



*A Tribute to Mahamana  
Pt. Madan Mohan Malviya ji*

*Dedicated*  
*To*  
*My Son*  
*Karanjeet Chowdhury*

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**Md. Koushik Chowdhury**

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## List of Abbreviations

<b>ADA</b>	: American Diabetes Association
<b>AHA</b>	: American Heart Association
<b>AM</b>	: Amplitude Modulation
<b>BGL</b>	: Blood Glucose Level
<b>CE</b>	: Conformité Européenne (European Conformity)
<b>CEG</b>	: Clarke Error Grid
<b>CGMS</b>	: Continuous Glucose Monitoring System
<b>CUSUM</b>	: Cumulative Sum
<b>CI</b>	: Confidence Interval
<b>DCCT</b>	: Diabetes Control and Complications Trial
<b>D-Glucose</b>	: Dextro-Glucose
<b>DM</b>	: Diabetes Mellitus
<b>DSO</b>	: Digital Storage Oscilloscope
<b>EGA</b>	: Error Grid Analysis
<b>EDTA</b>	: Ethylene Di-amine Tetra-acetic Acid
<b>FDA</b>	: Food and Drug Administration
<b>FFT</b>	: Fast Fourier Transform
<b>FM</b>	: Frequency Modulation
<b>FPG</b>	: Fasting Plasma Glucose
<b>GHb</b>	: Glycosylated Hemoglobin
<b>GmbH</b>	: Gesellschaft mit beschränkter Haftung
<b>HbA1c</b>	: Glycated Hemoglobin
<b>IC</b>	: Integrated Circuit
<b>IDF</b>	: International Diabetes Federation
<b>IFG</b>	: Impaired Fasting Glucose
<b>IGT</b>	: Impaired Glucose Tolerance
<b>IMS-BHU</b>	: Institute of Medical Sciences-Banaras Hindu University
<b>IR</b>	: Infra Red
<b>ISO</b>	: International Organization for Standardization
<b>Inc.,</b>	: Incorporation
<b>LASER</b>	: Light Amplification Simulation Emission Radiation
<b>LED</b>	: Light Emitting Diode
<b>MAE</b>	: Mean Absolute Error
<b>%MARE</b>	: Percentage of Mean Absolute Relative Error
<b>MdAE</b>	: Median Absolute Error
<b>%MdARE</b>	: Percentage of Median Absolute Relative Error
<b>MATLAB</b>	: Matrix Laboratory
<b>MIR</b>	: Mid Infra Red

<b>MUS-IR</b>	: Modulated Ultra Sound-Infra Red
<b>NIR</b>	: Near Infra Red
<b>OCT</b>	: Optical Coherence Tomography
<b>OGTT</b>	: Oral Glucose Tolerance Test
<b>PA</b>	: Photo Acoustic
<b>P-BGL</b>	: Predicted-Blood Glucose Level
<b>PBS</b>	: Phosphate Buffer Solution
<b>PP</b>	: Post Prandial
<b>PEG</b>	: Parkes Error Grid
<b>PM</b>	: Phase Modulation
<b>RAD</b>	: Relative Absolute Difference
<b>RBC</b>	: Red Blood Corpuscles
<b>R-BGL</b>	: Reference-Blood Glucose Level
<b>RIGMD</b>	: Reverse Iontophoresis based Glucose Monitoring Device
<b>RMSE</b>	: Root Mean Squared Error
<b>r value</b>	: Correlation Coefficient
<b>SD</b>	: Standard Deviation
<b>SNR</b>	: Signal to Noise Ratio
<b>SEP</b>	: Standard Error of Prediction
<b>TM</b>	: Trade Mark
<b>THb</b>	: Total Hemoglobin
<b>UK</b>	: United Kingdom
<b>UKPSD</b>	: United Kingdom Prospective Diabetes Study
<b>USA</b>	: United States of America
<b>USD</b>	: United States Dollar
<b>US\$</b>	: United States Dollar
<b>USR</b>	: Ultra Sound Receiver
<b>UST</b>	: Ultra Sound Transmitter
<b>UV</b>	: Ultra Violet
<b>WHO</b>	: World Health Organization

## **Preface of the Thesis**

Diabetes Mellitus has progressed as an important healthcare endemic of the contemporary world. The diabetic subject needs to monitor their Blood Glucose Level regularly for three to four times per day for circumventing the terminal stage medical complexities and expenses. The invasive device based blood glucose monitoring comprises painful procedures, mental agony, and infection liabilities and high cost per measurement. For all these reasons, at present a new noninvasive technique for blood glucose measurement is extremely demanding. In perspective of addressing the requirement for this necessity, the present thesis work objective is to validate our indigenously developed noninvasive technique for blood glucose measurement in the human subjects. The present thesis contains seven subsequent chapters as follows: Introduction; Literature Review; Concept, prototype fabrication, and methodology; Effect of glucose concentration on light transmission; Clinical investigation based results; Discussion; Conclusion and future recommendations.

**Chapter-1 Introduction:** This chapter briefly introduces the present scenario regarding regular blood glucose monitoring in diabetic subjects and the essential need for noninvasive blood glucose monitoring technique. This chapter briefly portrays the aims and objectives, research contributions and outcome of the present thesis work. The thesis organization section concisely highlights all the chapters present in this thesis. Further, it contains the full list of published research articles and honors received.

**Chapter-2 Literature Review:** This chapter provides brief illustration about Diabetes Mellitus, its related medical complications, and blood glucose monitoring techniques. This section concisely describes various developing noninvasive blood glucose measuring methods and their respective prototypes, mechanism for physiological blood glucose regulation and skin tissue characteristics, optical clearing effect related studies, in-vivo and in-vitro experiments, Glycated hemoglobin and blood pressure relation with blood glucose, and various additional effects.

**Chapter-3 Concept, prototype fabrication, and methodology:** This chapter represents the combined concept of Amplitude Modulated Ultrasonic waves and Infrared light-based approach for noninvasive measurement of blood glucose levels. This chapter describes the block diagram of our fabricated prototype unit including its light wavelength

and ultrasound frequency selection criterions, calibration aspects, in-vitro, and preliminary in-vivo results. Further, this chapter includes concise description of the Clarke error grid and statistical analysis based approaches for measuring the accuracy performance of our prototype unit in measuring predicted blood glucose levels.

**Chapter-4 Effect of glucose concentration on light transmission:** This chapter represents the clinical study based on the optical clearing effect of blood glucose concentration over light transmission.

**Chapter-5 Clinical investigation based results:** This chapter reports the clinical investigation based results of our noninvasive technique applied over (i) healthy non-diabetic, (ii) pre-diabetic, and (iii) diabetic human subjects for blood glucose measurement purposes. All the clinical investigations mainly focus over noninvasive blood glucose level determining aspects and its clinically significant correlations with the invasive blood glucose measurements. Various clinical studies reported here include (i) Standard Oral Glucose Tolerance tests, (ii) Blood glucose level measurements during fasting stage, postprandial stage and random stage respectively. Further, it contain results about the clinical correlations of the blood glucose levels relationship with the (i) Glycated hemoglobin (HbA1c) concentration and (ii) blood pressure values in healthy normal and diabetic subjects. This section also includes comparison of our results with the published results to measure the performance index of our prototype unit in noninvasive blood glucose measurement.

**Chapter-6 Discussion:** This chapter contains brief description of our overall study and the medical importance of our results. Henceforth, it compares our overall blood glucose measurements with the published data available in the English language based research literatures. Further, various statistical methods evaluates the statistical significance of our overall results.

**Chapter-7 Conclusion and recommendations for future work:** This chapter presents the conclusion of the present thesis work and direction for future research work. Afterwards, the reference portion enlists overall research papers utilized to pursue this present work.