1. INTRODUCTION

Wearable sensors and systems have evolved to the point that they can be considered ready for clinical application. The use of wearable monitoring devices that allow continuous or intermittent monitoring of physiological signals is critical for the advancement of both the diagnosis as well as treatment of diseases.

Wearable systems are totally non-obtrusive devices that allow physicians to overcome the limitations of ambulatory technology and provide a response to the need for monitoring individuals over weeks or months. They typically rely on wireless miniature sensors enclosed in patches or bandages or in items that can be worn, such as ring or shirt. The data sets recorded using these systems are then processed to detect events predictive of possible worsening of the patient’s clinical situations or they are explored to access the impact of clinical interventions.

2. DEVELOPMENT OF WEARABLE BIOSENSOR

2.1 RING SENSOR

It is a pulse oximetry sensor that allows one to continuously monitor heart rate and oxygen saturation in a totally unobtrusive way. The device is shaped like a ring and thus it can be worn for long periods of time without any discomfort to the subject.

The ring sensor is equipped with a low power transceiver that accomplishes bi-directional communication with a base station, and to upload date at any point in time.

2.1.1 BASIC PRINCIPLE OF RING SENSOR

Each time the heart muscle contracts, blood is ejected from the ventricles and a pulse of pressure is transmitted through the circulatory system. This pressure pulse when travelling through the vessels causes vessel wall displacement which is measurable at various points. In order to detect pulsatile blood volume changes by photoelectric method, photo conductors are used. Normally photo resistors are used, for amplification purpose photo transistors are used.

Light is emitted by LED and transmitted through the artery and the resistance of photo resistor is determined by the amount of light reaching it. With each contraction of heart, blood is forced to the extremities and the amount of blood in the finger increases. It alters the optical density with the result that the light transmission through the finger reduces and the resistance of the photo resistor increases accordingly. The photo resistor is connected as a part of voltage divider circuit and produces a voltage that varies with the amount of blood in the finger. This voltage closely follows the pressure pulse.

2.1.2 WORKING

The LEDs and PD are placed on the flanks of the finger either reflective or transmittal type can be used. For avoiding motion disturbances quite stable transmittal method is used. Transmittal type has a powerful LED for transmitting light across the finger. This power consumption problem can be solved with a light modulation technique using high-speed devices. Instead of lighting the skiing continuously, the LED is turned ON only for a short time, say
10-100 ns, and the signal is sampled within this period, high frequency, low duty rate modulation is used for preventing skin-burning problem.

The motion of the finger can be measure with an optical sensor. This motion detector can be used not only for monitoring the presence of motion but also for cancelling the noise. By using PD-B as a noise reference, a noise cancellation filter can be built to eliminate the noise of PD-A which completes with the noise references used. And adaptive noise cancellation method is used.

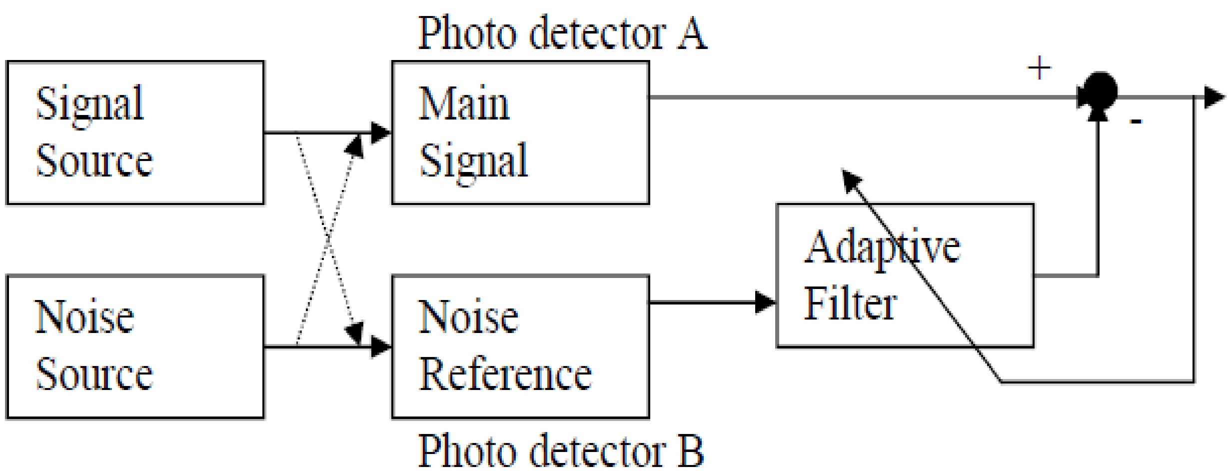


Fig.1.Noise Cancellation Mechanism

The noise-cancelling filter combines two sensor signals; one is the main signal captured by PD-A and the other is the noise reference obtained by PD-B. The main signal mostly consists of the truce pulsate signal, but it does contain some noise. If we know the proportion of noise contained in the main signal, we can sensate the contained in the main signal, we can generate the noise of the same magnitude by attending the noise reference signal and then subtract the noise from the main signal to recover the true pulsatile signal.

Fig. 9. First prototype ring sensor with RF transmitter powered by a coin-size cell battery.

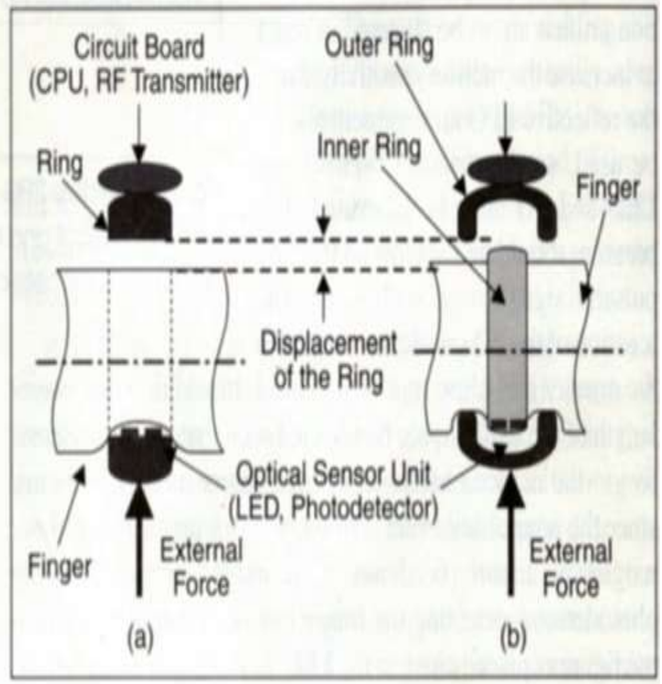
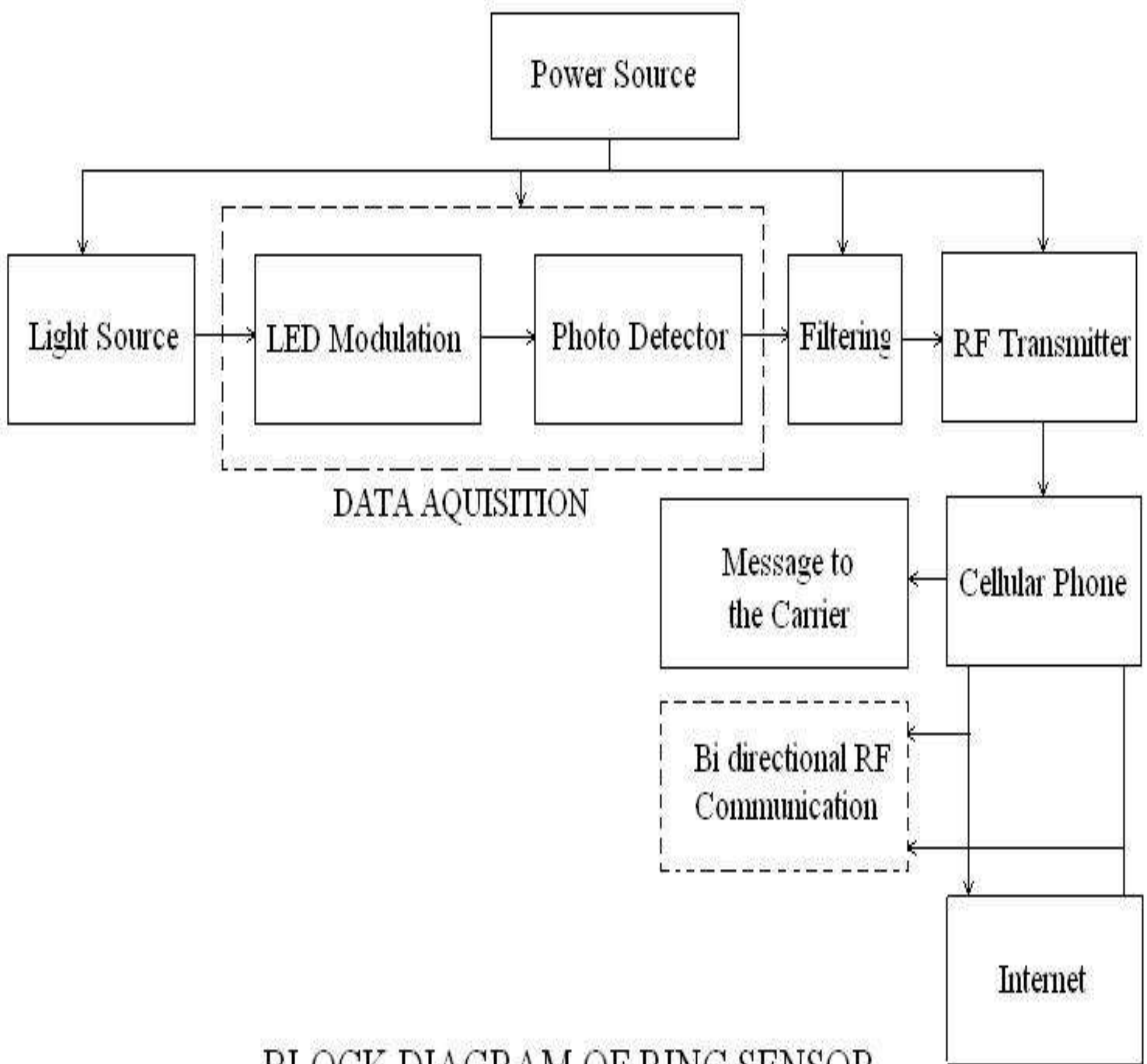


Fig. 10. Dislocation of ring sensors due to external load. (a) Traditional single-body design under external force. (b) New isolating double ring sensor under external force (31).

The ring has a microcomputer performing all the device controls and low level signal processing including LED modulation, data acquisition, filtering, and bi-directional RF communication. The acquired waveforms sampled at 100Hz are transmitted to a cellular phone carried by the patient through an RF link of 105Kbps at a carrier frequency of 915 MHz. The cellular phone accesses a website for data storage and clinical diagnosis.

2.1.3 BLOCK DIAGRAM OF RING SENSOR



BLOCK DIAGRAM OF RING SENSOR

Power Source

Power for light source, photo detector, RF transmitter and analog and digital processing units provided by a tiny cell battery used for wrist watches. Lifetime is 2 or 3 weeks.

Light Source

Light source for the ring sensor is the LED, approximately wavelength of 660 nm.

Photo Detector

Photo detector is normally photodiode or phototransistor used for detecting the signal from the LED.

RF Transmitter

It is used for transmitting the measured signals. Its carrier frequency is 915MHz.

LED Modulation

Power consumption problem can be solved with a lighting modulation technique. Instead of lighting the skin continually the LED is turned on only for a short time, say 100-1000ns and the signal is sampled within the period. High frequency low duty cycle modulation implemented minimizes LED power consumption.

Data Acquisition

It is used to collect the data from sensor and data are sampled and recorded.

Filtering

The signal from the PD-B as a noise reference a noise cancellation filter can be built to eliminate the noise of PD-A which correlates with the noise reference signal. For noise cancellation we use the adaptive noise filter.

2.1.4 APPLICATIONS OF THE RING SENSOR

CATRASTOPHE DETECTION

- Wireless supervision of people during hazardous operations

Eg: military, fire fighting

- In an overcrowded emergency department

CHRONIC MEDICAL CONDITION

- In cardiovascular disease for monitoring the hyper tension
- chronic surveillance of abnormal heart failure

ADVANTAGES

- continuous monitoring
- detection of transient phenomena
- promote further diagnostic and therapeutic measures
- easy to use
- reducing hospitalization fee

DISADVANTAGES

- initial cost is high
- limited number of physiological parameters are to be monitored

2.2 SMART SHIRT (WEARABLE MOTHERBOARD)

Research on the design and development of a smart shirt fort a combat casualty care has led to the realization of the world's first wearable motherboard or an "intelligent" garment for the 21st century. The Georgia tech wearable motherboard (GTWM) uses optical fibers to detect bullet wounds and special sensors and interconnects to monitor the body vital signs during combat conditions.

This GTWM (smart shirt) provides an extremely versatile framework for the incorporation of sensing, monitoring and information processing devices. The principal advantage of smart shirt is that it provides for the first time a very systematic way of monitoring the vital signs of humans in an unobtrusive manner.

2.2.1 REQUIREMENTS OF SMART SHIRT

Casualties are associated with combat and sometimes are inevitable. Since medical resources are limited in a combat scenario, there is critical need to make optimum use of the available resources.

Mentally ill patients need to be monitored on a regular basis to gain a better understanding of the relationship between their vital signs and their behavioural patterns so that their treatments can be suitably modified.

Similarly on the civilian side, the population is aging and the cost of the health care delivery is increasing. With the decreasing number of doctors in rural areas, the doctor/patient ratio is in certain instances reaching unacceptable levels for ensuring a basic sense of security when they leave the hospital because they feel “cut-off” from the continuous watch and care they received in the hospital. This degree of uncertainty can greatly influence their postoperative recovery.

Therefore there is a need to continuously monitor such patients and give them the added peace of mind so that the positive psychological impacts will speedup the recovery process.

2.2.2 ARCHITECTURE

The GTWM was woven into a single –piece garment (an undershirt) on a weaving machine to fit a 38-40” chest. The plastic optical fiber (POF) is spirally integrated into the structure during the fabric production process without any discontinuities at the armhole or the segms using a novel modification in the weaving process.

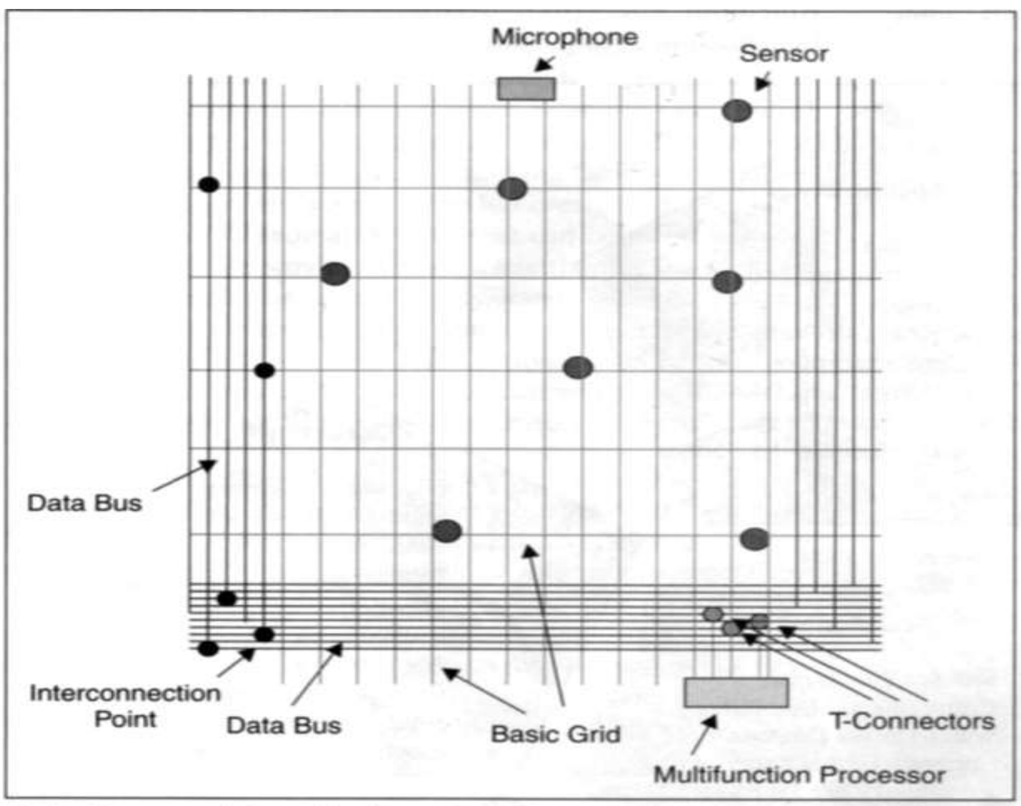


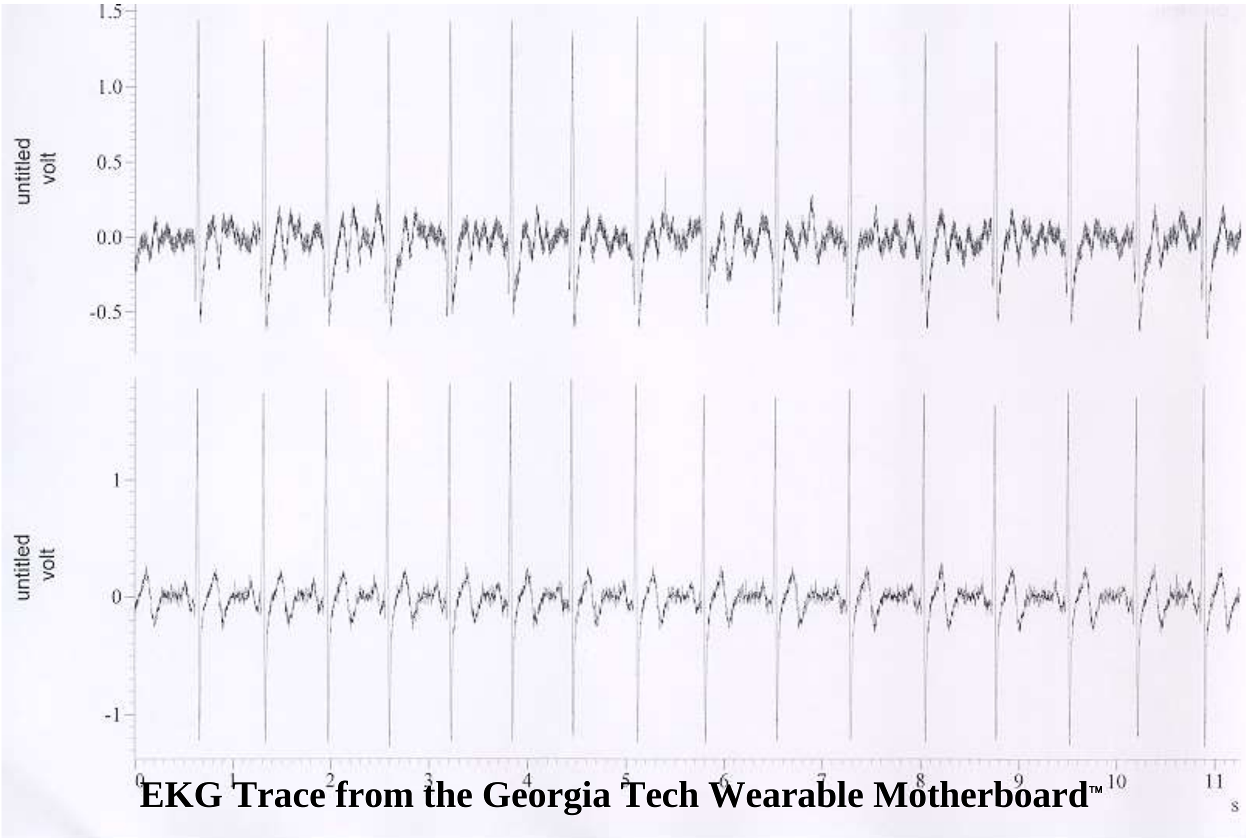
Fig. 3. The wearable motherboard architecture.

An interconnection technology was developed to transmit information from (and to) sensors mounted at any location on the body thus creating a flexible "bus" structure. T-connectors –similar to "button clips" used in clothing are attached to the fibers that serve as a data bus to carry the information from the sensors (eg: ECG sensors) on the body. The sensors will plug into these connectors and at the other end similar T-connector will be used to transmit their information for monitoring equipment or DARPS (Defence Advanced Research Projects Agency) personnel status monitor.

By making the sensors detachable from the garments, the versatility of the Georgia Tech Smart Shirt has been significantly enhanced. Since shapes and sizes of humans will be different, sensors can be positioned on the right locations for all users and without any constraints being imposed by the smart shirt can be truly "customized".

Moreover the smart shirt can be laundered without any damage to the sensors themselves. The interconnection technology has been used to integrate sensors for monitoring the following vital signs: temperature, heart rate and respiration rate. In addition a microphone has been attached to transmit the weavers voice data to monitoring locations. Other sensors can be easily integrated into the structure.

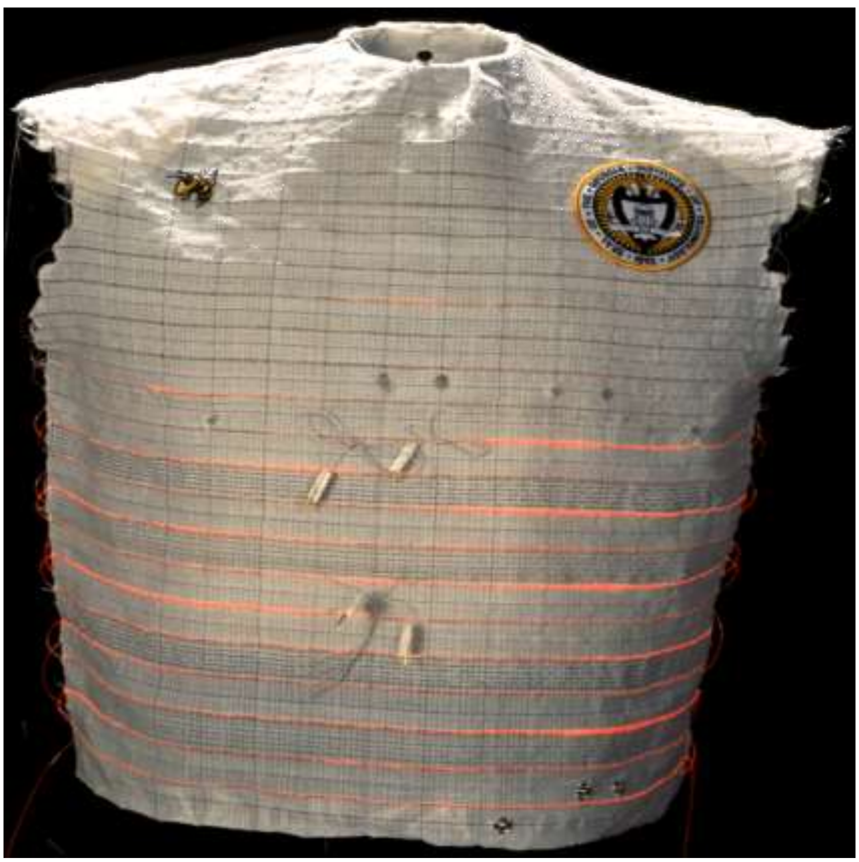
The flexible data bus integrated into the structure transmits the information from the suite of the sensors to the multifunction processor known as the Smart shirt controller. This controller in turn processes the signals and transmits them wirelessly to desired locations (eg: doctor's office, hospital, battlefield). The bus also serves to transmit information to the sensors (and hence the weaver) from the external sources, thus making the smart shirt a valuable information infrastructure.



EKG Trace from the Georgia Tech Wearable Motherboard™

A combat soldier sensor to his body, pulls the smart shirt on, and attaches the sensors to the smart shirt. The smart shirt functions like a motherboard, with plastic optical fibers and other special fibers woven throughout the actual fabric of the shirt. To pinpoint the exact location of a bullet penetration, a "signal" is sent from one end of the plastic optical fiber to a receiver at the other end. The emitter and the receiver are connected to a Personal Status Monitor (PSM) worn at the hip level by the soldier. If the light from the emitter does not reach the receiver inside the PSM, it signifies that the smart shirt has been penetrated (i.e.; the soldier has been shot). The signal bounces back to the PSM forum the point of penetration, helping the medical personnel pinpoint the exact location the solider wounds.

The soldiers vital signs –heart rate, temperature, respiration rate etc. are monitored in two ways: through the sensors integrated into the T-shirt: and through the sensors on the soldier's body, both of which are connected to the PSM. Information on the soldiers wound and the condition is immediately transmitted electronically from the PSM to a medical triage unit somewhere near the battlefield. The triage unit them dispatches the approximate medical personnel to the scene .The Georgia tech smart shirt can help a physician determine the extent of a soldiers injuries based on the strength of his heart beat and respiratory rate. This information is vital for accessing who needs assistance first during the so-called "Golden Hour" in which there are numerous casualties.



2.2.3 IMPACT OF THE SMART SHIRT

The smart shirt will have significant impact on the practice of medium since it fulfils the **critical need** for a technology that can enhance the quality of life while **reducing the health care cost** across the continuum of life that is from newborns to senior citizens, and across the continuum of medical care.

Patients could wear the smart shirt at home and be monitored by a monitoring station; thereby avoiding hospital stay cost and reducing the overall cost of healthcare. At also same home, a home setting can contribute to faster recovery.

For example, if the patient recovering at home from heart surgery is wearing the smart shirt, the ECG can be transmitted wirelessly (through mobile phone, internet etc) to the hospital on a regular basis. This monitoring will help the patient feel more "secure" and will facilitate the recuperation while simultaneously reducing the cost time associated with recovery.

Moreover, in the event of an emergency, the doctor can be notified instantaneously. Using the online medical records (available over the web) the physician can administrate the right investment at the right time at the right cost and indeed save a life.

Furthermore, persons who have known disorders can wear the smart shirt and be under constant monitoring of the physical conditions by medical personnel. Yet another potential impact of the smart shirt technology is the eventual **disappearance of geographical/physical boundaries** as barriers for individual seeking the best in healthcare worldwide.

The smart shirt technology has the means to provide **unobstructed monitoring** for individuals and can thereby play a critical role **disease management** for the large numbers of individuals at risk for high blood pressure, heart disease, diabetes, chronic bronchitis, and depression by enabling early systematic intervention.

2.2.4 ADVANTAGES OF THE SMART SHIRT

- Continuous monitoring
- Right Treatment at the right time at the right cost
- Easy to wear and takeoff
- reducing the health care cost

DISADVANTAGES OF THE SMART SHIRT

- Initial cost is high
- Battery life is less

APPLICATIONS OF SMART SHIRT

- Combat casualty care.
- Medical monitoring

- Sports/ Performance monitoring
- Space experiments
- Mission critical/ hazardous application
- Fire- fighting
- Wearable mobile information infrastructure

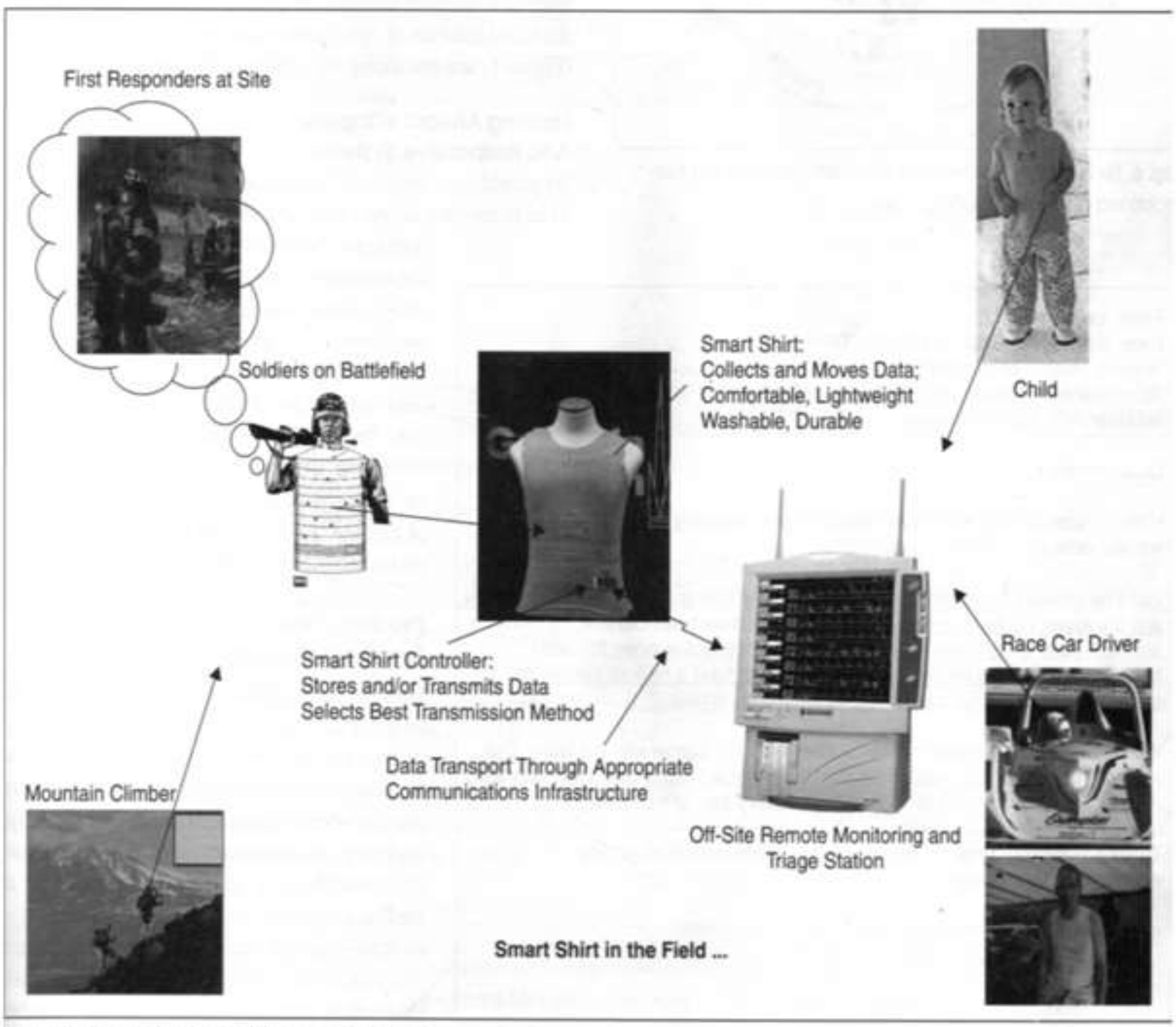


Fig. 5. Smart Shirt in various fields of application.

TABLE 1. The Wearable Motherboard/Smart Shirt: Potential applications.

Segment	Application Type	Target Audience
Military	Combat Casualty Care	Soldiers and Support Personnel in Battlefield
Civilian	Medical Monitoring	Patients: Surgical Recovery, Psychiatric Care
		Senior Citizens: Geriatric Care, Nursing Homes
		Infants: SIDS prevention
		Teaching Hospitals and Medical Research Institutions
	Sports/Performance Monitoring	Athletes, Individuals
		Scuba Diving, Mountaineering, Hiking
Space	Space Experiments	Astronauts
Specialized	Mission Critical/Hazardous Applications	Mining, Mass Transportation
Public Safety	Fire-fighting	Firefighters
	Law Enforcement	Police
Universal	Wearable Mobile Information Infrastructure	All Information Processing Applications

3. CONCLUSION

The ring sensor and smart shirt are an effective and comfortable, and mobile information infrastructure that can be made to the individual’s requirements to take advantage of the advancements in telemedicine and information processing.

Just as special-purpose chips and processors can be plugged into a computer motherboard to obtain the required information processing capability, the smart shirt is an information infrastructure into which the wearer can “plug in” the desired sensors and devices, thereby creating a system for monitoring vital signs in an efficient and cost effective manner with the “universal“ interface of clothing.

Advanced technologies such as the smart shirt have at partial to dramatically alter its landscape of healthcare delivery and at practice of medicine as we know them today. By enhancing the quality of life, minimizing “medical” errors, and reducing healthcare costs, the patient-control wearable information infrastructure can play a vital role in realizing the future healthcare system.

Just as the spreadsheet pioneered the field of information processing that brought “computing to the masses”. It is anticipated that the smart shirt will bring personalized and affordable healthcare monitoring to the population at large, thus leading to the realization of “Affordable Healthcare, Any place, Anytime, Anyone”.

4. BIBLIOGRAPHY

1. H. Harry Asada, “mobile monitoring with wearable PPG sensors”, *IEEE engineering in medicine and biology magazine*, vol. 22, pp- 28-39 May/June 2003.

2. Park and Jayaraman, “enhancing the quality of life through wearable technology”, *IEEE engineering in medicine and biology magazine*, vol. 22, pp- 41-48 May/June 2003.

3. Handbook of biomedical instrumentation, Khandpur, pp-138,233,238.

4. R. Neuman, “biomedical sensors”, handbook of biomedical instrumentation, pp-725-755.

5. http://www.smartshirt.gatech.edu.

6. http://www.wearables.gatech.edu.