TRIZ-Based Approach in Remodeling Invasive Glucometer

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Abstract. Diabetes Mellitus is a serious clinical condition. If left unchecked the increased blood glucose level may predispose to cardiovascular disease, damages in nerves/veins, blindness, limb amputation and kidney disease. Utilising TRIZ based models such as Functional analysis and Su-field, we are able to model the problem appropriately by highlighting the key disadvantages for design improvement. Engineering and Physical contradiction models enabled us to address the problem effectively and provide an excellent case study for enhancing the present tool used in determining the blood glucose of a diabetic patient. A prototype model of the device has been developed and preliminary experiments are done to validate its efficacy. The potentials for further refinements can be expanded by addressing secondary problems that we have identified. We believe that noninvasive smartphone glucometer will be useful and a safer option in determining the blood glucose level.

Keywords: Invasive · Glucometer · TRIZ

1 Introduction

The need for a noninvasive method of detecting the presence of glucose in a person's body will be useful. The widely used mode of detecting glucose in a person's body is via blood sampling. Blood glucose detection is usually done by glucometer. Since it is an invasive method we shall address it as Invasive Glucometer (IG).

According to the International Diabetes Federation (IDF), as of 2021, approximately 537 million adults (aged 20–79) worldwide have diabetes, with type 2 diabetes being the most common form [1]. Diabetes is a leading cause of death globally, with approximately 4.2 million deaths in 2019 attributed to the disease. Low- and middle-income countries tend to be disproportionately affected by diabetes, with 80% of people with diabetes living in these countries. Diabetes prevalence is increasing globally, and it is

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estimated that by 2045, approximately 783 million adults worldwide will have diabetes [1]. Diabetes is a major contributor to blindness, kidney failure, heart attacks, stroke, and lower limb amputation [2, 3]. It is not surprising therefore that the World Health Organisation has identified diabetes as one of the top ten global public health threats. Diabetes is also becoming a global public health epidemic [4].

Type 1 diabetes and type 2 diabetes are both chronic diseases that affect the way the body regulates blood sugar levels. However, they differ in several key ways. Type 1 diabetes occurs when the body's immune system attacks and destroys the insulin-producing cells in the pancreas, resulting in a lack of insulin in the body. This usually develops in children and young adults, but can also occur at any age. The individual will then require insulin therapy for life to regulate blood sugar levels and this condition cannot be prevented [5]. Type 2 diabetes occurs when the body does not use insulin properly (insulin resistance) or does not produce enough insulin [6]. Is often associated with lifestyle factors such as obesity, physical inactivity, and unhealthy diet. This typically develops in adults, but can occur in children and adolescent as well. The condition may be managed through lifestyle changes which include healthy eating and exercise, and may require medications and insulin therapy if blood sugar levels cannot be controlled through lifestyle changes alone. The consequences of the disease can often be prevented or delayed through lifestyle changes. In summary, while both types of diabetes affect blood sugar levels, Type 1 is an autoimmune disease that requires insulin therapy for life, while Type 2 is often associated with lifestyle factors and can sometimes be managed with lifestyle changes alone.

To diagnose diabetes, measurement of blood glucose is required. Therefore, to measure blood glucose we can use invasive or non-invasive techniques. An invasive procedure is a medical procedure that involves inserting instruments or devices into the body or cutting into the body's tissues or organs. The purpose of an invasive procedure is usually to diagnose or treat a medical condition. Invasive procedures carry a higher risk of complications compared to non-invasive procedures. However, they may also provide more accurate and definitive diagnoses or treatments for certain medical conditions. The decision to perform an invasive procedure has to be made by a healthcare provider after considering the potential risks and benefits.

Diabetes patients tend to have slower level of wound healing process and in extreme cases impaired wound healing that may lead to amputation [7]. In general, anyone will feel pain during an invasive process. IG process will also cause wound in order to measure blood glucose. The current available IG is useful and reliable but it has its disadvantage. The end users who are diabetic patients generally will complain of it being cumbersome, expensive and a painful experience to do blood glucose detection using IG. This obvious contradiction suggests an inventive problem [8]. The technical and physical contradiction in this particular problem allowed us to use TRIZ to better understand and discover a solution for the existing problem. Furthermore, by utilising the Su-field modeling technique we were able to conceptualise the product better. Using TRIZ we were able to come up with a Smartphone Glucometer (SG) solution. SG will stand out as a solution for not only diabetic patient but also for general population to detect their glucose level in their body. This paper delivers the use of TRIZ in conceptualising the essence of the problem and using Engineering and Physical Contradictions plus Su-field modeling to elicit a probable TRIZ based solution for glucose measuring in humans.

2 Research Methodology

The application of a systems approach with functional analysis has been explored as a means to characterise the problem of Invasive Glucometer (IG). The lack of proper tool to screen, detect and monitor non-invasively an ongoing global epidemic problem has been adopted as the target problem. This problem requires an immediate practical solution.

The IG was studied and this was followed by the formulation of the Function Analysis. Figure 1 shows a typical IG. Then system analysis and contradictory analysis were used to conceptualize the problem [9]. The tools rendered insights into the nature of the problem. To understand in further clarity Su-field modeling was employed. The overall methodology of the SG project is illustrated in Table 1.

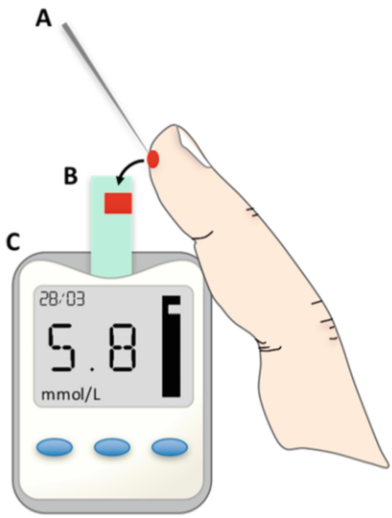

Fig. 1. General Invasive Glucometer adopted from Bruen et al. [10]. A. Invasive lancet needle; B. Blood sample on test-strip; C. Glucose meter displaying glucose concentration in mmol/L.

2.1 Function Analysis

The initial analysis shows the main useful functions as an engineering system of IG is depicted in Fig. 2. IG's main function is to hold test strip, sensor unit, display unit and power unit. A lancing device is required for IG. In a nutshell an IG is able to detect blood glucose level in a person. The preliminary component analysis (see Table 2) indicates that the system is composed of the Glucometer. This system interacts directly with the super system which is subject to spatial and temporal changes, which in return will affect

Table 1. Overall concept methodology of the project.

Research Methodology	Tools
Review of Related Work	Review covered articles with "glucometer" in reliable databases
Problem Modelling based on Function Analysis	Function Model was formulated to model domain knowledge
System Analysis as inventive problem solving model	Engineering Contradiction as a Triz knowledge based approach was utilized to elicit directions
Contradictory Analysis as a deep knowledge model of inventive solution Su Field Modelling	Physical Contradiction served as an instrument for deepening our understanding Su-field modeling was used to represent elements and interactions in order to characterize the behavior of our technical system
Designing Smartphone Glucometer	Utilising designing tools to work out a practical model of Smartphone Glucometer. Ongoing discussion with the end user of Smartphone Glucometer for feedback and further enhancements

and influence the IG device. The product in our component analysis is the Glucose. IG subcomponents are test strips, lancing device, glucose sensor, display unit and power unit. This analysis showed that the application of a systems approach by using of function model was informative.

In brief the role of the main components of IG is highlighted. Lancing device: A tool used to puncture the skin and collect a small blood sample. Test strip: A small strip of material used to collect the blood sample and measure the glucose level. Glucose meter: A device that reads the glucose level on the test strip and displays the result. Lancet: A small, disposable needle used to puncture the skin and collect the blood sample. Electricity/Battery: A power source that allows the glucometer to function. Display unit: A screen that shows the user their glucose level and other important information. Memory function: A feature that allows the glucometer to store and recall previous test results.

2.2 Engineering Contradiction

Based on the initial analysis the following Engineering systems were formulated.

a. **IF** blood is used in an invasive glucometer **THEN** blood glucose is measured **BUT** glucometer user feels pain. The improving parameter was selected as 39: "Productivity". The invasive glucometer is functional as it becomes productive with ability to measure the patient's blood glucose level. On the other hand, the worsening parameter

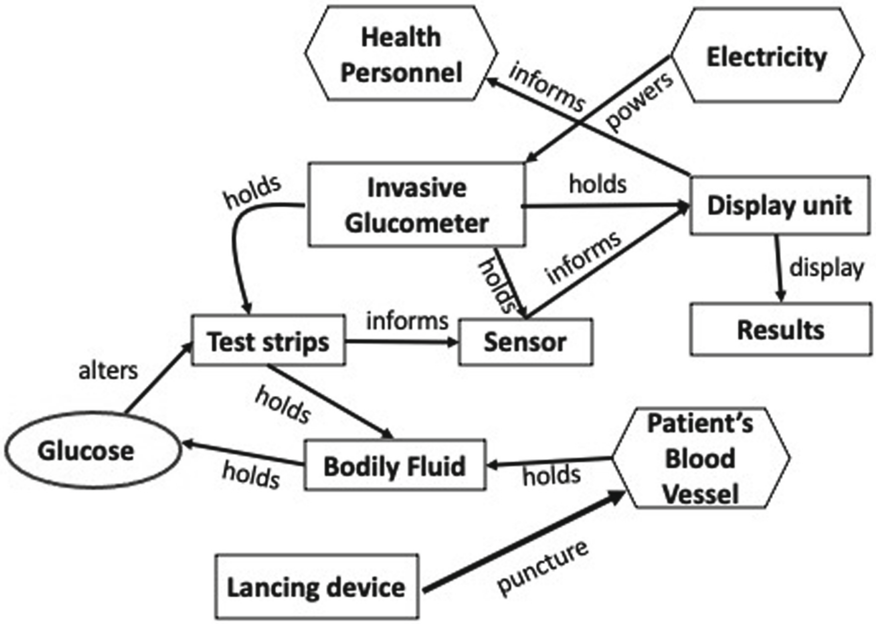

Fig. 2. Function Model for Invasive Glucometer.

Table 2. Preliminary Component Analysis.

Components	Super System	System	Product
Items	Environment Electricity User Health Personnel	Glucometer -Test Strips -Glucose Sensor -Display unit -Lancing device	Glucose

was selected as 30: "Object-affected harmful effect", which suggest that the invasive glucometer may render a health hazard to the end user in the form of pain.

b. **IF** an invasive glucometer is used regularly **THEN** blood glucose can be monitored frequently **BUT** the user has to get more resources. The improving parameter was selected as 39: "Productivity". The invasive glucometer is functional as it becomes productive with ability to monitor the patient's blood glucose level. On the other hand, the worsening parameter was selected as 31: "Object-generated harmful effect", which suggest that the invasive glucometer forced the end user to use more resources therefore losing valuable material.

The inventive principles provided an insight in the modelling of smartphone glucometer by suggesting intuitive strategy in designing and modelling a purposeful yet safer glucometer for end user. Based on this model, the possible approaches are listed as shown in Tables 3 and 4.

Table 3. Engineering contradiction based on Smartphone Glucometer (SG) with considering the improving parameter as "39: Productive" and the worsening parameter as "30: Object-affected Harmful Effect" were contemplated and its possible solutions postulated.

Inventive principles	Possible solutions
13 The other way around	Currently we are sampling blood which is required in our body, instead of this we sample a bodily fluid that is not required in the body
22 Blessings in Disguise	The procedure for monitoring glucose level will not be a painful experience
24 Intermediary (Mediator)	The gold standard for glucose level in the body is measuring the blood glucose, instead now we can measure something else to correlate to the gold standard
35 Parameter changes	Instead of looking for glucose in an important fluid of the body, we can be flexible in looking for glucose in some other substances of the body

Table 4. Engineering contradiction based on Smartphone Glucometer (SG) with considering the improving parameter as "39: Productive" and the worsening parameter as "23: "Loss of substance" were contemplated and its possible solutions postulated.

Inventive principles	Possible solutions
10 Prior action	Procedure for the SG process will be present in the smartphone for user to refer
23 Feedback	The app present in the smartphone will be used to give feedback to the user
28 Mechanical substitution	Replace the present electrical-electrode system with smartphone based imaging system
35 Parameter changes	Instead of looking for glucose in an important fluid of the body, we can be flexible in looking for glucose in some other substances of the body

2.3 Physical Contradiction

The following physical contradiction can be proposed here, describing a situation which requires one parameter to take opposing values in order to meet contradictory demands to a system:

Glucometer has to be *invasive* to obtain bodily fluid and *noninvasive* to avoid inflicting pain.

2.4 Su-Field Modeling

Su-field modeling was explored where the original problem was formulated as a harmful system. By transforming the solution in considering the Mechanical, Acoustic, Thermal, Chemical, Electric and Magnetic (MATCHEM) as an alternative, we were able to propose the following model using the biological system (see Fig. 3a).

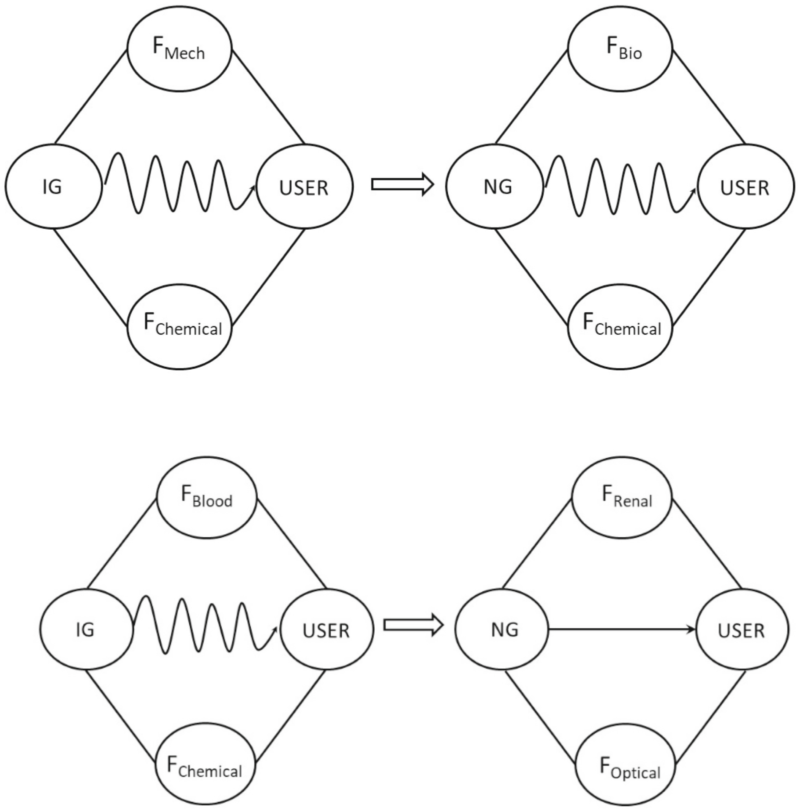

Fig. 3. a. Double Su-field Modeling for Invasive Glucometer problem. $F_{chemical}$: Chemical field, IG: Invasive Glucometer, F_{Mech}: Mechanical field, NG: Noninvasive Glucometer, F_{Bio}: Biological field and USER: Patient or End user. b. Double Su-field Modeling for Noninvasive Glucometer in the Biological System. F_{Blood}: Blood system, IG: Invasive Glucometer, F_{Mech}: Mechanical field, NG: Noninvasive Glucometer, $F_{Optical}$: Optical field, F_{Renal}: Renal system and USER: Patient or End user.

We considered the Biological system (F_{Bio}) due to the nature of our product. Further to this we analysed this model by delineating in detail the main biological body system which are, Blood, Skeletal, Muscular, Nervous, Cardiovascular, Respiratory, Digestive, Renal, Reproductive, Endocrine and Lymphatic. The main issue to address was the invasiveness of the system and keeping this in mind, here is the following Su-field model proposed. We choose the renal system as the sampling of the urine which will not harm the user. Our next Double Su-field Modeling for Noninvasive Glucometer in the Biological System is depicted in Fig. 3b.

3 Results

In order to validate the concept, our group have built the system design of the noninvasive Smartphone Glucometer. The possible solutions that was proposed is given in Tables 3 and 4. Applying the solutions we have proposed a new component analysis of the noninvasive Smartphone Glucometer, shown in Fig. 4.

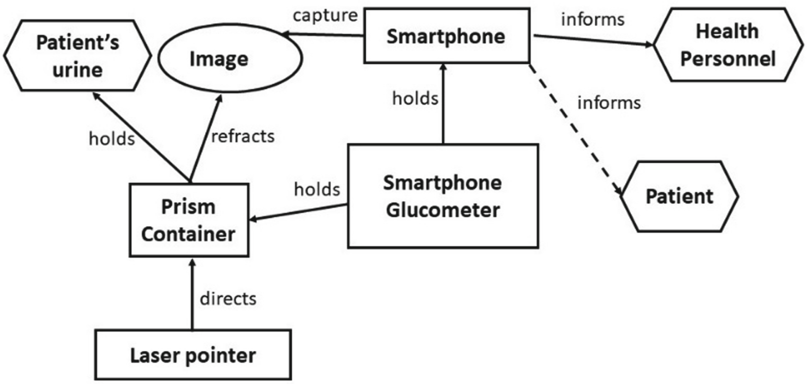

Fig. 4. Function Model for Noninvasive Smartphone Glucometer.

The function modeling in Fig. 4 is captured as a schematic diagram of noninvasive Smartphone Glucometer. The design thinking approach was implemented whereby we engaged an active discussion with the parties of concern, mainly healthcare personnel and diabetic patients. This led us to build a schematic diagram of the new noninvasive glucometer, as shown in Fig. 5, which is called Noninvasive Smartphone Glucometer.

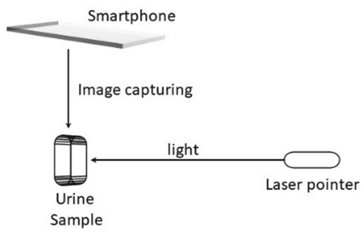

Fig. 5. Schematic Diagram of the noninvasive Smartphone Glucometer.

The application of a systems approach with functional analysis has been used to understand the problem of IG. Figure 6 depicts the isometric view of the noninvasive Smartphone Glucometer system design. The Engineering Contradiction and Physical

Contradiction analysis enabled us to look deeper at the inventive principles proposed by the contradiction matrix based on the improving and worsening parameter analysis.

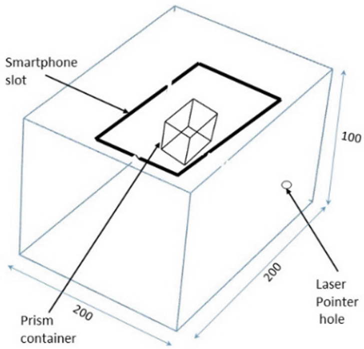

Fig. 6. Isometric View of Smartphone Glucometer System Design (dimensions in mm).

The system design shown in Figs. 5 and 6 are noninvasive Glucometer device. The main components in this system are the laser pointer, prism container and smartphone. As the laser beam is refracted into the prism container containing the noninvasive sample (urine), the refracted image is captured by the smartphone camera. The image captured will be processed using a designated software in an App. Preliminary experiment using refractive index of sugar concentrates versus Glucometer reading of sugar concentrates correlated very well. A regression analysis showed R^2 of 0.98, indicating that 98% of the variance in our data is accounted for by the experiment [11].

4 Discussion

Trimming is a way of increasing system ideality by removing a component of the system. According to Genrich Altshuller, a system's Ideality is affected by Useful Function, Harmful Function and Resources [12]. In TRIZ, Trimming is the way of making a system better by removing things while keeping all the useful functions [8].

Based on Fig. 2, the four major functions of IG have been replaced by 2 functions in Fig. 4. Figure 4 depicts the Function model for noninvasive Smartphone Glucometer (SG). The test strip and lancing device are trimmed and their functions are taken over by the prism container. While the function of the sensor and display units are taken over by the smartphone. Removing the lancing device certainly will have a major impact on the system as it also exerted a harmful effect on the user. The new system, noninvasive Smartphone Glucometer is free of harmful functions.

Two undesirable characteristics of the IG system are removed, they are the inflicting pain on user by the lancing device and the cost of replacing the test strip after each test. Certainly this is leading towards Ideality. The proposed noninvasive glucometer has its limitation such as patients who are on drugs that inhibit the Sodium Glucose Cotransporter 2 protein which enables glucosuria, will not be able to use this system.

Further studies in this cohort of patients using the proposed tool need to be undertaken to validate its usefulness.

Noninvasive SG can be used regularly without inflicting pain on the user. The IG tends to create wound which is not good for diabetic patients, as they tend to have an impaired function of wound healing [7]. The specificity of noninvasive SG test maintained by using urine sample of patient and not an invasive sample such as blood. Since diabetic patients require regular monitoring of blood level which may cost dearly due to the use of fresh test strips. In noninvasive SG, we can continue monitoring regularly without implicating further cost because we are capturing image of diffracted laser beam in urine sample via smartphone. Although frequent urine samples are required with the proposed tool, patients no longer suffer pain and the loss of precious resources.

Lastly, when dealing with a problem that involves multiple goals, TRIZ provides several tools and principles that can help in finding creative solutions. Future problem solving can be enhanced with powerful TRIZ tool such as Function Oriented Search (FOS), Ideal Final Result (IFR), System Operator, Resource Analysis, TRIZ Contradiction-Solving Process and others. TRIZ is a systematic and structured approach to problem-solving, and its tools can be tailored to the specific needs of a problem with multiple goals.

5 Conclusion

An invasive technique is not good because it is expensive and painful. Furthermore, if a diabetic patient requires frequent monitoring of the glucose level, then the constant state of wound is created. Diabetic patients have low wound healing ability. So an alternative method is required. We have proposed a conceptual idea for noninvasive Smartphone Glucometer using urine as the sample. The effectiveness and functionality of urine glucose was proved through the sugar concentration experiment. The refractive index of urine was well correlated with actual blood glucose level measured via Glucometer. Once again TRIZ has enabled us to zoom-in on the key functions to resolve Ideality. Further analysis using higher TRIZ tools will certainly gear us towards an ideal pathway through TRIZ-modelling of Invasive Glucometer.

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