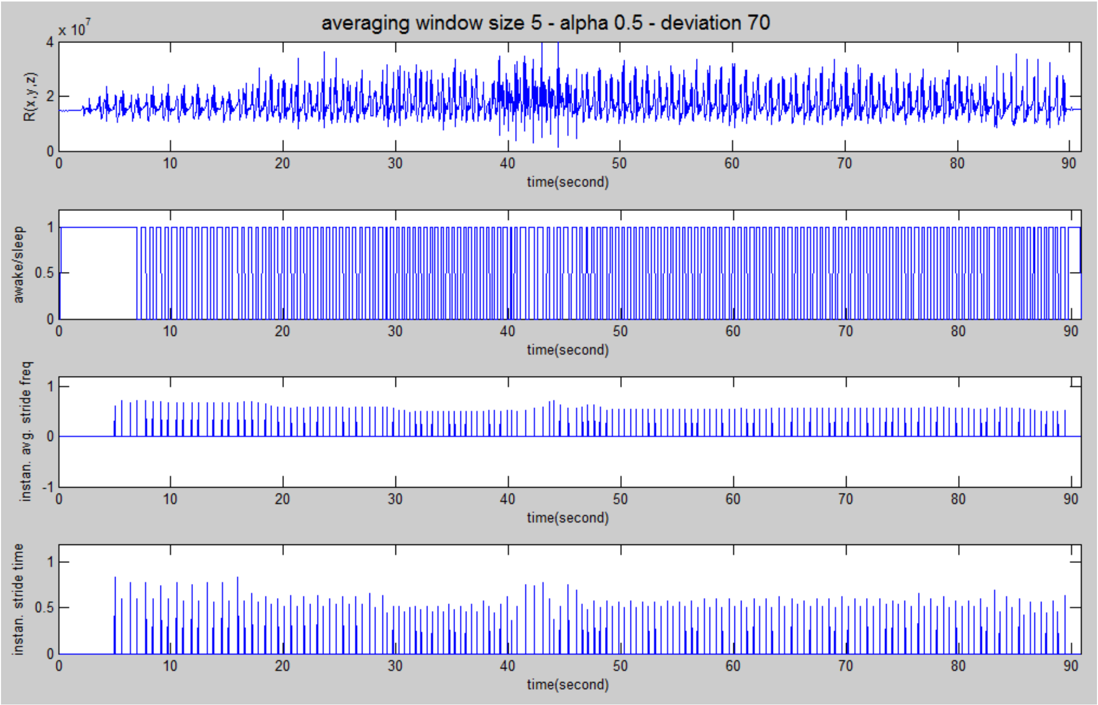


Figure 6.3.1-2 – Real Data Set No: 1 Case: <w=5, α=0.5 β=0.7>

The second row of the same figure is the awake/sleep state of the sensor device. In that minor graph, zero (0) signifies the sleep duration and one (1) means that sensor is awake and works on sampling. As the coefficient for the sleep schedule is set to 0.5, sleep duration is half of the average stride time storage in the buffer whose size is 5.

For all graphs, x-axis shows the time in terms of seconds. In the third row, instantaneous average stride frequency is given. This means after starting the storage stride times in the buffer, we can calculate the average stride times by using the existing stride times in the buffer. The fourth row is also related with the stride frequency. It shows the instantaneous stride time which means the time difference between the current stride and the stride that last detected.

In this case with the given parameters there is not any lose of step. Buffer doesn’t need to be clean up for the new type movement because the sleep duration coefficient is not high and the stride time tolerance is acceptable.

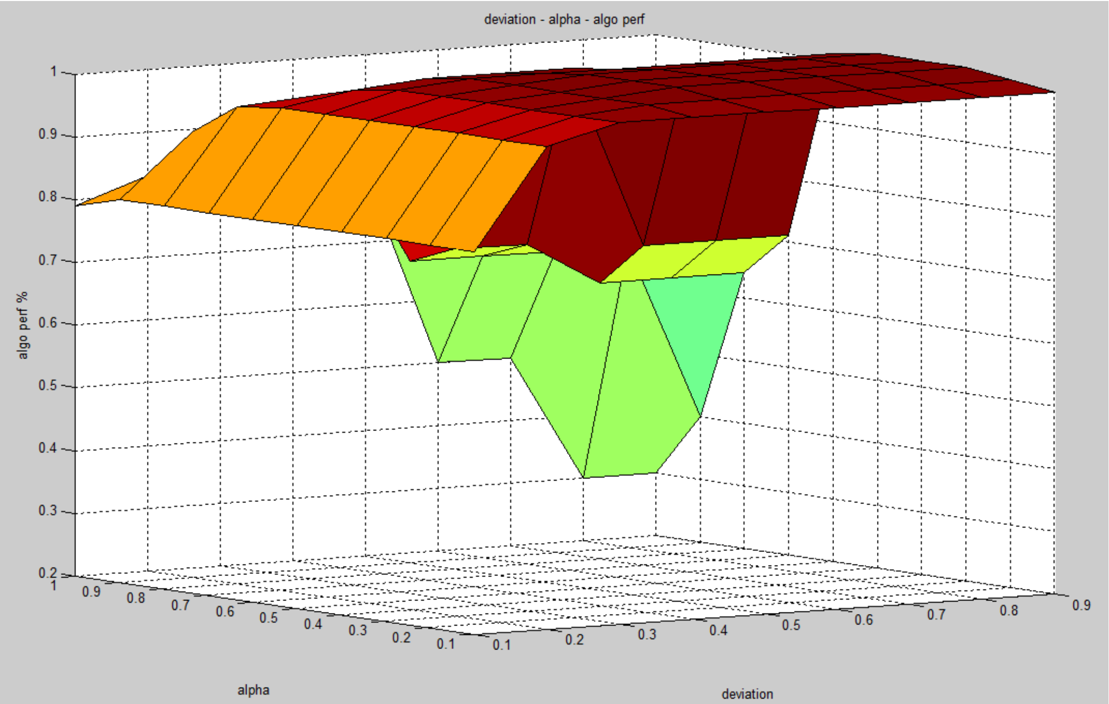


Figure 6.3.1-3 - Data Set No: 1 - Pedometer Algorithm Performance

In Figure 6.3.1-3, pedometer algorithm performance is given.

Axes are below:

- x: alpha
- y: deviation
- z: algorithm performance (%)

It is clear that for the alpha ϵ [0.1, 0.7], algorithm performance is really good but when the coefficient alpha passes 0.8, we begin to miss the steps; on the other hand for the deviation with high values, again we miss steps, because of the high tolerance value, we continue sampling and continue sleep process. That explains the sharp dive for the deviation close to 0.9 and alpha also.

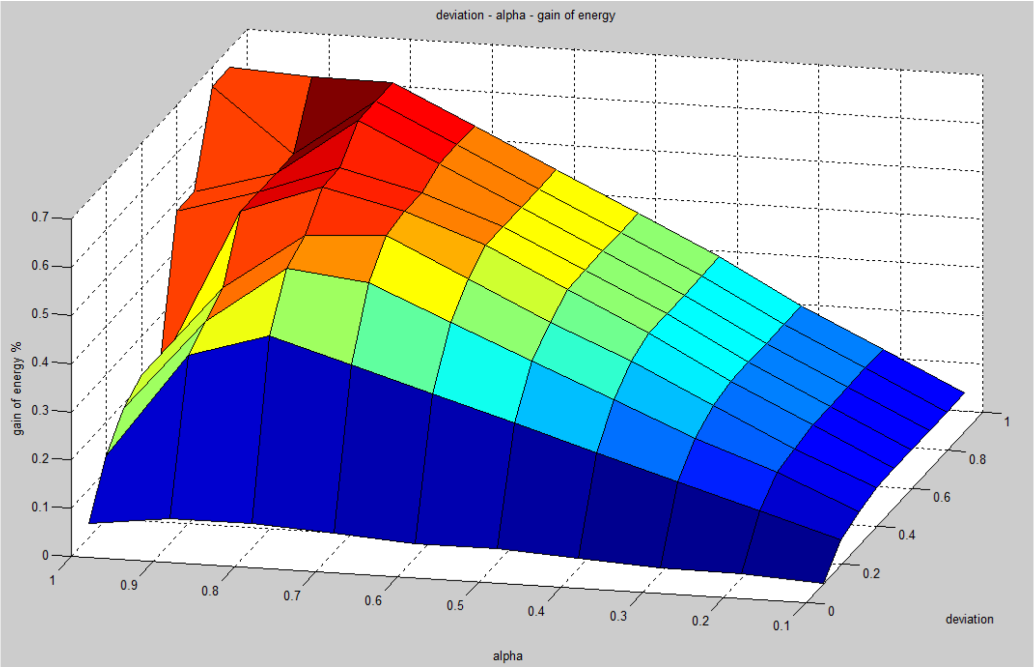


Figure 6.3.1-4 - Data Set No: 1 - Gain of Energy

In Figure 6.3.1-4, the gain of energy is given. This time, z axe shows the gain of energy (%). As the coefficient alpha increases, gain of energy increases also because the time passed in the sleep state gets higher, but on the other hand, because of the same reason that cited in the previous figure, for the deviation and alpha values greater than 0.7, 0.8, we start to miss steps. Rise in the parameters makes the sleep duration longer which results with gain of energy but after 0.7 and 0.8, when we start to miss steps, our algorithm considers the steps as a new movement so that sleep mode turns off and gain of energy decreases.

In Figure 6.3.1-5, both metrics algorithm performance (above one) and gain of energy are given in the same graph. This graph shows us the area where we can get high performance with less consumption of energy. For the area where alpha parameter is near 0.7 and the tolerance value 0.6, we can reduce more energy without losing algorithm performance.

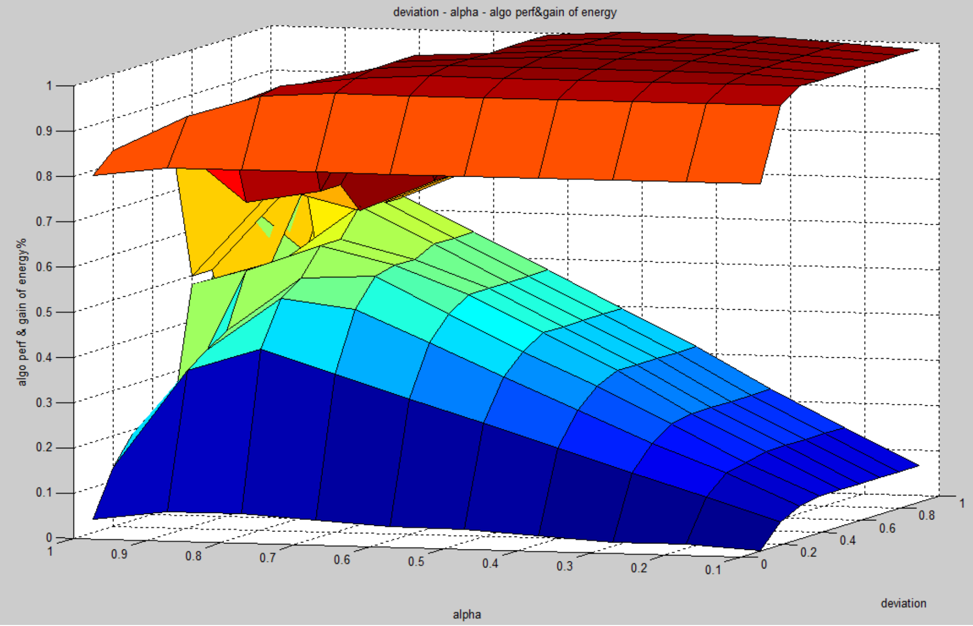


Figure 6.3.1-5 - Data Set No: 1 - Both Metrics

In order to see the cost and the algorithm performance, we calculated algorithm performance divided by (1-enery gain). So that we can compare for which performance, we consume energy. Figure 6.3.1-6 shows related graph.

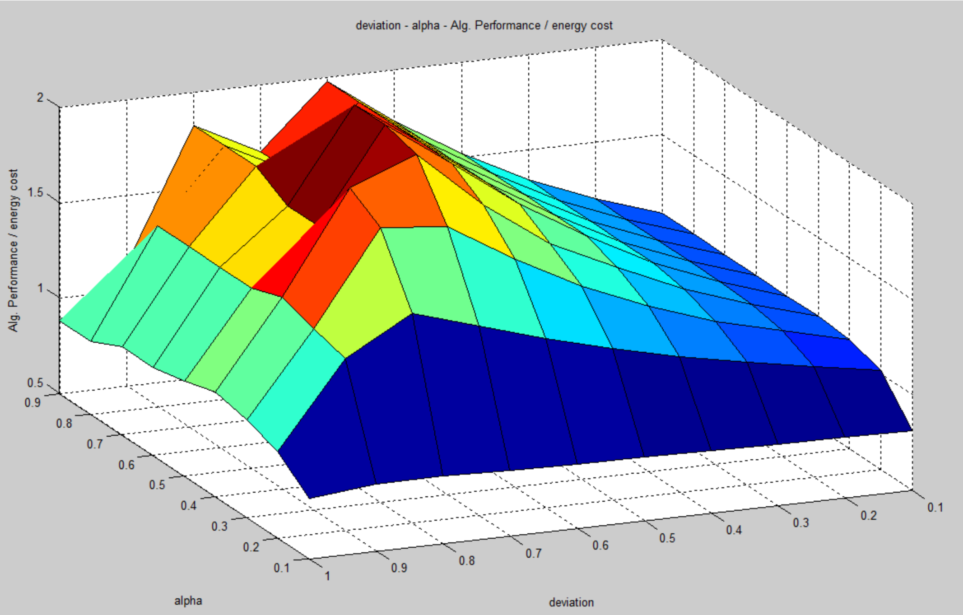


Figure 6.3.1-6 - Algorithm performance / energy cost

6.3.2. Real Data Set -2

Second real data set is 70 seconds of walking including 10 seconds of downstairs. Figure 6.3.2-1 shows the 80second data set. For this experiment, parameters are given below:

- w = 5 (Stride Interval Estimator Window Size)
- α = 0.1 – 0.2 – 0.3 – 0.4 - 0.5 – 0.6 – 0.7 – 0.8 – 0.9 – 1
- ß = 10 – 20 – 30 – 40 - 50 – 60 - 70 – 80 – 90 (percentage)

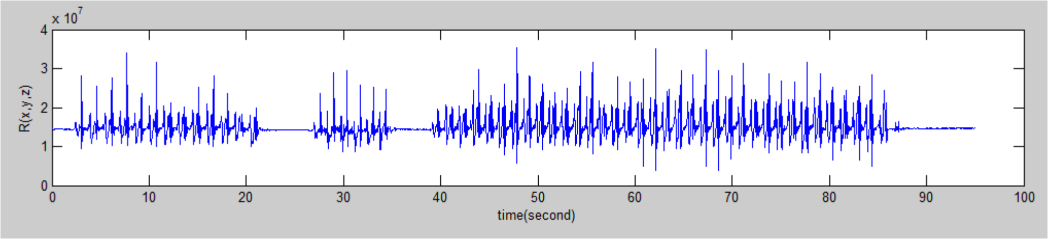


Figure 6.3.2-1 - Walking Accelerometer Signal of real Data set No:2

In this experiment, a different gait regime "downstairs" exists where it is difficult to detect all steps. This is the main reason why during downstairs gait regime, step detector algorithm does not work properly. Case w=5, alpha=0.3 and deviation=0.9 is given in Figure 6.3.2-2. For the walking periods, because of the low sleep duration and high deviation value, algorithm thinks that there is no miss step.

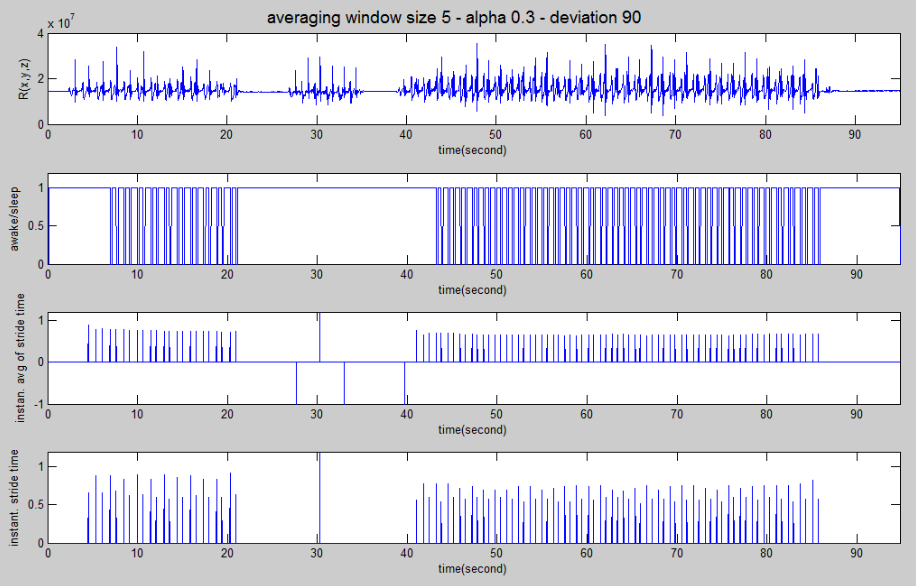


Figure 6.3.2-2 – Real Data Set No: 2 Case: <w=5, α=0.3 β=0.9>

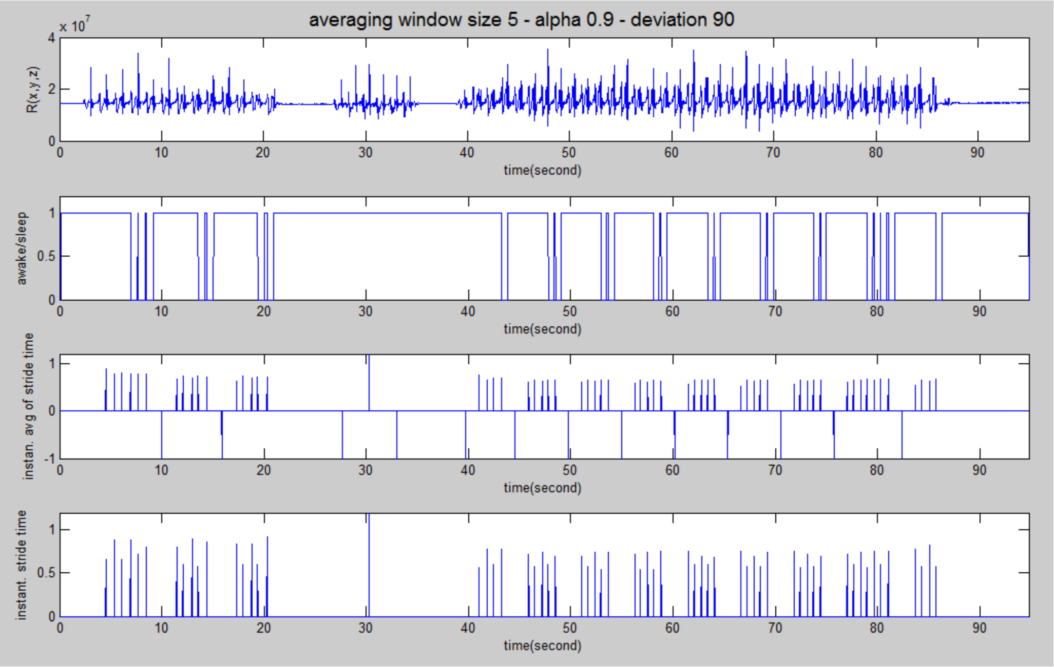


Figure 6.3.2-3 - Real Data Set No: 2 Case: <w=5, α=0.9 β=0.9>

In another case where we increased just the alpha parameter, we observe that sleep duration increases and we start missing steps. So that we turn off sleep schedule and wait until we fill the averaging windowing size in order to go to sleep mode again. As a result, figure 6.3.2-4 shows the algorithm performance and 6.3.2-5 gain of energy.

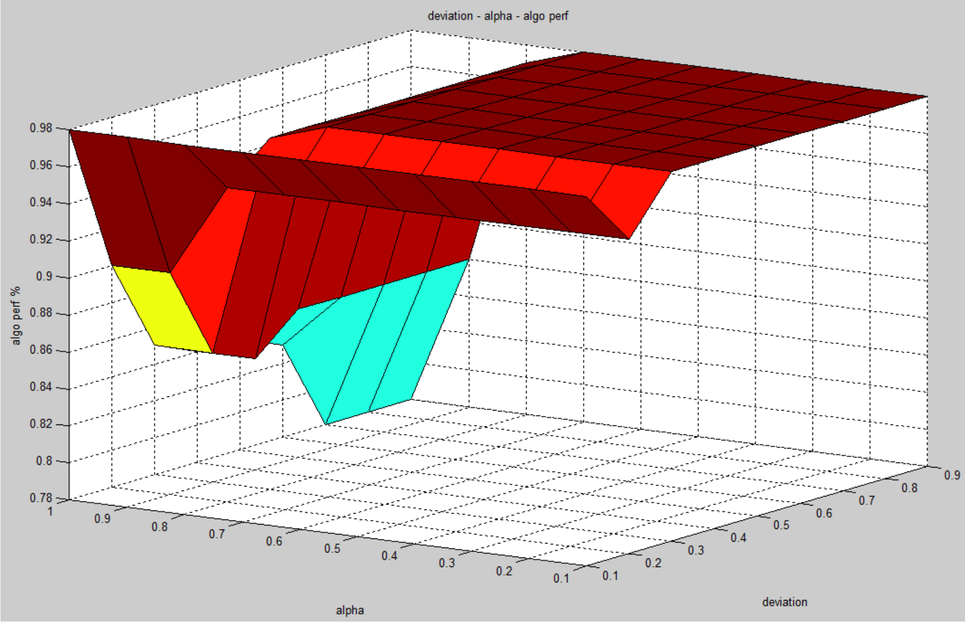


Figure 6.3.2-4 - Real Data Set No: 2 - Algorithm Performance

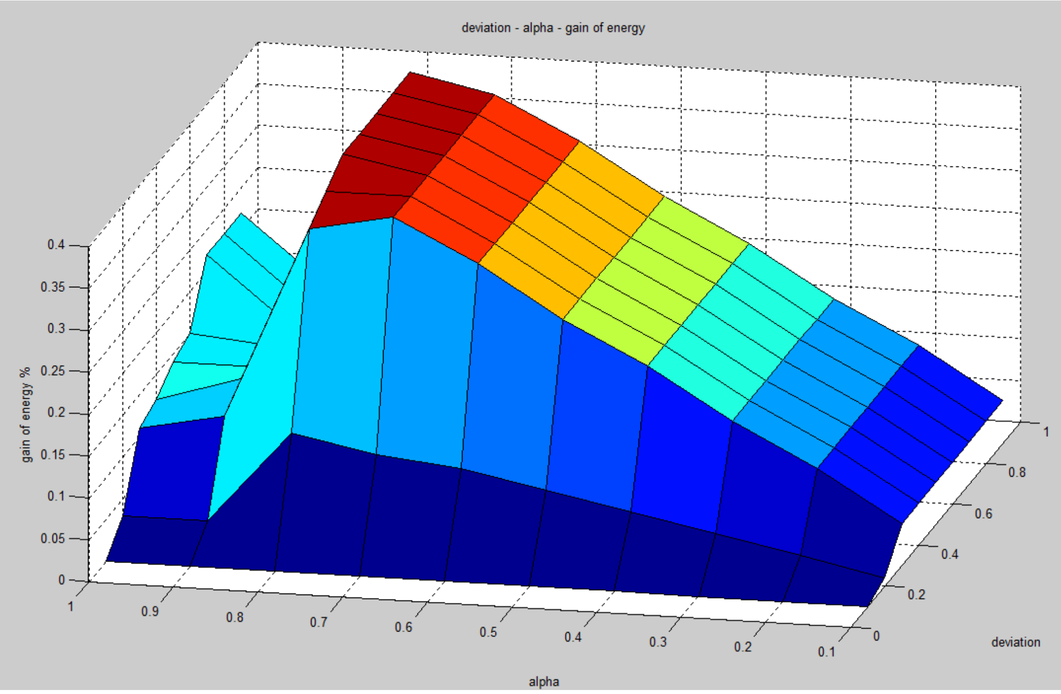


Figure 6.3.2-5 - Real Data Set No: 2 - Gain of Energy

When we combine algorithm performance and gain of energy, we obtain Figure 6.3.2-6.

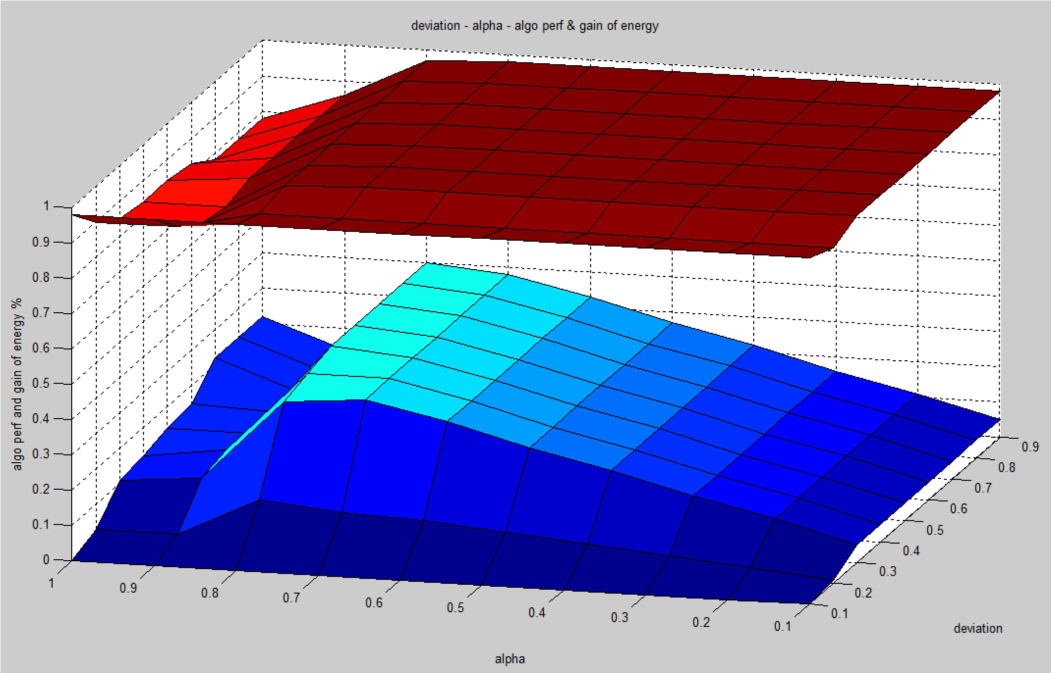


Figure 6.3.2-6 - Real Data Set No: 2 - Both Metrics

6.3.3. Synthetic Data Set -1

By the simulator that we created for this work, we can generate stride times with the parameters given in the configuration process of the simulator. In one of the synthetic data, here is the number of steps and the internal intervals

- Duration: 440 steps
    - Steps [1,200] with period 0.7s ±0.1
    - Steps [201,220] with period 0.65s ±0.1
    - Steps [221,230] with period 0.6s ±0.1
    - Steps [231,240] with period 0.55s ±0.08
    - Steps [241,440] with period 0.5s ±0.06

- Experiment Parameters:
    - w = 5 (Stride Interval Estimator Window Size)
    - α = 0.1 – 0.2 – 0.3 – 0.4 - 0.5 – 0.6 – 0.7 – 0.8 – 0.9 – 1
    - ß = 10 – 20 – 30 – 40 - 50 – 60 - 70 – 80 – 90 (%)
    -

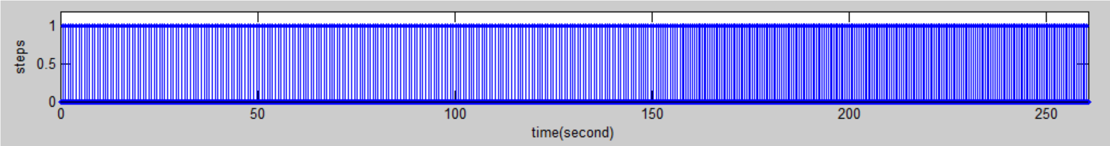


Figure 6.3.3-1 - Synthetic Data Set No: 1 – Stride Times

Figure 6.3.3-1 shows the stride times. As it is indicated in the experiment parameters and steps, the step frequency increases during the experiment, this phenomena is seen in the right side of Figure. The frequency of the bars which indicate steps are getting denser in the right side of Figure.

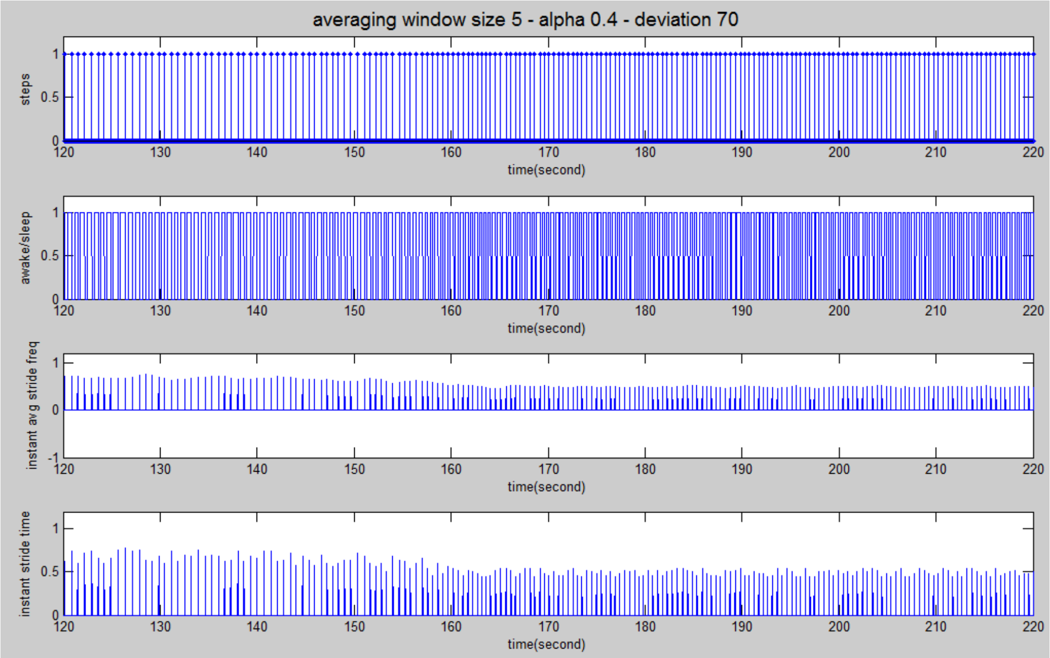


Figure 6.3.3-2 - Synthetic Data Set No: 1 - Case: <w=5, α=0.4 β=0.7>

In Figure 6.3.3-2, the summary of the experiment with the synthetic data is given. The four rows are the same as the previous one with the real data except in the first row which shows just the stride time instead of original signal.

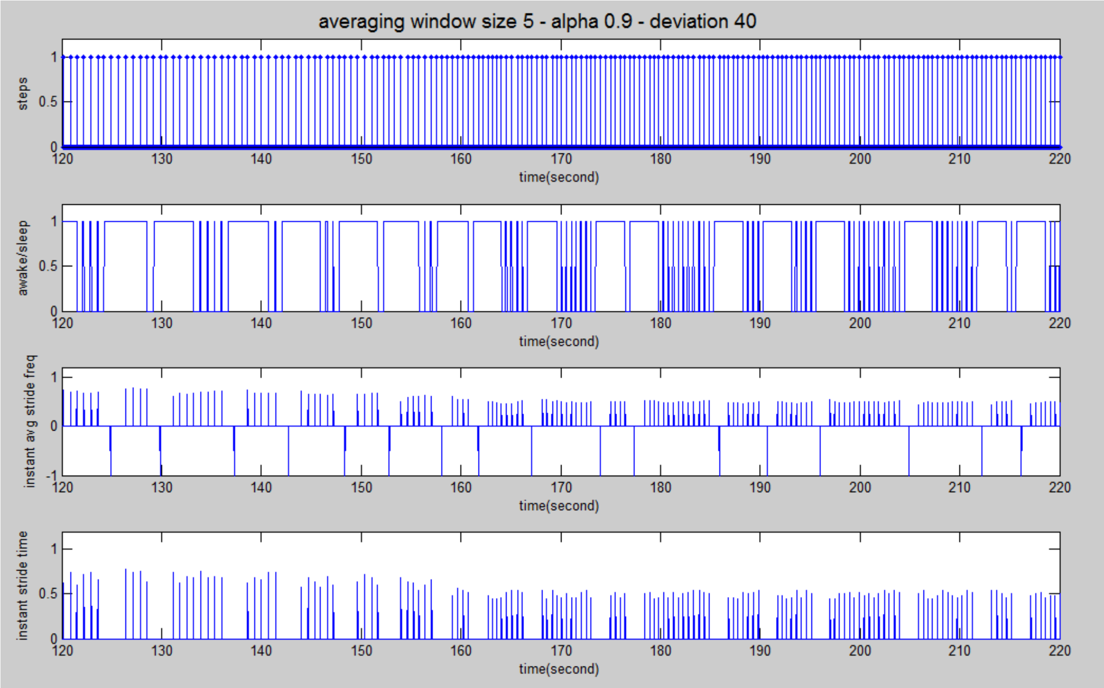


Figure 6.3.3-3 - Synthetic Data Set No: 1 - Case: <w=5, α=0.9 β=0.4>

In all data set we have, we ran the algorithm for analyzing data for each parameter. Figure 6.3.3-2 and 6.3.3-3 show the main effect of parameters on the results. In the first graph, alpha is set to 0.4 which means short sleep periods for not missing steps and deviation 0.7 for the high acceptance of the steps. On the other hand, the second figure, alpha is set to 0.9 which means high sleep duration and tolerance value is 0.4 that means less tolerable version. With these values, we expect missing steps and the third row indicates the moments where we miss the steps and restart the duty sleep schedule process. In the third graph, value “-1” shows the moment when we clean up the buffer which means the detection of a new type of step different from the ones in the buffer.

Also as it is explained in the presentation of the process, when we clean up the buffer, we turn off the sleep mode and this is why in the second graph of Figure 6.3.3-3, awake states after cleaning up the buffer are seen.

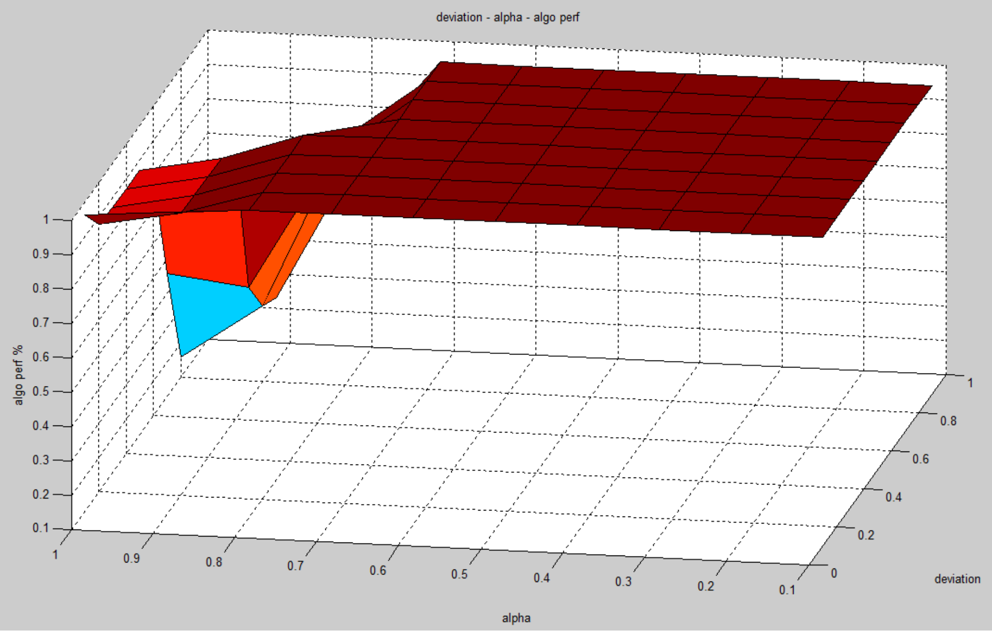


Figure 6.3.3-4 - Synthetic Data Set No: 1 - Pedometer Algorithm Performance

In figure 6.3.3-4, algorithm performance is given. As the steps are generated by the simulator, for the suitable coefficient values, our algorithm performance is 100%. When we increase the value alpha until 0.7, the algorithm runs correctly but then we start to miss the steps and at the same time if we increase the deviation value also > 0.7, the performance gets worse.

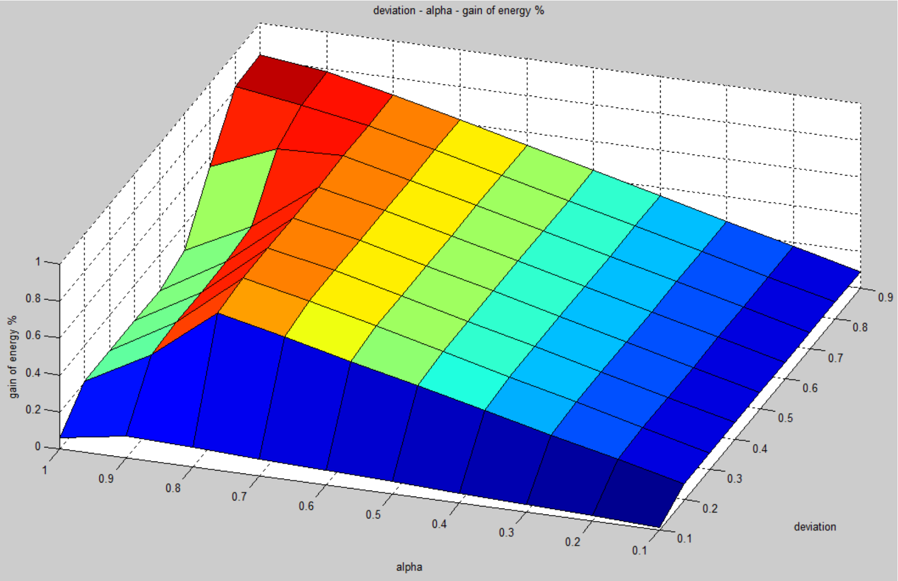


Figure 6.3.3-5 - Synthetic Data Set No: 1 - Gain of Energy

In Figure 6.3.3-5, gain of energy for the synthetic data is given. For the same reasons, until alpha is equal to 0.8 and deviation is equal to 0.7, we see a good result for the gain of energy but for the area where alpha is greater than 0.8 and for the tolerance greater than 0.7, we start missing steps because of the high sleep duration and high tolerance value. When sensor node sleeps with high sleep duration, it misses steps and for the high tolerance value, even if the gait regime changes, algorithm accepts steps as the same regime so it may miss steps also. In Figures 6.3.3-6 and 6.3.3-7, algorithm performance (above one) and gain of energy graphs are given.

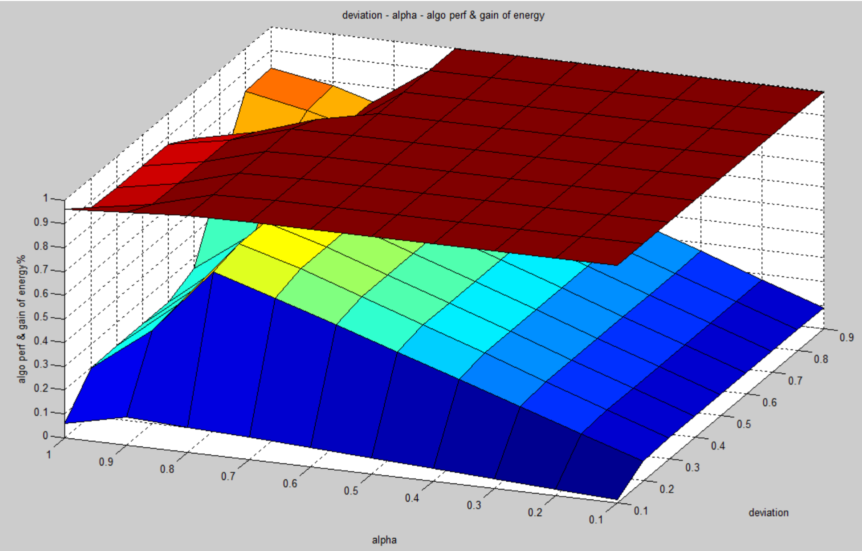


Figure 6.3.3-6 - Synthetic Data Set No: 1 - Both Metrics, view 1

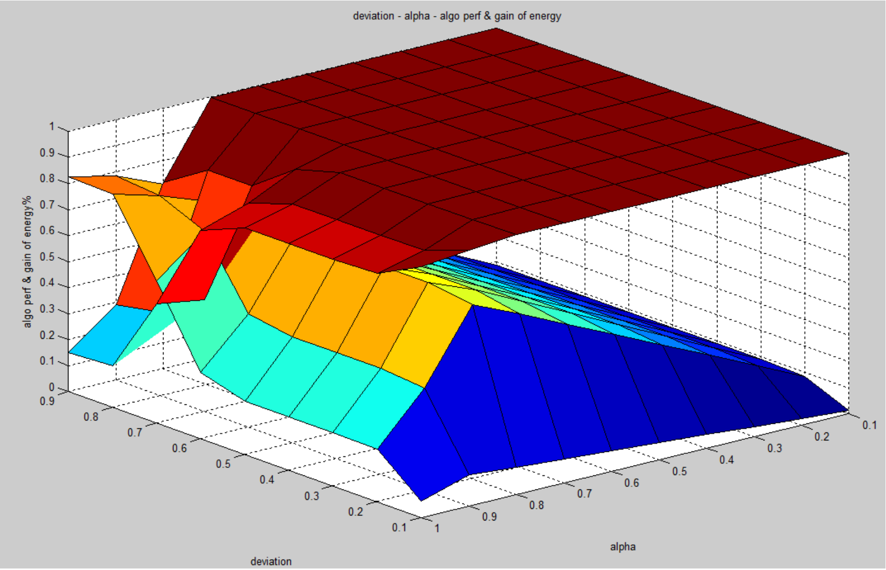


Figure 6.3.3-7 - Synthetic Data Set No: 1 - Both Metrics, view 2

6.3.4. Synthetic Data Set -2

This dataset contains accelerometer signal of walking with average stride time 0.7 second. Experiment parameters are the same as the previous one. For the stride interval estimator window size, we set 5. For the coefficient alpha which determinates the sleep duration starts with 0.1 until 1 with the 0.1 incensement. For the beta that takes decision of step starts with 0.1 and ends with 0.9 with the 0.1 incensement.

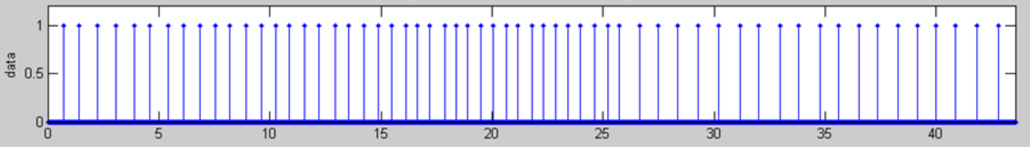


Figure 6.3.4-1 - Stride time of 100 steps

After obtaining stride times by the data generator, we run the data analyzer with the given parameters.

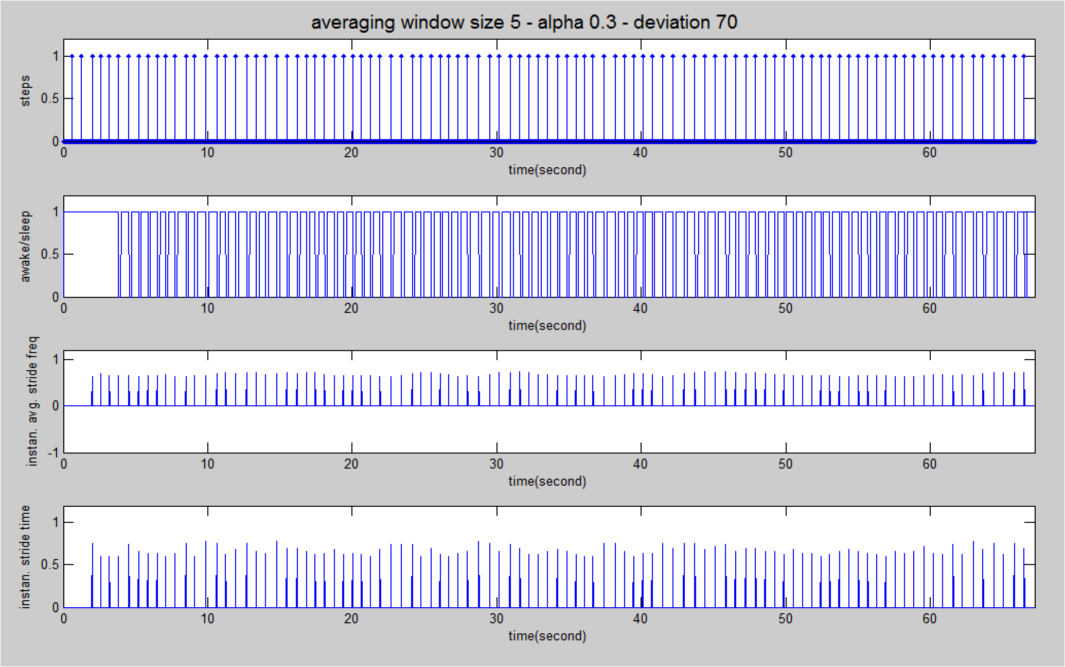


Figure 6.3.4-2 - Synthetic Data Set No: 2 - Case: <w=5, α=0.3, β=0.7>

The given figure above is obtained by the parameters (w=5, alpha=0.3, beta=0.7). For the alpha value 0.3 means the sleep duration is equal to average stride time*0.3. In Figure 6.3.4-2, the first graph shows the stride times. The second graph shows the CPU state awake or sleeps. 1 means awake and 0 means sleep. The third graph shows the instantaneous average stride time stocked in the buffer. After detecting each step, according to type of the step, the average stride time is calculated and multiplies by the alpha coefficient to set the sleep duration. The last graph shows the instantaneous stride time which means the time difference between the current stride time and the last detected stride time.

During this simulation all steps have the same behavior and as the coefficient alpha is small, all steps are detected and there is no need to empty buffer and recalculate the sleep duration. As opposite to this, Figure 6.3.4-3 shows the result of the simulator with alpha = 0.9 and deviation = 0.7. In this case, we set high sleep duration with high tolerance. It is seen that there are many miss step events occurred during this simulation. The second graph of the same figure shows the seconds where the system couldn't detect steps. When the system misses the step, the stride time difference becomes greater (the last step time and the current detected step after missed one). So that the time interval passes the deviation value and this makes system to accept the detected step as a new type of step and it deletes all steps in the buffer and turns off the sleep mode.

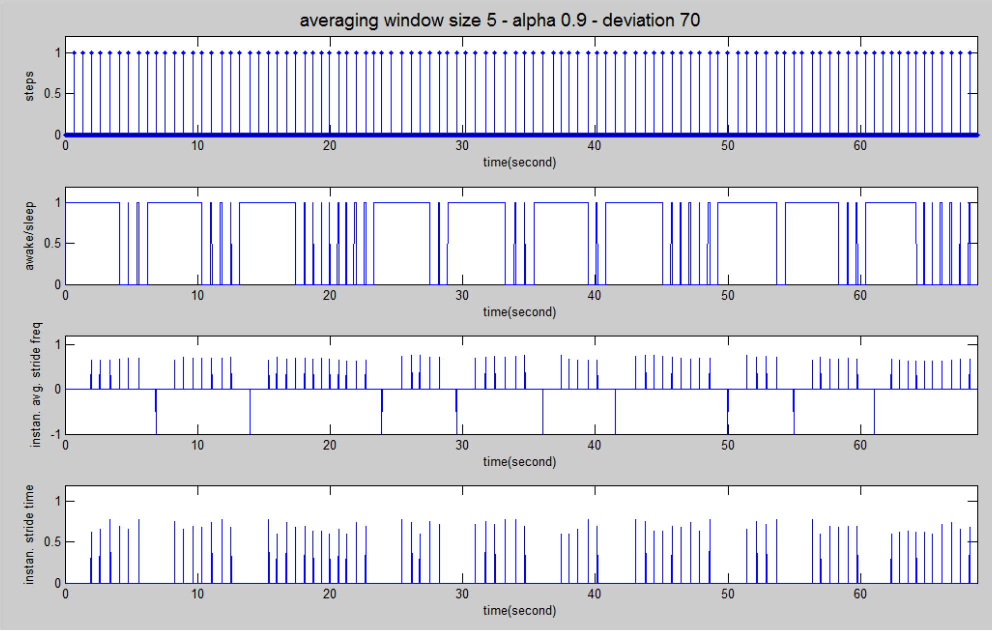


Figure 6.3.4-3 - Synthetic Data Set No: 2 - Case: <w=5, α=0.9, β=0.7>

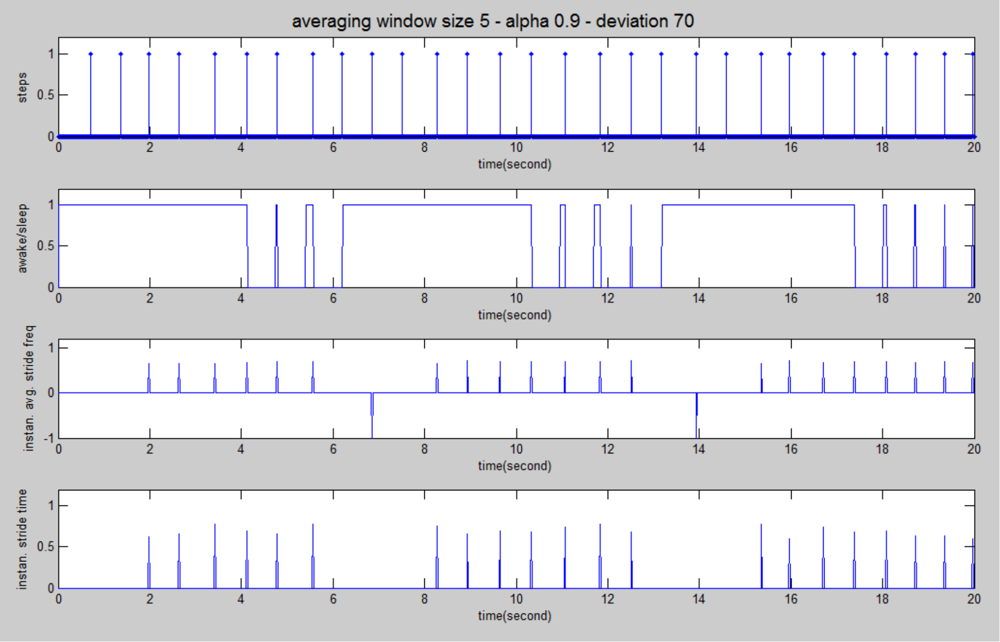


Figure 6.3.4-4 - Synthetic Data Set No: 2 - Case: <w=5, α=0.9, β=0.7> Zoomed view

Figure above 6.3.4-4 is the same graph as the previous one. This figure is the zoomed version of that figure. We focus on the first 20 seconds of the simulation. When t= 4, the buffer becomes full and we can start sleep duration. After 3 sleep duration, we miss a step, as missing step process disables the sleep mode, second graph of Figure shows that CPU and radio is awake until filling the buffer with steps. Making buffer empty is shown in the third graph as -1. During this 20 seconds, 2 times we missed a step, so that at t=7 and t=14 we needed to make the buffer empty.

After analyzing these graphs, we can pass to performance evaluation of this simulation. Figure 6.3.4-5 shows the performance of the algorithm. As the stride times are generated by the data generator, the performance is 100%, however when we increase the coefficient alpha to 0.8, we start missing steps.

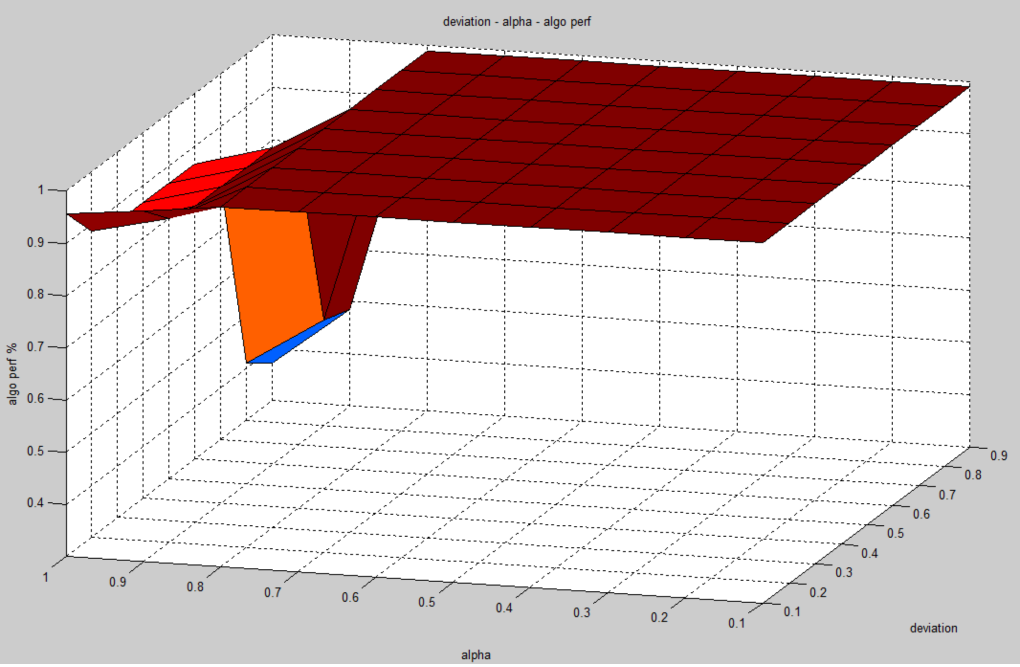


Figure 6.3.4-5 - Synthetic Data Set No: 2 - Pedometer Algorithm Performance

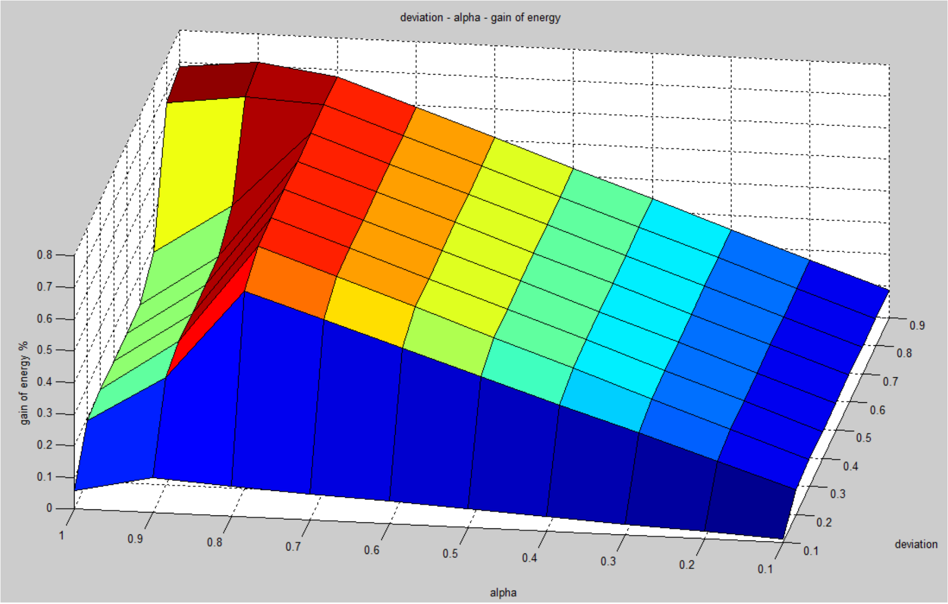


Figure 6.3.4-6 - Synthetic Data Set No: 2 - Gain of Energy

In Figure 6.3.4-6, the graph related with the gain of energy is given. As it is indicated before, for the alpha value 0.8, there is not any problem and system works well. When we still increase the alpha parameter, we miss the step and system turns off sleep mode which makes more energy consumption.

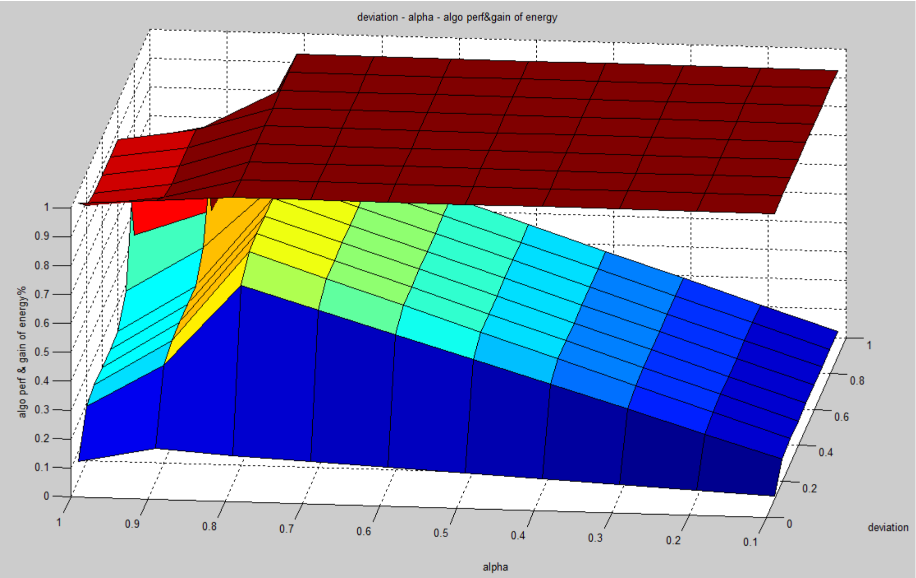


Figure 6.3.4-7 - Synthetic Data Set No: 2 - Both Metrics

Figure 6.3.4-7 is the combination of the 2 previous figures which show the performance of algorithm and the gain of energy on the same graph with the same parameters alpha and deviation.

7. CONCLUSION

It is known that limited battery energy of the wearable nodes is a major problem for the remote health monitoring applications. Due to the fact that they have limited energy, they need to be recharged periodically. Our mission on this research topic is to find a way to increase the lifetime of the sensor which means gaining energy and making the sensor to consume less energy. The necessity for periodic recharging is troublesome for most applications and need to be carried out as rarely as possible. Increasing the energy efficiency of the nodes has been extensively studied in the WSN domain and solutions customized for certain networking layer(s) have been proposed. In this work, we propose a novel approach for increasing the lifetimes of the wearable sensor nodes participating in the remote health monitoring applications by focusing on the application specific physical signal collection and processing. There is a trade of about where in the system the information relevant to the monitoring activity can be deduced. On one extreme, the sensor nodes themselves can process the measured data and report relevant information when it is required by the application. On the other extreme, the nodes can wirelessly transmit all measured data as they are being generated and let the local center do all the processing.

Due to the fact that the computation requires less energy when compared with sending data over a wireless medium, processing data on the sensor nodes is advantageous in terms of energy consumption. However, limited computational resources do not allow computation of any complexity to be carried out on the nodes. Therefore, the remaining operating region between the extreme approaches can be examined and energy efficiency can be sought based on the application requirements.

To demonstrate the concepts involved in the thesis, a physical testbed based on Shimmer wearable sensor devices is constructed. Experiments with real subjects are carried out where the shimmer nodes communicate with a local center via Bluetooth communication channel.

In this study, the first remote monitoring application focused on was the heart rate monitoring using ECG signal. By using the embedded computation on the sensor device, instead of sending all sampled data which corresponds approximately 500 packets in a second the lifetime of the sensors is increased by 6.5 times.

To further exploit application dependent operational dynamics, a second application studied was the pedometer. The periodic but dynamic character of the pedometer application enabled us to lower the duty cycle of the sensors by introducing a sleep schedule. A dynamic sleep scheduling algorithm is designed with three main parameters that analyze the human stride times and configure system dynamically for the sleep schedule. These parameters which are averaging window size, determination of sleep duration and the tolerance value; have visible effects on the energy consumption and the monitoring application performance. We have clearly shown the operating regions where dynamic sleep scheduling affects the overall performance. We determined the values of the scheduling parameters that lead to higher energy efficiency without compromising monitoring quality.

The concepts put forward by this thesis were evaluated for two different monitoring applications that differed in character. As a further study, we plan to categorize and model a wider range of health monitoring applications that will enable us to devise more generic approaches that validly works for a family of applications rather than single instances.

REFERENCES

[1]. Hassan Ghasemzadeh, E.G., Roozbeh Jafari, *Energy-Efficient Information-Driven Coverage for Physical Movement Monitoring in Body Sensor Networks.* IEEE Journal On Selected Areas In Communications, 2009. 27.

[2]. Lynch, J.P., *An overview of wireless structural health monitoring for civil structures,* Structural health monitoring 2006.

[3]. W. Marnane, S.F., C. Bleakley, R. Conway, E. Jones, E. Popovici, M. de la Guia Solaz, F. Morgan, K. Patel, *Energy Efficient On-Sensor Processing in Body Sensor Networks,* Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE, September 2010, pp.2025-2029.

[4]. V.Shankar, A.N., S.K.S.Gupta, L.Schwiebert, *Energy-Efficient Protocols for Wireless Communication in Biosensor Networks.* Personal, Indoor and Mobile Radio Communications, 12th IEEE International Symposium, Sep 2001, v.1, pp.D-114-D-118.

[5]. LI Ya, Q.H.-b., XU Wei,ZHANG Lian, *A WSN based Information Acquisition System of Fire Risk.* Electronics & Packaging, 2008.

[6]. BEKMEZCI, I., *Wireless Sensor Networks: A Military Monitoring Application.* VDM Verlag Saarbrücken, 2009, Germany.

[7]. JeongGil Ko, C.L., Mani B. Srivastava, John A. Stankovic, Andreas Terzis, Matt Welsh, *Wireless Sensor Networks for Healthcare,* Proceedings of the IEEE, Nov. 2010, v.98(11), pp.1947-1960.

[8]. Lin, Y.G., *An Intelligent Monitoring System for Agriculture Based on Zigbee Wireless Sensor Networks.* Advanced Materials Research, November 2011. Manufacturing Science and Technology: p. 383 - 390.

[9]. Adam T. Barth, M.A.H., Harry C. Powell Jr., Dincer Unluer, Stephen G. Wilson, John Lach, *Body-Coupled Communication for Body Sensor Networks,*

Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering, ICST, Belgium, 2008.

[10]. Dinesh Bhatia, L.E., and Shekar Rao, *Energy Efficient Contextual Sensing for Elderly Care,* Conf Proc IEEE Eng Med Biol Soc. 2007.

[11]. Li, Y., *Energy-efficient packet transmission schemes for Mobile Healthcare and Telemedicine.* Information Technology and Applications in Biomedicine, ITAB, May 2008, pp.259-262.

[12]. Yanyan Zhuang, J.P., Lin Cai, *Minimizing Energy Consumption with Probabilistic Distance Models in Wireless Sensor Networks.* IEEE INFOCOM 2010.

[13]. Silvio Croce, F.M., Massimo Vecchio, *Reducing Power Consumption in Wireless Sensor Networks Using a Novel Approach to Data Aggregation.* The Computer Journal (2008) 51 (2): 227-239.

[14]. Najmeh Kamyabpour, D.B.H., *Modeling overall energy consumption in Wireless Sensor Networks*, PDCAT 2010.

[15]. Yao Liang, W.P., *Minimizing Energy Consumptions in Wireless Sensor Networks via Two-Modal Transmission,* ACM SIGCOMM Computer Communication,v.40 (1), January 2010.

[16]. Chompunut Jantadrasorn, C.P., *Minimizing Energy Consumption in Wireless Sensor Networks using Binary Integer Linear Programming,* World Academy of Science, Engineering and Technology, 2012.

[17]. Bruce Moulton, G.C., Andrew Varis, *Method for Increasing the Energy Efficiency of Wirelessly Networked Ambulatory Health Monitoring Devices.* Journal of Convergence Information Technology 2010.

[18]. Hande Alemdar, C.E., *Wireless sensor networks for healthcare,* Elsevier North-Holland, October 2010, v.54(15), pp.2688-2710.

[19]. Jovanov, E., *Wireless Technology and System Integration in Body Area Networks for m-Health Applications* Proceedings of the 2005 IEEE, Engineering in Medicine and Biology 27th Annual Conference, Shanghai, China, , September, 2005.

[20]. Steven D. Glaser, R.A.S., David Pescovitz, *Frontiers in sensors and sensing systems.* Smart Structures and Systems, 2005.

[21]. Chris Otto, A.M., Corey Sanders, Emil Jovanov, *System Architecture of WBAN for Ubiquitous Health Monitorin.* Journal of Mobile Multimedia, 2006.

[22]. Naoto Kimura, S.L., *A Survey on Data Compression in Wireless Sensor Networks.* ITCC '05 International Conference on Information 2005.

[23]. Ranganathan Vidhyapriya, o.V., *Energy Efficient Data Compression in Wireless Sensor Networks.* The International Arab Journal of Information Technology July 2009, 6(3).

[24]. Marcelloni, F., *A Simple Algorithm for Data Compression in Wireless Sensor Networks.* Communications Letters, IEEE, June 2008. 12(6): p. 411- 413.

[25]. Hsing-Shao Liu, C.-C.C., Chih-Chung Lin, Ray-I Chang, Chia-Hui Wang, Ching-Chia Hsieh, *Data Compression for Energy Efficient Communication on Ubiquitous Sensor Networks.* Tamkang Journal of Science and Engineering, 2011, 14(3), p. 245-254.

[26]. M. V. M. Figueredo, v.J.S.D., *Mobile telemedicine system for home care and patient monitoring.* Proceedings of the 26th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2004.

[27]. Donoho, D.L., *Compressed Sensing,* Information Theory, IEEE Transactions, April 2006, v.52(4).

[28]. E. Jovanov, A.M., C. Otto, P. De Groen, B. Johnson, S. Warren and G. Taibi, *A WBAN System for Ambulatory Monitoring of Physical Activity and Health Status: Applications and Challenges,* Engineering in Medicine and Biology Society,IEEE-EMBS, Jan. 2006, pp.3810-3813.

[29]. D. Schmidt, M.K., T. Kuhn and N. Wehn, *Energy modelling in sensor networks,* Advances in Radio Science, 2007.

[30]. Hai-Ying Zhou, D.-Y.L., Yan Gao, De-Cheng Zuo *Modeling of Node Energy Consumption for Wireless Sensor Networks,* Wireless Sensor Network, 2011.

[31]. Nicolas Saunier, A.E.H., Karim Ismail, Catherine Morency, Jean-Michel Auberlet, Tarek Sayed, *Pedestrian Stride Frequency and Length Estimation in Outdoor Urban Environments using Video Sensors,* Transportation Research Record: Journal of the Transportation Research Board, 2011, pp.138-147.

[32]. Karol J. O'Donovan, B.R.G., Denise McGrath, Ross O'Neill, Adrian Burns, Brian Caulfield, *SHIMMER: A new tool for temporal Gait analysis* 31st Annual

International Conference of the IEEE EMBS, Minneapolis, Minnesota, USA, September, 2009.

[33]. Shimmer Research User Guide, Available at http://www.shimmer-research.com/download/documentation

[34]. Texas Instruments MSP430f1611 Datasheet, Available at http://www.ti.com/product/msp430f123

[35]. Shimmer Research, Available at *www.shimmer-research.com*

[36]. A. Burns, B.R.G., M. J. McGrath *SHIMMER (TM) - A Wireless Sensor Platform for Noninvasive Biomedical Research.* IEEE Sensors Journal, Sep, 2010.

[37]. A. Burns, E.P.D., B. R. Greene, *SHIMMER: An extensible platform for physiological signal capture,* Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE, September 2010, pp.3759-3762.

[38]. TinyOS, Available at http://www.tinyos.net

[39]. Philip Levis, N.L., Matt Welsh,David Culler, *TOSSIM: Accurate and Scalable Simulation of Entire TinyOS Applications.* In Proceedings of the First ACM Conference on Embedded Networked Sensor Systems (SenSys 2003), 2003.

[40]. Chris Peters, R.V., Jan Bergmans, Guid Oei, Pieter Wijn, *Heart Rate Detection in Low Amplitude Non-Invasive Fetal ECG Recordings,* 28th IEEE EMBS Annual International Conference, September 2006.

[41]. Pomalaza-Ráez, C.C.a.C., *Implementing and evaluating a wireless body sensor system for automated physiological data acquisiton at home.* International Journal of Computer Science and Information Technology, June 2010.

[42]. Yang Xue, L.J., *A Naturalistic 3D Acceleration-based Activity Dataset & Benchmark Evaluations,* Systems Man and Cybernetics (SMC), Oct. 2010, pp.4081-4085.

[43]. Yoshihiro Kawahara, N.R., Tohru Asami, *Monitoring Daily Energy Expenditure using a 3-Axis Accelerometer with a Low-Power Microprocessor,* International Journal on Human-Computer Interaction, Vol 1(5), 2009.

[44]. Ayan Banerjee, S.N., Sandeep K.S. Gupta and Radha Poovendran, *Energy-efficient Long Term Physiological Monitoring,* WH '11 Proceedings of the 2nd Conference on Wireless Health, 2011.

[45]. Jamshid Abouei, J.D.B., Konstantinos N. (Kostas) Plataniotis, Subbarayan Pasupathy, *Energy Efficiency and Reliability in Wireless Biomedical Implant Systems.* IEEE Transactions On Information Technology In Biomedicine, May 2011.

[46]. D. Ebenezer, F.F.P., *"A Recursive Digital Differentiator for Ecg Preprocessing.* Medical Engineering & Physics, Jul, 1994. 16(4): p. 273-277.

47]. N. Maglaveras, T.S., K. Diamantaras, *ECG pattern recognition and classification using non-linear transformations and neural networks: A review.* International Journal of Medical Informatics, Oct-Dec, 1998. 52(1-3),p.191-208.

[48]. Janani Sriram, M.S., Tanzeem Choudhury, David Kotz, *Activity-aware ECG-based patient authentication for remote health monitoring*, International Conference on Multimodal Interfaces and Workshop on Machine Learning for Multi-modal Interaction (ICMI-MLMI), November 2009, pp. 297-304.

[49]. Chulsung Park and Pai H. Chou, Y.B., Robert Matthews, and Andrew Hibbs, *An Ultra-Wearable, Wireless, Low Power ECG Monitoring System*, IEEE, Biomedical Circuits and Systems Conference BioCAS, 2006, pp.241-244.

[50]. Ćirković, P.A., Anđa, *Processing of Medical Signals (ECG) in Wireless Sensor Networks* , IPSI Bgd Internet Research Society, June 2009.

[51]. K. Akazawa, K.M., A. Sasamori, *Adaptive Threshold Qrs Detection Algorithm for Ambulatory Ecg.* Computers in Cardiology : Proceedings, 1991.

[52]. R. Poli, S.C., G. Valli, *Genetic Design of Optimum Linear and Nonlinear Qrs Detectors.* IEEE Transactions on Biomedical Engineering, Nov, 1995.v 42(11), p. 1137-1141.

[53]. Özgün Pınarer, B.A., Atay Özgövde *Uzaktan Sağlık İzleme Uygulamalarında Kaynak Kısıtlarının İzleme Süresine Etkisi.* Akademik Bilişim, Şubat 2011.

[54]. MMA7260Q Three Axis Low-g Micromachined Accelerometer, Datasheet.

[55]. Bluetooth RN 42 DataSheet. Available at http://www.rovingnetworks.com/products/RN_42

BIOGRAPHICAL SKETCH

Özgün PINARER was born in İstanbul on November 24, 1986. He went to French high school Notre Dame de Sion and he graduated in 2006. He started his undergraduate studies at Computer Engineering Department of Galatasaray University in 2006.

In 2010, he graduated from Galatasaray University with getting first rank in his class. He got the rector award. In September 2010, he started his master education, in parallel he became a research assistant in Computer Engineering Department of Galatasaray University, at the same time with Mr. Atay ÖZGÖVDE and Mr. Burak ARSLAN they built “Pervasive Computing and Ambient Intelligence Laboratory” in Galatasaray University. In February 2012, he went to Université Joseph Fourier Grenoble, France to work in Verimag Lab and to finish his thesis.

In February 2011, his paper “Extending the Wireless Monitoring Period for E-Health Applications” was accepted for a national conference “Akademik Bilişim 2011” that took place in Malatya, Turkey. In June 2011, he participated to an international conference with workshop “ICOST 2011” in Montreal, Canada. In October 2011, his paper “Wireless Monitoring of Health Data via an Open Platform” was accepted for a national conference “BIYOMUT 2011” in Antalya, Turkey. At last, in February 2012, he got acceptance from international conference “BIOMED 2012” Innsbruck, Austria with his paper “Wireless Health Monitoring of Multi-Patient on Android Phone with Embedded Computation”.