

ORIGINAL ARTICLE

The Role of Amplitude Modulated Ultrasonic Standing Waves and Infrared Light in Noninvasive detection of Blood Glucose Levels

Md Koushik Chowdhury¹, Anuj Srivastava¹, Neeraj Sharma¹, Shiru Sharma¹

¹School of Biomedical Engineering,

Indian Institute of Technology (Banaras Hindu University),

Varanasi, Uttar Pradesh, India

E-mail: kchoudhary.rs.bme11@itbhu.ac.in

ABSTRACT

The experimental technique for noninvasive blood glucose level detections using amplitude modulated ultrasound and infrared technique has been proposed and investigated here. Amplitude modulated ultrasonic standing wave has been generated here utilizing the carrier wave, modulating wave units and 40 kHz ultrasonic transmitter respectively. The produced amplitude modulating ultrasonic radiating wave has been applied over the target area such as human finger. This amplitude modulating ultrasonic wave initiates the process of vibrations in that respective blood tissue medium of the human finger. The molecules present in that medium vibrate specifically according to their physical characteristics at particular frequency responses. The glucose sensitive 940nm based near infrared light wavelength has been applied here to recognize those explicit vibrations specific to glucose molecules in that respective blood tissue medium. The output signal generates peak to peak amplitude variation in the Fast Fourier Transform domain with respect to change in blood glucose concentration levels. This light acquired output signal has been processed for blood glucose level information analysis and detection purposes. This method has been conducted over human healthy subjects for investigation purposes only. The promising result acquired through this new technique has been reported in this research paper.

Key Words: Standing wave, Ultrasound, Fast Fourier Transform Domain, Infrared light, Glucose, Noninvasive.

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INTRODUCTION

The metabolic disorder often referred as Diabetes Mellitus in the long run has an ill effect over vital biological organs like heart, kidneys, eyes and nervous systems respectively. Various complexities related to diabetes include cardiac myopathy, renal failures, diabetic retinopathy, nerve disorders, etc [1-3]. At present nearly 38.2 crores of people, globally face challenges daily due to diabetic mellitus related various complexities [1, 4, 5]. Within 15 to 20 years from now this count will rise steeply to acquire 55% overall growth in diabetic population worldwide [1, 4, 5]. The primary and essential step in diabetes mellitus includes frequent blood glucose monitoring and its accurate controlled regulation through proper medications and physical exercises [1-5]. Actually, the normal blood glucose levels acts a marker for proper diet and medications [1-3]. The existing invasive procedure includes skin tissue pricking for obtaining minute blood droplets, which has to be analyzed by the invasive glucometer for blood glucose level estimations. This process hurts the skin tissues, painful in nature, increases skin infection probabilities. All these factors produce ill effect like patient's in compliance towards strict blood glucose monitoring processes [3]. As a result, diabetic treatment and management suffers a major setback [1-3]. All these medical problems have opened the urge for research and development in noninvasive blood glucose detection technologies [6]. Within this medical field, the optical method based techniques have shown promising results [6]. Various light based methods are Infrared spectroscopy [7, 8], Raman spectroscopy [7, 9], Photo Acoustic spectroscopy [10, 11], Fluorescence spectroscopy [7, 12], Polarimetry

Techniques [7, 13], Optical Coherence Tomography [7, 14] respectively. Worldwide, at present even after such an exhaustive research and developmental efforts, noninvasive glucometer with clinically acceptable accuracy has been not available [7]. Moreover, none of these methods has got approval from any regulatory bodies (FDA of USA, CE of Europe) for large scale distribution in the markets [7].

Usually, the signals are acquired from human subject's various measuring sites like finger tip, earlobes, etc. [7,15,16]. The prime and critical obstacle exist within the noninvasive blood glucose instruments has been the glucose based weak Signal to Noise Ratios (SNR). 10 μ AU absorbance unit changes have been measured when 10mg/dl of glucose (dextrose) are added to the sample solution within 1mm cuvette path length [15, 16]. This value indicates that surrounding noises that easily overlaps the glucose based signal spectrum when measured [7, 15, 16]. Various factors like accuracy, precision, signal to noise ratios, quality of the signal spectrum plays a vital role for predicting noninvasive blood glucose levels [7-16]. Our indigenous technology utilizes amplitude modulated ultrasound and infrared techniques to enhance the sensitivity, specificity for noninvasive blood glucose level detections [17-19].

This research paper has been emphasized over the utilization of amplitude modulated ultrasonic waves and infrared techniques for noninvasive blood glucose level detections over human subjects. Rest of the paper, sectional organization has been structured as follows: Second Section focuses on the materials and methodology involved. Third section constitutes the result and discussion portions. Similarly, section four includes the conclusion portion of this research paper.

MATERIALS AND METHODOLOGY

The amplitude modulated ultrasonic waves and infrared light has been applied to conduct noninvasive blood glucose determinations in human subjects. The standing wave pattern of ultrasonic beam has been focused over the finger skin tissues. These waves propagate and exert radiations force inside the blood tissue medium [16-19]. When larger ultrasonic waves act on the smaller molecules within the blood tissue medium, impact of the radiation force has been obtained from gradient profile of acoustic potential energy [17-28] and represented as follows:

$$F_r = - \left[\frac{\pi p_o^2 V_c \beta_w}{(2\lambda)} \right] \cdot \Phi(\beta, \rho) \cdot \sin(4\pi z/\lambda) \quad (1)$$

Here (F_r) refers to the radiation forces which had acted over the molecular volume (V_c) for a distance assumed as (z). Amplitude of the peak acoustic pressure waves and ultrasonic sound waves in the suspending phases has been represented as (P_o) and (λ) respectively [17-28]. The compressibility factor (β_w) of the suspending medium plays a vital role here [17-28]. These facts were represented as follows:

$$\Phi(\beta, \rho) = \left[\frac{5\rho_c - 2\rho_w}{2\rho_c + \rho_w} - \left(\frac{\beta_c}{\beta_w} \right) \right] \quad (2)$$

The molecular concentrations for both the phases like suspending molecules (glucose) and suspending medium (blood medium) has been designated by (ρ_c) and (ρ_w) notations respectively [17-28]. The molecular compressibility for the respective molecules has been represented as (β_c) [17-28]. To predict the absorption (A) profile at the specific light wave number (ν), the standard equation of **Lambert-Beer law** has been applied here [17-20, 24]. It has been represented as follows:

$$A(\nu) = -\log I(\nu)/I_0(\nu) \quad (3)$$

(I_0) stands for local interference due to adjacent medium light intensity, similarly (I) represents the intensity at a specific wave number (ν) used for the experimental purposes [17-20, 24].

The experimental set up utilized here comprises two major operating units. The amplitude modulated ultrasonic unit and the infrared unit. It has been named together here as MUS-IR unit (Modulated Ultra Sound - Infra Red unit). Modulated ultrasonic unit consists of carrier wave, modulating signal unit, modulation unit, ultrasonic transmitter and receiver unit of 40 kHz each. The carrier wave and the modulating signal unit provides two types of typical sine wave inputs for producing amplitude modulated signal waves. These signals were applied to the ultrasonic transmitter to provide an amplitude modulated signal to the finger holder. The accuracy and calibration of ultrasonic waves were performed by observing the ultrasonic wave pattern through ultrasonic receiver unit. The properties of ultrasonic standing wave are vital, as this wave pattern plays an important role for blood glucose level determinations [17-20].

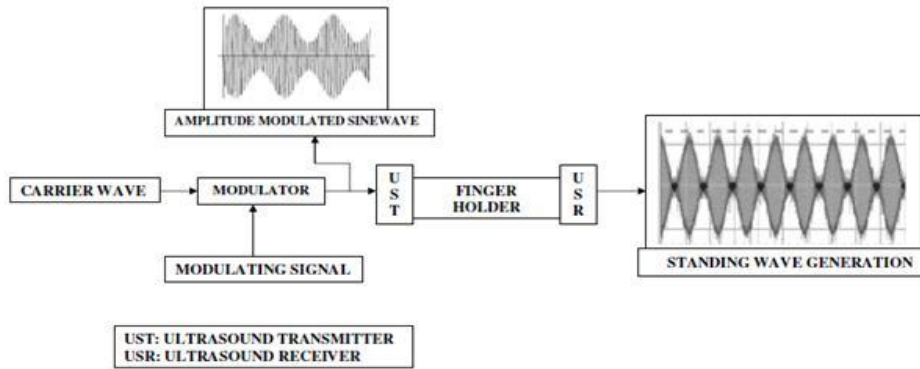


Figure No. 1. Depict the schematic block diagram of amplitude modulated ultrasonic unit of the MUS-IR unit.

The infrared unit consists of 940nm LED (Light Emitting Diode) and its respective detector. The 940nm light wavelength has been chosen here as it exists between physiological “Tissue Optical Window” range extending from 700nm to 1100nm respectively [29-32]. Moreover, as seen from Figure No.2 and 3 the background interference from water, oxy-hemoglobin, deoxy-hemoglobin, etc. has been considerably low in that respective “Tissue Optical Window” zone [29-32]. Additionally, the 940nm LED has been selected because the glucose molecule exhibits satisfactory absorption peak near to 940nm wavelength as depicted from Figure No.4 respectively [29-32, 34]. Furthermore, the fact behind 40 kHz central frequency based ultrasound transmitter & receiver pair selection has been its harmless effect over human beings [11, 19, 34].

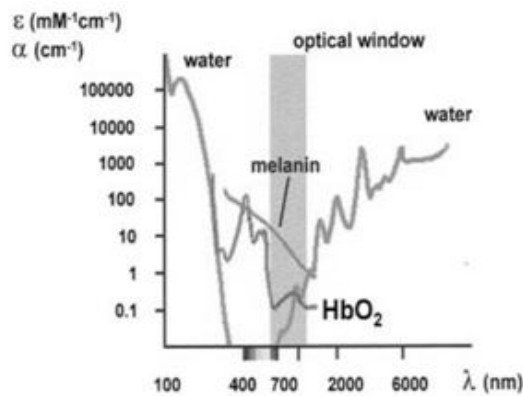


Figure No.2: Depicts the tissue optical window phenomenon respectively [29-32].

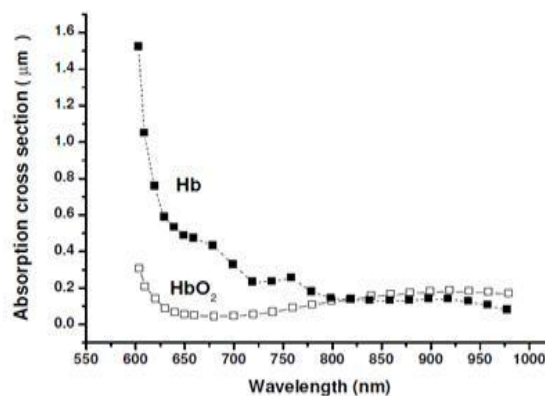


Figure No.3: Depicts the absorption cross section of oxyhemoglobin and deoxy hemoglobin respectively [29-32].

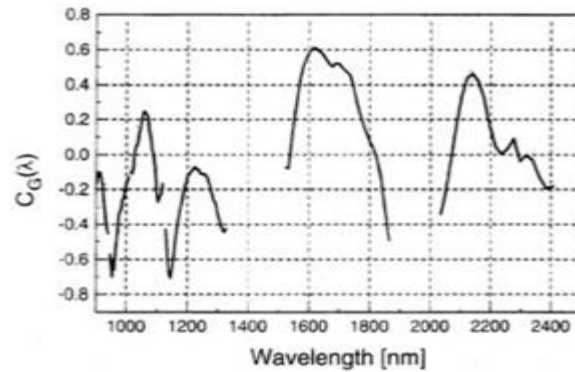


Figure No.4: Depicts the absorption profile of glucose between 900nm to 2400nm respectively [29-32].

Figure No. 5. Shows schematic block diagram of the MUS-IR experimental unit setup. The square wave pulses were provided to the LED as an input. Light and ultrasound transmitter based sources were perpendicular in their respective arrangements as compared to finger holder positioning. The amplitude modulated ultrasound produces series of vibrational pattern in the blood tissue medium inside the human finger. The molecules vibrate specifically depending upon their mass, density and other physical and chemical characteristics [17-24]. The Infra Red light sensitive to glucose molecule had been applied here to detect glucose specific vibrational patterns. The observed signals were processed suitably to determine the respective blood glucose levels in human subjects.

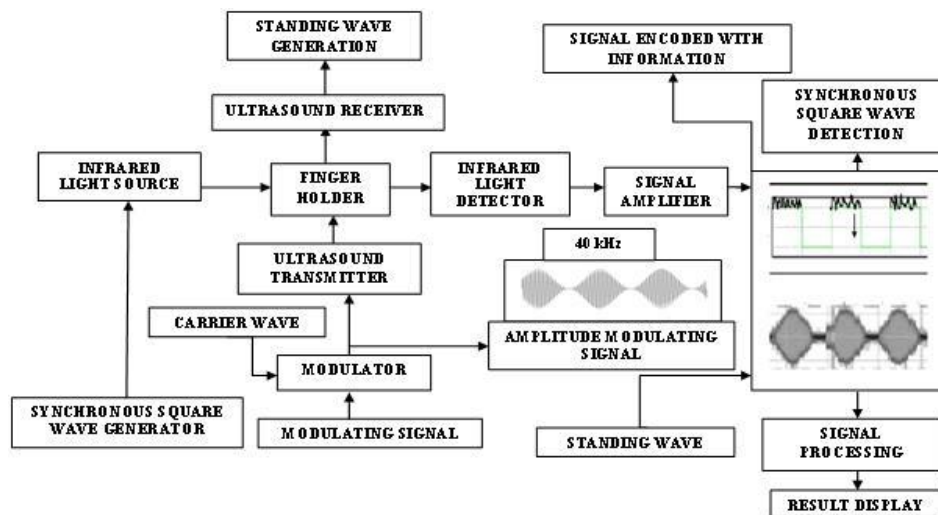


Figure No. 5. Depict the schematic block diagram of MUS-IR unit experimental setup.

Study Subjects

A total of 05 subjects (four male, one female, aged 25 to 30 years, of height 158 ± 4.0 cm, weight 64.8 ± 16 kg) has been allotted here for these experimental investigation purposes. They all understood the experimental protocols and gave their written consent. The pilot study has already been approved by the local ethical committee.

RESULT AND DISCUSSION

The significant role of ultrasonic waves in predicting blood glucose level and increasing trend of diabetic population worldwide [1-3] had influenced us to conduct such type of experiments. The MUS-IR unit based practical experimentations has been performed in two stages. Both the stages are described as follows:

Stage I (i): Before Meal Session in absence of Amplitude Modulated Ultrasound in MUS-IR unit

In this stage, the amplitude modulated ultrasound unit had been turned OFF. Only the infrared unit kept on working mode. The subjects (before meal) were directed to insert their respective index fingers in the finger holder of the MUS-IR unit as seen in Figure No. 5 respectively. After that data acquisition process had been initiated. Usually the observed signal and peak voltage amplitude in FFT spectrum in absence of ultrasound were recorded and analyzed as seen in Graph No.1. (a) and 1(b) respectively. Simultaneously,

invasive Blood Glucose Level (BGL) readings as acquired from all the subjects have been shown in Table No. 1 respectively.

Stage I (ii): Before Meal Session in presence of Amplitude Modulated ultrasound in MUS-IR unit

During this experimental period both the ultrasonic and infrared units were kept ON and in working mode. Again, the subjects provided their index fingers in MUS-IR unit to give their respective readings. All the signals were electronically documented and analyzed as seen in Graph No.2. (a) and 2(b) respectively. At same time, the invasive BGL readings have been obtained from the participating subjects as shown in Table No. 1 respectively.

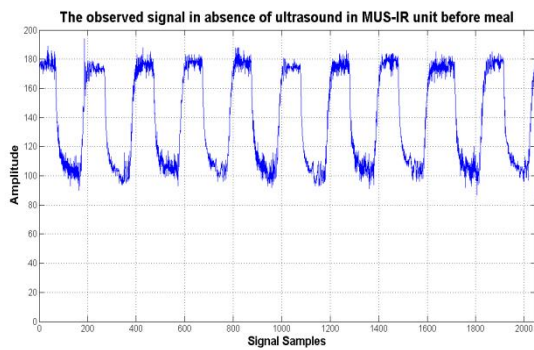
Stage II: One hour After Meal session in presence of Amplitude Modulated ultrasound in MUS-IR unit

Similarly as in stage I (ii) the experiments were conducted and readings of one hour after meal session have been stored electronically and analyzed as shown in Graph No.3. (a) and 3(b) respectively. The subjects also give their invasive BGL readings as shown in Table No. 1 respectively.

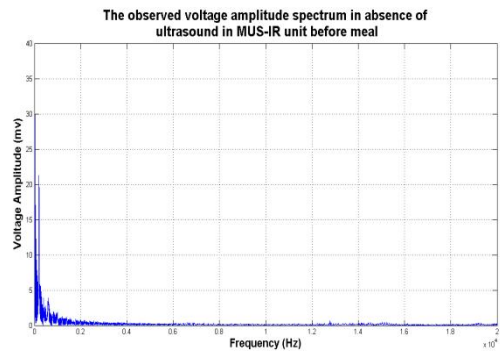
Table No. 1. Shows the variation in voltage amplitude in the FFT domain with related to glucose concentration in healthy subjects before and 1 hour after meal intake sessions respectively.

Serial. No.	Healthy Subjects	Voltage variations in response to BGL changes in MUS-IR unit		Invasive Method Based Blood Glucose Levels (BGL)	
		Peak voltage amplitude values (mV) as obtained in FFT domain during before meal sessions	Peak voltage amplitude values(mV) as obtained in FFT domain during after meal sessions	BGL(mg/dl) Before meal intake	BGL(mg/dl) 1 hour after meal intake
1.	Subject 1	6.7	13.2	70.0	128.0
2.	Subject 2	7.2	12.5	75.0	120.0
3.	Subject 3	6.1	12.2	69.0	130.0
4.	Subject 4	5.0	12.9	60.0	136.0
5.	Subject 5	6.8	13.6	68.0	143.0

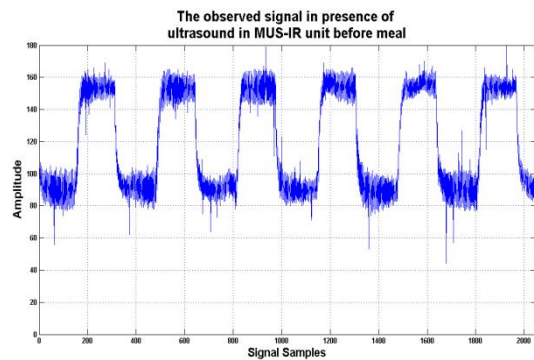
- **FFT DOMAIN: FAST FOURIER TRANSFORM DOMAIN.**



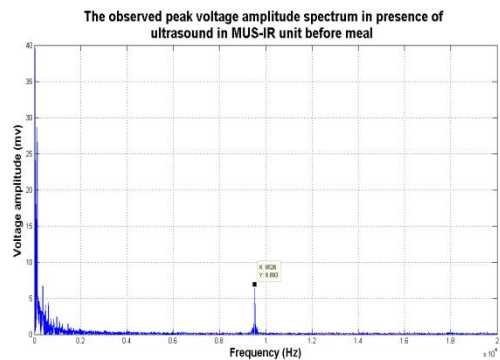
Graph No. 1(a). The observed signal in absence of amplitude modulated ultrasound in MUS-IR unit before meal.



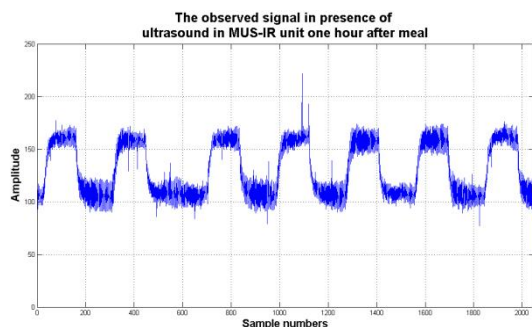
Graph No. 1(b). The observed voltage amplitude spectrum in absence of amplitude modulated ultrasound in MUS-IR unit before meal.



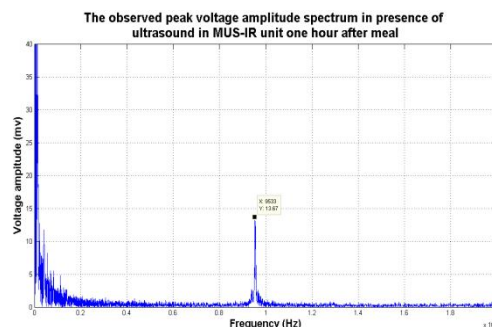
Graph No. 2(a). The observed signal in presence of amplitude modulated ultrasound in MUS-IR unit before meal.



Graph No. 2(b). The observed peak voltage amplitude spectrum in presence of amplitude modulated ultrasound in MUS-IR unit before meal.



Graph No. 3(a). The observed signal in presence of amplitude modulated ultrasound in MUS-IR unit one hour after meal.



Graph No. 3(b). The observed peak voltage amplitude spectrum in presence of amplitude modulated ultrasound in MUS-IR unit one hour after meal.

Graph No. 1(a), 2(a), 3(a) depicts the various observed signals and Graph No. 2(b), 3(b) shows the peak voltage amplitude spectrum characteristics which changes with respect to glucose concentrations in Fast Fourier Transform Domain as recorded by the MUS-IR unit respectively.

As depicted from the Graph No. 1(b) the voltage amplitude spectrum in FFT (Fast Fourier Transform) domain reveals that there are no peak values due absence of amplitude modulated ultrasound in the MUS-IR unit. On the contrary, in presence of ultrasound in MUS-IR unit, all the other observed signals like Graph No. 2(b) and 3(b) shows respective peak voltage amplitude spectrum in the Fast Fourier Transform Domain. Moreover, those respective peaks vary in their peak voltage amplitude with respect to blood glucose concentrations as revealed from the Graph No.2 (b); 3(b) and Table No.1 respectively. Similarly, the Table No.1 shows information about respective correlation between BGL (Blood Glucose Level) readings as provided by invasive glucometer [33] and the respective varying peak voltage amplitude values in the FFT domain respectively. The results confirm that the amplitude modulated ultrasound and infrared technique together plays a vital role for blood glucose level detections in noninvasive manner.

CONCLUSION

The significant use of amplitude modulated ultrasound with infrared unit for noninvasive blood glucose determination has been elaborated in this research article. The nascent idea for utilizing the ultrasound has been described here and the results so obtained supports the usefulness of this novel methodology. These facts might be helpful for designing and developing a noninvasive glucometer device in near future.

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