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A Diet Suggestion System for Diabetic Patients Based on Linear Programming

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***Abstract*—With urbanization, changes in lifestyle and diet habits of people have paved way for chronic diseases which were either not known or were very less prevalent in the past. Diabetes is one such disease which has been considered as one among the top four non communicable diseases that is of major threat to all countries. This paper focus on developing a diet recommender system for diabetic patients by obtaining the list of available food items from the user and refining the proportion of each of the food items to result in the best composition of a balanced and healthy diet. Further the system ensures that the composition of diet recommended, results in least deviations in blood sugar levels of the individual, thereby helping them maintain their blood glucose levels. The system makes use of two important factors related to food that directly impacts the blood glucose level of a diabetic patient namely, Glycemic Index and Glycemic Load. Consideration of Glycemic Load ensured us to take into account the quantity of the food item being consumed along with the type of the food item. The system firstly obtains the food items that are currently available to the individual and then determines features such as Glycemic Index and Glycemic Load for each of the food item from a central repository. This information is then framed as a linear programming problem with the optimization function being to reduce the overall Glycemic Load. The linear programming problem is then feed to a simplex algorithm which then suggests the best proportion of each of the food item that can be consumed by the user. Finally the suggestion system is applied to a sample food items list and the predictions made are discussed.**

***Index Terms*—Diabetes, glycemic index, glycemic load, linear programming, simplex algorithm.**

I. INTRODUCTION

Diabetes mellitus, or simply Diabetes, is a prolonged condition that results from either the inability of pancreas to produce required amount of insulin needed by the human body or as a result of inability of the bodily cells to make use of the insulin produced by the pancreas. Insulin is a hormone, produced by pancreas in the human body that controls the blood glucose levels. People with diabetes will generally have frequent urination and will also feel increasingly thirsty and hungry. In general there are three types of Diabetes, namelyType-1 Diabetes, Type-2 Diabetes and Gestational Diabetes.

Type-1 Diabetes is the result of deficiency of insulin production in the human body. It is observed that majority of type 1 diabetes occurs in children and adolescents and among people below the age of 40 years. The exact cause of Type-1 Diabetes is unknown. Condition such as diabetic ketoacidosis is commonly observed if this type of diabetes is not detected and monitored properly.

Type-2 Diabetes occurs due to the inability of human body to effectively use the insulin produced by pancreas. Adults are most commonly affected by this category of diabetes. It may be attributed to the fact that age is a primary factor for this type of diabetes. A major portion of type 2 diabetes results from overweight and physical inactivity. Also some people develop the habit of smoking which at later stages of their life may lead to type-2 diabetes. Complications such as diabetic ketoacidosis is developed due to Type-2 diabetes, which if not properly treated may lead to Hyperosmolar coma.

A third kind of diabetes is Gestational diabetes (GDM), which develops due to complications during pregnancy. A woman with gestational diabetes has her blood glucose levels higher than the normal levels, yet it is found to be below the blood glucose levels of patients with Type-1 or Type-2 diabetes. Excess weight gain during pregnancy, age, family history of diabetes etc is some of the primary factors that could suggest the likeliness of this type of diabetes to occur. GDM can affect the normal growth of the child and could lead to complications such as fetal loss, prenatal death, malformations etc. Studies carried in this context have proved that the higher the reproductive age of a woman, the higher is her likeliness of developing a GDM.

Recent years has seen an exponential rise in the number of people affected by diabetes which may be the result of changes in the lifestyle and diet habits of the individuals. There has been huge impact of diabetes on the various economies. Most of the countries are spending large amount of money in finding ways to predict and prevent diabetes. Further majority of this lump some cash is invested in treating diabetes and the complications that results from them. Also as the most of the currently available medications are injection based, hospitals and health-cares spend large amounts on them. Diabetes not only results in economic crisis to the country but also could affects the lifestyle of their families. This may be the result of loss of income due to disability or the loss of life due to premature death of the individual. Recent studies have listed Diabetes among the top four non-communicable diseases that are of current focus by all leading nations.

As mentioned in Ref.[11], largest number of deaths due to diabetes is found to occur in upper-middle income nations while the same has been found to be least in lower income countries. The figures below (Fig 1.1) shows the deaths resulting from diabetes and its complications for both sexes across various nations based on their income. Both male and female plots clearly shows net rise in death rates by the time the individual reaches his/her 50’s, for all nations. Also it can be observed that the situation is more crucial in lower and upper middle income countries.

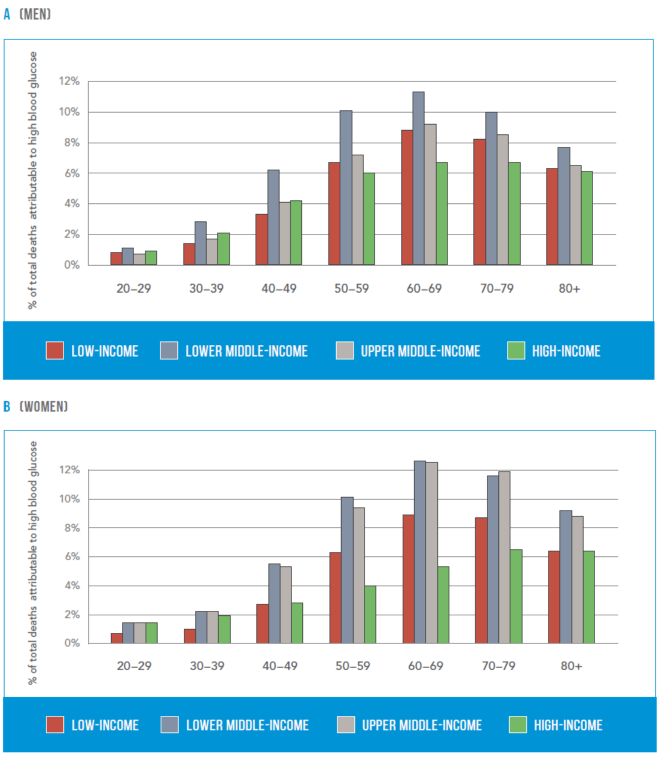

Fig 1.1 Deaths in nations due to diabetes based on gender

Various risk factors help us to determine the likelihood of individual developing diabetes in future. One of these key factors is the amount of physical activity done by an individual. It has been found that regular physical activity reduces the chances of developing diabetes at later stages of life. Nearly 84% of girls and 78% of boys in their adolescence are found to be not carrying out even the minimum amount of physical activity that is actually needed at their age. Studies suggest a relatively high level of inactivity among people in Eastern Mediterranean countries. Yet another important factor is Obesity. Studies suggest strong correlation between obesity and diabetes. It was found that nearly 1/3 of the people above the age of 18 years were overweight and 1/10th were obese. Also surveys suggests there are more obese women than men. Also countries with higher income are found to have greater proportion of population who are obese.

II. Previous Works

Even though significant amount of research has been going on, there have been comparatively fewer works in the area of developing systems that could recommend good proportion of diet to the diabetic patients. In this section we will be considering the previous works that has been carried out in the area of prediction and management of diabetes.

A. Food Recommendation System using Clustering Analysis for Diabetic Patients

Ref.[1] proposes a food recommender system for diabetic patients by grouping and clustering of similar food items. The clustering is performed based on the nutrition and other characteristics of individual food items. The food items are further subdivided into subgroups based on the proportion and type of carbohydrates in them. Here the objective is to replace the food items which are high in additional sugars and fat content, with an alternative from the same cluster. Further eighteen important nutrients necessary for diabetic patients were identified and were ranked. Based on this ranking, top eight nutrients among them were used as features to clustering algorithms, namely K-mean and Self Organizing Map. The recommender system proposes the food item with same food characteristics and having approximately the same proportions of all the eight nutrients and in addition will have comparatively low carbohydrate content.

B. Dietary Recommendation Based on Recipe Ontology

Ref.[4] proposes a food recommender system for diabetic patients with the primary focus on providing necessary nutrients that may be needed by them. This system extracts the recipe information from different sources and creates databases separately for health and nutrition. The database lists out the various nutrients and the amount of nutrient that must be part of one meal. The system obtains queries from the user and proposes a balanced diet based on the nutrients intake. The system includes 18 subclasses of food while the disease subclass includes two subclasses namely for Diabetes mellitus and Hypertension. Further the system considers the health status information of the user in order to recommend them a healthy and balanced diet considering their current health context.

C. Mobile Application for Diabetes Control in Qatar

Ref.[3] focuses on developing a mobile application for glucose monitoring and diet management for diabetic patients, specifically the population of Qatar as it is one of the most widespread epidemic there. The application allows the user to manually enter their blood sugar levels, which are then sent to a centralized database of health cares. Various factors such as age, height, weight, amount of physical activity etc is considered by the system in determining the amount of energy needed by the patients. It allows the user to enter the food items they have consumed into the system, once they have got the recommendations. The system contains a food database which is created based on food ontology techniques. The system then send a query request to the server which then based on user's personal data and history of food intake, recommends appropriate diet back to client's system. Nutrients necessary for diabetic patients forms the primary features of this recommendation model.

III. Theoretical Foundation

Previous studies in the area of diabetes have found to have high correlation between the constituents of a diet and the corresponding variations in blood sugar levels. Factors associated with food, namely Glycemic Index, Glycemic Load etc. have been found to show linear relationship with blood sugar level changes.

A. Glycemic Index

Glycemic Index (GI), as mentioned in Ref.[14], is used as a ranking measure which depicts the glycemic response of human body based on the type of carbohydrates intake. GI is measured on a scale of 1-100. The GI of pure glucose is 100 and it is used as a reference to determine the glycemic indices of other food items. Food items that have larger values of GI is observed to result in large deviations in blood glucose levels. GI of a food is estimated by observing it's impact on blood glucose level of the subject who, at regular intervals is feed this food item. Their blood samples are collected at regular intervals and then experiments are performed on the sample collected. Glycemic Index was introduced with the primary focus on handling problems related to insulin by recognizing food with high GI and avoiding its consumption. Foods with GI less than 36 is considered to result in low variations in glucose levels while foods with GI greater than 70 have larger glucose level deviations.

B. Glycemic Load

Significant researches in the past have shown that the blood glucose levels variations cannot be accurately studies only on the basis of Glycemic Index. This was so because GI only considers the type of food and does not take into consideration the quantity of carbohydrates in it, which is proportional to quantity of the food item. Thus a new factor namely Glycemic Load (GL) was introduced to incorporate this information and is given by,

$$Glycemic\ Load(GL) = (GI * Net\ Carbs)/100$$

where,
GI = Glycemic Index,
Net Carbs = Total Carbohydrates minus Dietary Fibers

As GL is proportional to GI, food items having smaller values of GL, shows smaller deviations and the ones with larger values, shows large variations in blood glucose levels. Foods with GL less than 10 are considered to be safe and the ones with GL greater than 20 are considered to be very risky for diabetic patients to eat.

C. Linear Programming

Linear Programming is an optimization technique which can be applied on any mathematical model that can be represented as a optimization problem. This technique focuses on identifying linear relationships existing between the features and the dependent parameters. This approach takes a set of linear equalities and inequalities as input. The objective of the approach is to maximize or minimize a linear objective function provided the values of the features also satisfy the various constraints imposed in the problem (Ref[17]).

The region which satisfies the linear inequality constraints is referred to as feasible region and contains the vector values of the features that optimize the objective function. Every optimization problem is converted to canonical form to represent a linear program, which is given by,

$$Maximize\ C^T X$$
$$Subject\ to\ AX \leq B\ and\ X \geq 0,$$

where,
X = Feature Vector containing all the variables to be determined,
B, C = Coefficient Vector containing all know values,

D. Simplex Algorithm

Simplex algorithm is one among the various algorithms know to find solutions to linear programs. Even though many other methods including ellipsoid algorithm, criss-cross algorithm etc have been developed, due to its simplicity and comparatively better performance in real world applications, its widely preferred for both academic and industrial purposes.

Simplex algorithm can be applied to any linear programming program in its generic form. Here the solution lies in a region called polytope. It has been found that for such linear programming problems, their optimal solution lies at one of the vertex x = (x1,x2,...xn).

1. The first and the most important step is the conversion of the linear program into its standard form in which case a new variable is introduced, representing the difference between the lower bound of the constraint and zero.
2. This is followed by introduction of a slack variable for each inequality constraint, thereby converting them into an equality constraint.
3. The final step involves elimination of unrestricted variables by solving them and then performing substitution.
4. Finally the objective function is converted to the form where the right hand side evaluates to zero.

Once converted to standard form, an initial tableau is created, consisting of the decision variables, slack variables and artificial variables that were generated. The first row of the tableau consists of the objective function, with the subsequent rows containing all the constraints that the problem demands. The algorithm stops when there is no possibility of improvement in the objective function.

Each step involves identification of a pivot which is then which is followed by generation of the new tableau where,

1. For pivot row,
$$New\ Value = Previous\ Value/Pivot$$
2. For other rows,
$$New\ Value = (Previous\ Value) - (New\ Value\ of\ Pivot\ Row * Previous\ Value\ of\ pivot\ column)$$

IV. Diet Suggestion Algorithm

As the objective of the diet recommender system is to recommend the best proportions of the various food items available to the patient and include it in their diet, the objective of this system can be represented as an optimization problem.

A. Identification of Problem Constraints

One of the key steps involved in finding solutions to an optimization problem is the identification of the problem constraints. The problem constraints involved in our optimization algorithm for each food item are,

1) Constraints to ensure non-negative values

Let us consider there are N food items that we have in the menu to eat. Also let $x_1, x_2 \ldots x_N$ are the portions of the diet recommended by the optimization algorithm. Then the algorithm should also ensure that all of the recommended portions are non-negative to be valid. So,

$$x(i) \geq 0, \forall 1 \leq i \leq N$$

B. Objective function

Objective functions refer to the linear equalities in the optimization problem that should be maximized or minimized. For our optimization problem the objective is to minimize Glycemic Load of the diet that will be recommended. This is so because the lower the GL value, lesser the variations in the blood glucose levels, which is necessary for diabetic patients.

So the objective function is to minimize$\sum_{i=1}^{N} GL(i)$, where

$$GL(i) = (GI(i) * Net\ Carbs(i))/100$$

V. Experimental Results

The figure below (Fig 5.1) shows the experimental results obtained by executing the diet recommender system against a sample list of food items. This sample consists of white rice, white bread, apple and brown rice, four common food items that are part of everyone's diet. The results shows the glycemic index and carbohydrate content in 100 grams of each food item in sample, and also lists down the features considered in the linear program. The program then transforms the problem into a linear programming problem with n variables where n indicates the number of food items. There are n+2 constraints in which the first n constraints refers to the condition to ensure that the food item quantities recommended are all greater than or equal to zero. The other two conditions are to ensure that the sum of quantities recommended is equal to the one time diet requirements of the user.

```
run:
_______________________________________________________________
| Food Name  | Glycermic_Index| Total_Grams| Total_Carbohydrates|
|==============================================================|
| White Rice | 64.0           | 100.0      | 28.0               |
| Apple      | 36.0           | 100.0      | 14.0               |
| Brown Rice | 55.0           | 100.0      | 23.0               |
| White Bread| 70.0           | 100.0      | 49.0               |

Features considered : 4, namely
-----------------------------------
Glycermic_Index
Total_Grams
Total_Carbohydrates

Food Items specified by User : 4

Output :
X =     30.263152    54.554902    40.181947     0.000000

Diet Recommended by the System :

White Rice : 31 grams
Apple : 55 grams
Brown Rice : 41 grams
White Bread : 1 grams
BUILD SUCCESSFUL (total time: 0 seconds)
```

Fig 5.1 Results from sample food items list

As seen here, the diet recommended by our system ensures the food item recommended satisfies the diet needs of an individual and yet ensure that these food items intake results in least deviations in their blood sugar levels.

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